Physics

For Rwanda Schools

Senior 1

Student's Book

Contents

UNIT 1 Laboratory safety rules and measurements of physical quantities

Key Unit Competence

By the end of this unit, I should be able to explain the importance of Physics, measure physical quantities and express findings in appropriate units.

Unit outline

- Physics as science subject.
- Definition of Physics.
- Relationship between Physics, other science subjects, society and technology.
- Science processes skills used in learning of Physics.
- Laboratory safety and safety rules.
- Fundamental and derived quantities.
- International System of Unit (SI).
- Measuring instruments.
- Prefixes for SI units.
- Density.

Introduction

Welcome to the world of science and Physics. Science is a way of learning about the natural world by gathering information. Science includes all of the knowledge gained by exploring nature. To think and work like a scientist, you need to use the same skills that they do. Scientists use the skills of observing, inferring and predicting to learn more about the natural world. Here Scientists usually make observations in a careful and orderly way by making both qualitative (descriptions) and quantitative (measurements) observations.

Therefore, be prepared to acquire more interesting scientific skills in this course and then, we explore different branches of science and get to know what Physics means and related concepts.

Fig. 1.1: Science in action

1.1 What is science?

Activity 1.1 **Classifying Perform the following tasks**

1. Which of the following questions can be answered by scientific inquiry?
   - Is running a better sport than swimming?
   - Does running make your muscles stronger than swimming does?
   - Which brand of running does looks best?
   - Why does the passenger in a fast moving vehicle surge forward when the brakes are suddenly applied?
   - Why a pen rubbed onto the hair, it attracts small pieces of paper?

2. How did you make your decision in each case?

3. Explain the meaning of physics and why it is recognized as a science based on its importance and tasks above?

Key facts

Scientific inquiry refers to the different ways scientists study the natural world. It is the ongoing process of discovery in science. Just like you, scientists often find being curious is the first step in scientific inquiry.

Scientists have habits of mind as well: honesty (reporting observations truthfully), open-mindedness (accepting new and different ideas), skepticism (being doubtful about information presented without evidence) and creativity(coming up with new ways to solve problems). The questions in the activity can be answered based on personal opinion but scientific inquiry cannot answer questions based on opinions, values or judgments.

The word *science* is derived from the Latin word '*scientia*' which means knowledge attained through study and practice.

Thus, *science refers to a systematic study that uses observation and experimentation to describe and explain natural phenomena*. The word also refers to the organised body of knowledge people have gained using a system of observation and experimentation. This system of study is called the *scientific method* or *scientific investigation*.

The purpose of science is to produce useful models of reality which are used to advance the development of technology, leading to better quality of life for man and the environment around him.

There are many branches of science and various ways of classifying them. One of the most common ways is to classify the branches into *social sciences*, *natural sciences* and *formal sciences*.

Social sciences deal with the study of human behaviour and society. Examples of these are psychology and sociology. *Natural sciences* deal with the study of natural phenomena, for example lightning, motion, earthquakes all which can be observed and tested. Examples of these are physics, chemistry and biology. *Formal sciences* deal with mathematical concepts and logics. An example of this is mathematics.

1.2 Physics as a science and its characteristics

Activity 1.2

To define Physics as a science

- Let each of your group members at their own time conduct a research from the Internet or reference books on the definition of physics and a justification why physics is a science.
- In addition, find out the branches of physics and why it is important to study physics.
- In your research, identify some key early philosphers and great scientists, the theories, principles, laws and the discoveries they came up with.
- Let each group member present his/her findings to the group. The group leader will then present your group findings to the class.

At Primary level science, we learnt that matter is anything that has weight and occupies space. Physics is a *natural science that is concerned with the study of matter and natural forces*. In this study, it employs a *scientific approach*. The approach is based on systematic experimentation through careful measurements and analysis. Conclusions are drawn from the analysis. These conclusions are tested to find out if they are valid. It is from the conclusions arrived at, that *general laws* and *principles* are stated. As such physics qualifies as a science.

History of Physics

Physics was born by the first people who started asking the '*why*' question. For example, why is there day and night? Why do objects fall downwards instead of going upwards when released in air? Why, why, why why? This question always requires that you give an *explanation*.

The first people to attempt to answer this question were the Greeks who started doing this before 400 BC (Before Christ). By about 320 BC one of the greatest physicists of the day, Aristotle had developed a comprehensive explanation of motion by 1543 AD (Anedomino means After Christ), Nicolus Copernicus had explained that the earth goes round the sun and not the other way round.

By 1727 AD, Isaac Newton had explained why objects always fall towards the earth.

By 1940, Albert Einstein had explained how nuclear energy can be gotten from the centre of the atom. Throughout history, Physics has continued to advance while making invaluable contributions to development of science and technology.

Importance of Physics

1. Physics provides the basic foundation on which other sciences are built. We have already mentioned that Physics enables us to understand the basic components of matter and their mutual interactions. This helps in explaining natural phenomena such as properties of matter. For instance, the knowledge of capillarity in liquids which is learnt in Physics is used to explain the rise of water in plants; pressure difference concept in liquids is also used to explain blood circulation in animals etc.
2. Knowledge and skills learnt in Physics find application in many areas of our daily lives. For example, proper use of household appliances such as refrigerators, iron boxes, television sets, replacing blown-up electric bulbs or fuses all require the knowledge learnt in Physics.
3. Knowledge in Physics helps in the acquisition of career of well paying jobs. The most obvious careers are in the field of engineering which include: civil, electrical, mechanical, agricultural, chemical, computer engineering etc. Other careers are in the fields like meteorology, computer science, laboratory technology, surveying, geology and astronomy. Besides, one may become a Physics teacher in secondary school, college and university. Physics is also useful to doctors, nurses and other science based careers.
4. Technical instruments and equipment provided by Physics find application in almost every area of research. For example, meteorologists make use of instruments such as thermometers, barometers, among others developed by physicists. In medical laboratories, Physics principles and equipments such as electric microwaves are used in carrying out research on HIV and AIDS and other diseases.

Healthy Matters

It is important to remember that though much research has been conducted, no cure for HIV and AIDS has been discovered yet. Abstinence is the best way to prevent HIV infection.

Branches of Physics

Physics is a wide body of knowledge which is studied under several overlapping branches. The following are the major branches of physics:

1. Electromagnetism: is the study of the interaction of electrical and magnetic fields. This has lead to development of useful electronic devices such as loudspeakers, electricity generators, telephone receivers and electric bells among other devices.
2. Mechanics: is the study of the action of forces on objects and motion. The knowledge of mechanics has lead to development of many motion related objects including vehicles, planes, ships, trains etc that have made our movement from one place to other faster and easier.
3. Thermodynamics: is the study of the relationship between heat, other forms of energy and work. The knowledge of thermodynamic is applied in making thermos flask, refrigerators, car engine radiators and air conditioners among other devices.
4. Optics: is the study of the behaviour and physical properties of light. This has lead to development of various optical devices like the lenses that are used in cameras by people with eye defects, projectors, microscopes, telescope, fibre optics among others.
5. Acoustics: is the study of sound and sound waves. This study has been an instrumental tool in the development of various musical instruments like guitars, drums and pianos among other devices.
6. Electronics: is the study of the flow of electrons, generally in a circuit. It has led to the development various telecommunication devices like television, radios, computers, amplifiers and mobile phones among others.
7. Geophysics: is the study of the substances that make up the Earth and the physical processes occurring on, in and above it. The knowledge gained has made it possible to predict, measure and analyse the magnitude of natural phenomena like earthquakes and tsunamis.
8. Atomic Physics – is the study of the structure of the atom, its energy states and how it interacts with other particles and with magnetic and electric fields. This has lead to great milestones in the study of the chemical properties of matter. This has lead to generation of useful atomic energy and atomic bombs.
9. Nuclear Physics - is the study of the physical properties of the nucleus of atoms. This has led to the generation of nuclear energy which is reliable, relatively cheap and makes minimal pollution to the environment.
10. Astronomy: is the study of the universe, the celestial objects like sun moon, planets and stars that make up the universe, and the processes that govern the lifecycle of those objects. The discoveries made through astronomy go along way in satisfying our curiosity of the world we live in. The study has aided the setting up of communication satellites and the development of devices such as Global Positioning System (GPS) that are key in locating points on the earth's surface.

1.3 Physics and other subjects

Activity 1.3 **To establish the relationship between Physics and other subject areas**

With the help of the knowledge of Physics and its branches so far covered, discuss how Physics relate to other subject areas like Chemistry, Biology, Technology, Medicine, Geography and Agriculture.

1. Chemistry mainly deals with the study of salts, acids and their reactions. For a physicist to understand the working mechanism of chemical cells, help is sought from a chemist. On the other hand, the reasons behind the various colours observed in most of the chemical reactions are explained by a physicist. Petroleum products are dealt with by the chemist, but the transportation of such products make use of the principles of physics.
2. In Biology, the study of living cells and small insects by a biologist requires magnification. The concept of magnification using simple or compound microscope is a brain child of a physicist. A good physicist needs to have good health.

A biologist will assist a physicist in the awareness of the following:

(a) A balanced and nutritive diet.
(b) Some simple physical exercises to keep fit.
(c) The various bacteria and viruses normally found in one's blood system e.g. malaria, HIV, etc.
(d) The possible preventive measures in dealing with people who have been infected with diseases such as small pox, HIV and AIDS, etc.
(e) Effects and dangers of drinking excess alcohol, drug abuse, etc.

3. In Geography, weather forecast, a geographer uses a barometer, wind gauge, etc. which are instruments developed by a physicist.
4. In Agriculture, the water sprinkler, insecticide sprayer, etc. make use of the principles developed by physicists.
5. In History, the determination of age fossils by historians and archaeologists use the principle developed by physicists.
6. The theatrical setup, the audio and visual arrangements are the creations of physicists.
7. In games and sports, accurate measurement of time, distance, weight, etc. uses instruments developed by physicists.

1.4 Career opportunities in Physics

Activity 1.4 **To identify career opportunities in Physics**

- Discuss of three the careers you think require knowledge in physics.
- From the careers you have identified, justify how physics knowledge has contributed to the well being of Rwanda as a country and its economy.

From Activity 1.4, you should have learnt that Physics, being a practical subject has many applications. These applications lead to diverse career opportunities depending on one's skill and aptitude. The most promising area of job opportunities is in engineering and technology. Some of the careers one can fit in after studying Physics include: laboratory technology, mapping and surveying, civil engineering, electrical engineering, mechanical engineering, instrumentation technology, meteorology, electronics and telecommunication engineering, architecture, environmental engineering, aeronautical engineering, etc. Apart from engineering, pure sciences such as physics, geology, astronomy, astro-physics, etc. also offer suitable and promising careers. In the application of medical physics, there are career openings in radiology, ultra-sound scanning, medical sports, optometry, etc. In education, one can be a school teacher, university lecturer or a researcher. Therefore, a successful physics student can always find a suitable career opportunity.

Fig. 1.2 shows an electrical engineer at work.

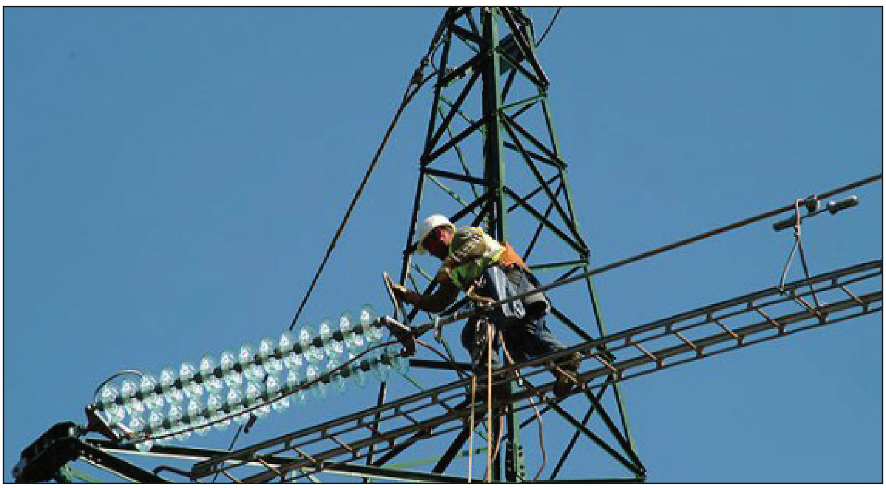


Fig. 1.2: An electrical engineer at work

1.5 Physics, society and technology

Activity 1.5 **To establish the relationship between physics technology and society**

Materials: 2 mobile phones, envelope, a bag

Steps

1. Let one of your members be 'Physics' and assume he/she has two mobile phones in a bag, another one to be 'technology', two of you to be two 'society' members and one member the group secretary.
2. Now, let 'Physics' and 'technology' move to one corner of your classroom or any other room and the two society members to one of the other corners.
3. Let 'Physics' produce the two mobile phones from the bag and give both to 'technology'.
4. Let 'technology' move to the 'society' corner and give the two mobile phones one to each of the society members.
5. Now, let the two 'society members' use the mobile phones to text each other the words *Physics, technology and society*. Let the secretary note down the time the message takes to reach each other. How long does it take?
6. Let the two society members move far from each other and let one of them make a call, to the other. Observe how long it takes for the other mobile phone to start ringing. Let them start communicating to each other.
7. Discuss in your group the importance and relationship between Physics as a subject, technology and society.
8. Now, repeat the role play by removing 'Physics' and 'technology' and let the society members be far away from each other (preferably outside the classroom).
9. Let one 'society' member be a messenger and the other one the recipient .
10. Let the messenger take the envelope to the recipient. Let the secretary note the time taken.
11. Compare the time taken in step 5 and 10. What do you notice? Explain.

Physicists search for reliable information and then organise it into fundamental laws and principles. On the basis of these laws and principles, the engineers and technologists design and develop devices and appliances, that make our living more comfortable. For example, windmills make drawing of water from deep wells easier (Fig. 1.3).

Fig. 1.3: Windmill drawing water from a well

The advancement of technology has led to the manufacture of computers, motor cars, aeroplanes, communication satellites, etc. Fig. 1.4 shows a communication satellite dish.

Fig. 1.4: Satellite dish for communication

These advancements have improved our lives greatly since we can nowadays know what is happening around the world within seconds. Indeed the world has become a global village.

In addition to the above, it is important to note that physics has played a very vital role in:

- Transport where high speed electrical trains larger and more fuel efficient marine vessels (e.g. ships), faster and safer automobiles have been developed.
- Manufacturing sector where labour efficient robots and other gadgetry have been developed.
- Medicine where development of better equipment in surgery and use of safer diagnostic techniques (such as Magnetic Resonance Imaging (MRI) have been developed.
- Recreation and sporting where better equipment for recreation and training are continuously being developed.

Physics continues to play an invaluable role in all activities that relate to energy and its interaction with matter. The principles and laws of physics continue to be used in all areas of human activities such as engineering, medicine, transport, food processing, communication and many other areas.

Here is a list of some of the milestones of advancements that have been achieved by application of physics:

- Computers
- The internet
- GPS
- Digital sound
- Digital video
- Artificial satellites
- Solar power
- TV
- Jet engine
- Nuclear energy
- Space craft
- Electron microscope

Exercise 1.1

1. What is science?
2. Differentiate between natural and social sciences.
3. State some aspects of the natural sciences which you have learnt at the primary school level.
4. Name any four branches of natural sciences.
5. Define the term Physics.
6. Name six different branches of physics.
7. Give instances where physics inter-depend with the following: chemistry, history and agriculture.
8. Mention four career opportunities of a physicist.
9. Describe five contributions of physics to the development of Rwanda as a nation.

1.6 Science processes skills used in learning Physics

Activity 1.6 **To identify the stages of a scientific investigation**

- As a young scientist you have set out to investigate who is heavier between you and your partner
- Together with your partner, list down all the steps you would follow to conduct all this investigation.

Scientific investigation is a systematic process of testing ideas or finding out answers to questions and observations. All scientific investigations are carried out using a common process.

The processes are observations, hypothesis (prediction), experiments and explanation. They form a cycle as shown in Fig. 1.5.

Stages of a scientific investigation

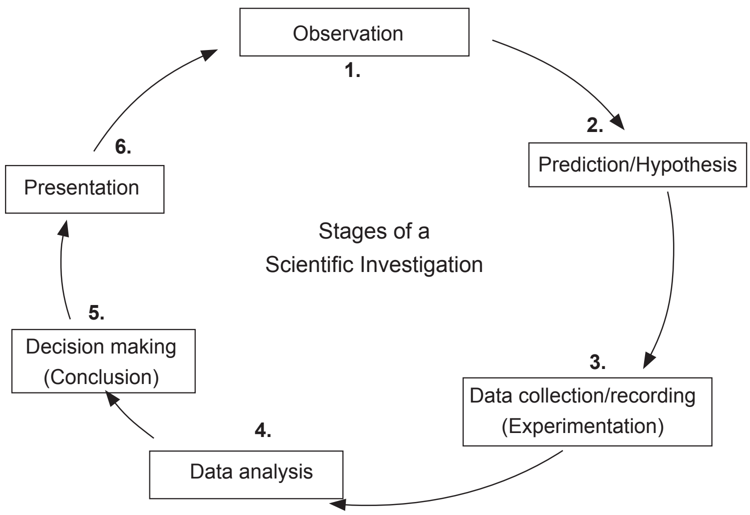


Fig. 1.5: Stages of a scientific investigation

(a) Observation

This is the initial step of scientific knowledge and investigation. Scientists make observations everyday, for which they wish to get answers and explanations.

The following is an example of an observation:

"When a pen is rubbed onto the hair, it attracts small pieces of paper".

Scientists then ask questions from the observations they make. The questions may take several forms such as *why*, *how*, *what* and *when*. A good question that can be answered through scientific investigation should be well *defined*, *testable*, *measurable* and *controllable*.

The following is an example of a scientific question:

"Why does the passenger in a fast moving vehicle surge forward when the brakes are suddenly applied ?"

It is important as a young physicist to be keen on observing things happening around you with a view to understanding how and why they happen.

(b) Prediction/hypothesis

A hypothesis or prediction is a guessed possible answer to the question. It can come from experience or existing scientific knowledge. It must however be testable in order to approve or disapprove it. Note that it is possible to have more than one hypothesis to one question.

The following is an example of a hypothesis:

"Wood floats on paraffin because its density is lower than that of paraffin.

(c) Experimentation (Data collection and recording)

This stage involves designing and carrying out an experiment in order to collect and record data. The experiment design outlines the materials to be used, procedures to be followed, precautions to take and the method of recording data.

The scientists carries out data collection and recording procedures and trials carefully in order to get the appropriate and accurate data. In carrying out the procedures, good scientist observes **health, safety** and **environmental measures**.

Safety Matters

Some chemicals and apparatus involved in some experiments can cause serious health and environmental problems.

Examples are toxic chemicals and X-rays equipment. One should follow the manufactures instructions carefully.

To get accurate results, a scientist collects and record the data to the right precision as he/she carries out the procedures.

The methods of recording data include tables, charts, photographing and recording of sound.

For example, Table 1.1 shows one way of recording the data obtained in the investigation to determine how pressure affects the volume of a fixed mass of a gas at constant temperature.

Constants: mass of gas = 0.5 g; temperature = 25°C

Pressure ($\times 10^5$ Pa)	**Volume (cm^3)**
1.00331	7.339
1.02180	7.241
1.03907	7.143
1.02565	7.038
1.07390	6.88
1.08481	6.83
1.09388	6.78
1.11137	6.67
1.12196	6.63

Table 1.1: Corresponding values of pressure and volume

(d) Data analysis

The raw data collected and recorded need to be analysed in order to give meaningful information. Data analysis may involve:

- Organising the data and studying the trend to determine how it is varying or it remain constant.
- Drawing graphs and charts to show the trend in the set of data.
- Calculating required values that are representative of the data.
- Identifying sources of error in the experiment.

(e) Interpretation of results

This involves deriving meaningful information from the analysed data.

This may include establishing the meaning of data values obtained, trend or the behaviour observed for the object under investigation.

(f) Drawing conclusions (decision making)

A conclusion is a summary of what was established through the investigation. It can be a statement to the effect that the quantities or objects considered in the investigation obey a certain law, condition etc. or not.

At this stage the scientists also compares the *hypothesis* with the conclusion, and gives a statement confirming the hypothesis as true or disapproving it all together.

The following is an example of a conclusion:

We have established that the volume of fixed mass of a gas at constant temperature is directly proportional to its pressure provided the temperature is kept constant.

(h) Reporting the results of a scientific investigation

In most cases, the findings of a scientific investigation have to be communicated in a formal way to the interested parties. Methods of presenting the findings of a scientific investigation include:

- Oral presentation.
- Power point presentation.
- Use of posters.
- Video conferencing.
- Scientific journals and publications, and reports.

The presenter should select the most appropriate method of presentation depending on the nature of research.

Evaluating a scientific investigation

After completing a scientific investigation, the researcher should evaluate the entire process of the investigation against the objectives that were outlined before the commencement of the investigation.

Activity 1.7 **To point out the scientific processes in a conducted-scientific investigation**

Isaac Newton, a famous scientist, observed that all free objects in the air fall to the ground. He then asked the question: **why do free objects in the air fall to the ground?** He guessed that they are heavier than air and that they are attracted to the ground. He went to the laboratory to investigate the accuracy of his hypothesis. The results showed that free objects fall to the ground because they are attracted by the earth.

Identify the **stages** in the Newton's investigation from this information.

Sample scientific investigation

Senior 1 students were given an exercise to practice the use of a mass balance to measure mass and a measuring cylinder to measure the volume of each of four different liquids. Their teacher recommended that they measure the mass and the volume of each liquid at least four times using different volumes of each liquid. The liquids were water, a salt solution, cow milk and a fruit juice.

While carrying out the exercise, two students noticed that for each liquid, the ratio $\frac{\text{mass}}{\text{volume}}$ was nearly the same for all portions of the liquids they used, and they alerted their teacher. The teacher suggested that they investigate this hypothesis with his help.

They formulated the following hypothesis:

Hypothesis

The ratio $\frac{mass}{volume}$ of a liquid is a constant for that liquid at a constant temperature.

They designed and conducted an experiment to investigate the hypothesis for water and filled the following report:

Title: To find out whether the ratio $\frac{\textbf{mass}}{\textbf{volume}}$ of water is a constant at room temperature.

Materials: A beaker, a measuring cylinder, a weighing balance, water

Procedure used

Fig. 1.6: Measuring the mass

1. Determine the mass (m_e) of the empty measuring cylinder using the mass balance (Fig. 1.6).
2. Add about 40 cm^3 of water to the measuring cylinder and determine the total mass (m_t) of the cylinder together with water.
3. Determine the mass of water (m_w) put in the measuring cylinder using $m_w = m_t - m_e$
4. Repeat steps 1 to 3 for seven readings of volume by increasing the volume with about 40 cm^3 each time.
5. Record the results in a tabular form as shown in Table 1.2.

6. Calculate the ratio of mass to volume i.e. $\frac{\text{mass}}{\text{volume}}$ for each set of values and enter in the table.
7. Draw a graph of mass against volume.
8. Determine the slope (gradient) of the graph.

Table of results

Average room temperature was 24°C.

Volume (cm^3)	Mass (g)	$\frac{\text{mass}}{\text{volume}}$ (g/cm^3)
41	41.9	1.02
80	81.3	1.02
122	123.9	1.02
161	162.8	1.02
201	203.2	1.01
244	249.9	1.02
281	283.2	1.01

Table 1.2: Corresponding values of volume and mass

They obtain the straight line graph shown in Fig. 1.7.

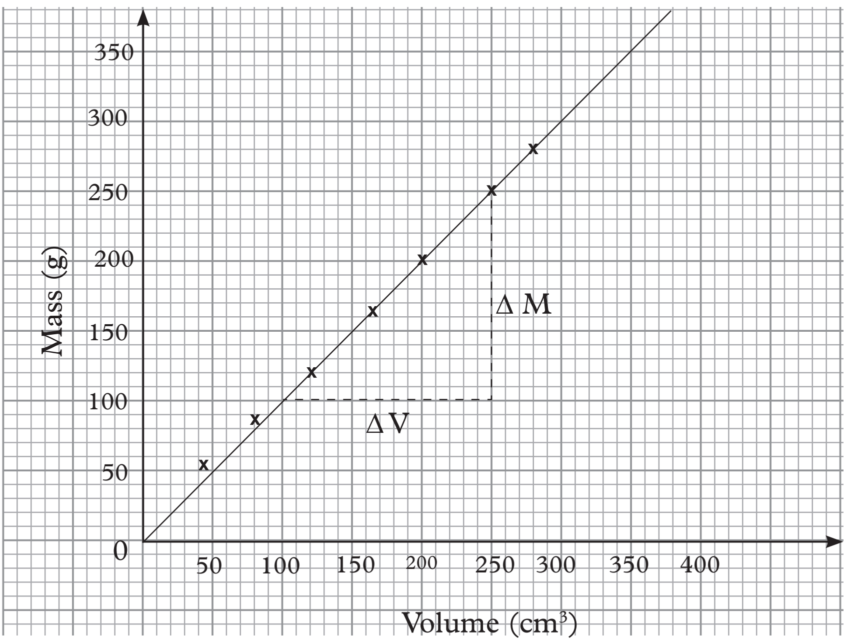


Fig. 1.7: Graph of mass against volume

The gradient = $\frac{\Delta \text{ mass}}{\Delta \text{ volume}} = \frac{(250 - 100)\text{ g}}{(250 - 100)\text{ cm}^3} = 1.00 \text{ g/cm}^3$

This shows that $\frac{\text{mass}}{\text{volume}}$ of the liquid is a constant at 24°C.

Analysis

The results show that indeed the ratio $\frac{\text{mass}}{\text{volume}}$ for water is a constant at a given temperature.

Its average value = 1.0 g/cm^3 at 24°C.

Conclusion

The ratio $\frac{\text{mass}}{\text{volume}}$ for water at 24°C is 1.02 g/cm^3.

This shows that, allowing for experimental error, the hypothesis has been proved to be correct at 24°C.

Activity 1.8 Identifying scientific processes

Go through the sample investigation we have just seen.

- Fill the following table with ✓ when a scientific process was conducted and X if it was not conducted
- Write down the evidence to show that it was conducted

Process	Tick ✓ or ×	Evidence
1. Observation		
2. Prediction		
3. Data collection		
4. Data analysis	√	Graph, calculation
5. Decision making		
6. Presentation		

Table 1:3: Scientific process

Note: It is always better to draw a graph than to find the average of a few pairs of values obtained in an experiment. This gives a more accurate value of the quantity being determined.

The line of best fit is an average of all possible pairs of results within a range. It is the preferred method of analysing graphical data.

Exercise 1.2

1. What is a scientific investigation?
2. Why is the step of making observation in the process of scientific investigation very important?
3. How is scientific investigation different from non-scientific investigation? Give examples.
4. Discuss the meanings of the following terms:
   (a) Prediction
   (b) Interpretation of result
   (c) Data analysis
   (d) Decision making

1.7 Laboratory safety measures

Activity 1.9 **To observe a laboratory and identify safety rules therein.**

- Your teacher will take you to the laboratory or science room; where you will be conducting physics experiments.
- Identify some apparatus you may have seen before.
- Identify some situations that may pose danger to learners while in the laboratory.
- List at least five safety rules you may think of that should be observed while in the laboratory.
- Compare and discuss your findings with other groups in your class.

A laboratory is a room in which science experiments or investigations are conducted. While in the laboratory, you are expected to observe some measures to avoid occurrence of accidents that may harm them or the apparatus..

The list of laboratory safety rules and regulations is quite long and you will be learning more rules and regulations throughout your study in Physics.

Generally, the rules and regulations fall under seven main categories as summarised in Table 1.4.

Name of category	Safety rules and regulation
1. Personal safety rules	• Read labels carefully. • Follow instructions to the latter. • Long hair or loose clothes must be tied back or confined. • Clean up your work area before leaving. • While inside the laboratory, do not run, play or throw things. • Never chew, eat or drink in the laboratory. • Inform the teacher at once about any accidents.
2. Emergency response safety rules	• Know the location of the fire extinguisher, eye wash and safety shower in your laboratory • Attend training by the teacher on how to use fire extinguisher, eye wash and safety shower. • Inform your teacher immediately at the occurrence of an injury, fire or explosion and spillages.
3. Equipment safety rules	• Follow all instructions on how to use an equipment carefully before using it. • Use the appropriate equipment for the appropriate purpose of laboratory activity. • Report to the teacher any damage to an equipment as well as any faulty equipment. • Never heat glass bottles and containers with the stoppers on as build up pressure could cause an explosion.

4. Electrical safety rules	• Report to the teacher the presence of loose electrical wires. • Switch on electricity only when instructed by the teacher or laboratory assistant. • Your hands must be dry when working with electricity. • Open live electrical circuits should be avoided under all circumstances. • Always ensure that the electric socket switch is off before plugging in any electrical device. • Never try to connect anything other than the proper plug into the mains socket.
5. Chemical safety rules	• Follow instructions on how to use the chemicals in any laboratory activity • Keep your skin away from contact with chemicals. • Ensure that you do not taste chemicals in the laboratory. • Never handle radioactive material with bare hands (use tongs and forceps).
6. Other safety rules	• Only experiments authorized by the teacher should be conducted in the laboratory • Conducting experiments in groups require team spirit. • 'Cleanliness is next to Godliness'. Ensure the laboratory is clean and organized. • All experiments must be completed before you can change places • Be honest with your work and data
7. Common sense safety rules	• 'Be responsible for your safety and that of others including the laboratory as a whole. • 'If at any time you are not sure of how to handle a particular situation, feel free to get advice from your teacher or laboratory assistant.

Table 1.4: Laboratory safety rules and regulations

Since it is impossible to eliminate all the risks of an accident, it is your responsibility to minimise them and ensure that you are able to take appropriate action should any occur. In case of an accident, despite taking all the precautions, the most important consideration at all times is human safety. You should act quietly and methodically. *Common sense* is the best judge.

1.8 First aid

Activity 1.10 **To define first aid and interpret hazard symbols**

(Work in groups)

Materials: first aid kit, chart showing hazard symbols

- In groups of three, discuss what first aid is and why it is important to have adequate knowledge on first aid.
- Open the first aid kit provided to you and identify all the items in it and their uses.
- Now, discuss each hazard symbols shown on the chart provided and suggest why it is important to understand them.

The purpose of *first aid* is to make the victim secure and comfortable. This prevents his/her condition from becoming worse until professional assistance is available.

All physics students need to have adequate knowledge of first aid. The physics laboratory should have a fire extinguisher and a first aid kit containing the following items:

- A pair of blunt-ended scissors.
- Safety pins.
- Gloves.
- Adhesive plaster.
- Mild antiseptic solution.
- Forceps.
- An assortment of bandages.
- Sterilised cotton wool and gauze.

1.9 Hazard symbols and their meanings

Signs and symbols(Fig 1.8) are meant to help us quickly identify the risks we are likely to be exposed to when handling equipments, apparatus and chemicals.

The following are some of the common hazard symbols in a laboratory.

(a) Oxidising liquids

(b) Harmful/Irritant to the environment

(c) Dangerous for acquatic environment

(d) General danger

(e) Risk of fire

(f) Risk of explosion

(g) Toxic

(h) Corrosive substance

(i) Risk of ionisation gradiation

(j) Risk of electric shock

(k) Laser beam

(i) Biohazard

Fig. 1.8: Hazard symbols

1.10 Laboratory hazards and safety precautions to be taken

Activity 1.11 **To identify laboratory precautions**

(Work in groups)

Steps

- Discuss with your group members what laboratory safety precautions are.
- List at least five precaution which must be taken when one is in the laboratory.
- Now, identify and discuss with your partner possible hazards if the precaution identified are not observed.

From Activity 1.11, you should have learnt that safety measures in the laboratory are the set of safety guidelines that are supposed to be followed incase of any laboratory hazards. Table 1.5 shows some of the hazards in the laboratory and safety precautions to be taken.

Laboratory Hazards	Safety precautions to be taken
1. Fire outbreak	• Move to fire assembly points using fire exit points. • Inform the teacher or the instructor. • If you can, use the fire extinguisher to put the fire off. • If you can, switch off the main switch of the laboratory wiring system. • Note: Do not scream or run randomly.
2. Electric shock	• Switch off the power at the socket first. • Pull out the victim from the appliances • Give the victim first Aid. • If the victim is not breathing, tap three times on his/her left side of the chest • If not breathing,'give a kiss of life' i.e. help the victim to breath • Seek for medical assistance from a medical personnel.
3. Suffocation	• Take the victim out of the laboratory to open air for fresh air. • Open all the windows and doors. • Seek assistance from the medical personnel.
4. Chemical spillage on the skin, floor, table etc	• Pour a lot of pure water to the affected part to dilute the chemical. • In case the chemical is in contact with your eye, use the eye wash. • If you tasted the chemicals, drink clean water. • Seek medication immediately.
5. Breaking of equipments	• The teacher should guide the students to use equipment correctly. • Inform the teacher immediately. • With the help of the teacher or instructor collect the pieces of broken apparatus.
6. Breaking of general safety	• Guide and counsel the students • Use school disciplinary committee to correct the student.

Table 1.5: Laboratory hazards and safety precaution to be taken

Exercise 1.3

1. Explain why it is important to observe laboratory rules and regulations.
2. State five laboratory safety rules and regulations.
3. You are working in the laboratory and you see the hazard symbols shown in Fig. 1.9 below:

(a) (b)

Fig. 1.9: Hazard symbols

   (a) Describe the meaning of each symbol.

   (b) Describe the steps you would take to guard against the hazard depicted by each symbol.

4. In every school, there is a procedure to be followed by every member of the school community in case of fire outbreak. Describe the procedure to be followed in your school. You may need to consult your teacher and other sources to answer this question.
5. Give three safety measures to be taken incase of fire outbreak.

1.11 Fundamental and derived quantities of measurements

Activity 1.12 **To describe and identify fundamental and derived quantities**

Materials: reference books, internet

Steps

1. Conduct a research from Internet or reference books on:

   (a) Definition of fundamental and derived quantities. Note down examples on each.

   (b) International System of Units (SI) for different quantities.

2. Identify the SI unit of height, mass and time.
3. Identify two smaller units of measurement mass, height and time and their symbols. Identify one unit for each larger than the SI unit.

From Activity 1.12, you should have discovered that any quantity of measurements are either a fundamental or derived quantity.

Fundamental quantities

A *quantity* may be defined *as any observable property or process in nature with which a number may be associated*. This number is obtained by the operation of measurements. The number may be obtained directly by a single measurement or indirectly, say for example, by multiplying together two numbers obtained in separate operations of measurement. *Fundamental quantities* are those quantities that are not defined in terms of other quantities. In physics there are 7 fundamental quantities of measurements namely length, mass, time, temperature, electric current, amount of substance and luminous intensity. In this book we will study the following 5 fundamental quantities: *length*, *mass*, *time*, *temperature* and *electric current*.

SI units and symbols

In order to measure any quantity, a *standard unit* (base unit) of reference is chosen. The standard unit chosen must be unchangeable, always reproducible and not subject to either the effect of aging and deterioration or possible destruction.

Before 1960, there were several systems of measurements in use around the world. In 1960, an international system of units was established. This system is called the *International System of Units* (SI). Table 1.6 contains the 7 fundamental physical quantities, their SI units and symbols.

Fundamental quantity	SI Unit	Symbol
1. Length	Metre	m
2. Mass	Kilogram	kg
3. Time	Second	s
4. Temperature	Kelvin	K
5. Electric current	Ampere	A
6. Amount of substance	Moles	mol
7. Luminous Intensity	Candela	cd

Table 1.6: Fundamental quantities and SI units

Derived quantities

Quantities which are defined in terms of the fundamental quantities via a system of quantity equations are called *derived quantities*. Examples of derived quantities include area, volume, velocity, acceleration, density, weight and force.

The SI units of derived quantities are obtained from equations using mathematical expressions as follows:

(a) Area (e.g for square objects)=length (m) × length (m).
The SI unit of area in symbols is m^2.

(b) Volume(e.g for cubic objects)=length (m) × length (m) × length (m).
The SI unit of volume in symbols is m^3

(c) Density $= \frac{\text{mass (kg)}}{\text{volume } (m^3)}$. The SI unit of density in symbols is kg/m^3.

(d) Velocity $= \frac{\text{displacement } (m)}{\text{time taken } (s)}$. The SI unit of velocity in symbols is m/s.

(e) Acceleration $= \frac{\text{change in velocity } (m/s)}{\text{time taken } (s)}$ The SI unit of acceleration in symbols is m/s^2.

Note that some derived units have been given names. For example, force is measured in kg m/s^2 and has been given a named unit called a newton (N). We shall encounter other derived quantities later in this course and other levels of physics.

Prefixes for SI units

Activity 1.1 **To practice the use of prefixes**

Steps

1. Write each of the following figures five times in your exercise book.
   (a) 1 000 000 (b) 2 000 000 000 metres
   (c) 0.000 001 kg (d) 0. 000 005 litre
2. Repeat step 1 by writing the values using prefixes like milli mega, micro milli and so on.
3. which step was faster and less tedious? Suggest the name given to figures when written as in step 2.

Physical quantities are of wide range of magnitude. For example the mass of earth is about 6 000 000 000 000 000 000 000 000 kg while the diameter of a molecule is 0.000 000 0001m. Writing such quantities is very tedious and clumsy. Some words have been used with SI units as short-cut to writing such magnitude. These words are associated with certain magnitude. For example a word like milli stands for $\frac{1}{1000}$, kilo for 1000. Since these words are used or fixed before the SI units, they are called *prefixes*.

Table 1.7 shows some common prefixes and their symbols.

Prefix	Symbol	Magnitude
nano	n	10^{-9}
micro	µ	10^{-6}
mill	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}
deca	da	10^{1}
hecto	h	10^{2}
kilo	k	10^{3}
Mega	M	10^{6}
Giga	G	10^{9}

Table 1.7: Prefix, symbol and magnitude of SI units

1.12 Measuring instruments

Activity 1.14 **To match an instrument with what it measures**

Instrument		Quantity measurement
Metre rule		Time
Thermometer		Small volume
Vernier callipers		Lengh in mm, cm, m
Beam balance		Temperature
Stop watch		Mass
Burrette		Diameters of objects

Table 1.8: Instruments and quantity of measurement

Measurements involve comparing an unknown quantity with a known fixed unit quantity (standard unit). This measurement consists of two parts, the unit and the number indicating how many units are there in the quantity being measured. In order to obtain various measurements, early scientists had to develop *measuring devices*. A measuring device has *a scale* marked in the standard or multiple units of the quantity to be measured. The choice of the instrument to be used depends entirely on the quantity being measured and the level of accuracy needed.

In this sub-unit, we shall learn how to use accurately the *metre rule* and *tape measure* for the measurement of length, *beam balance* for the measurement of mass, *stop clock* or *stopwatch* for the measurement of time and *measuring cylinder*, *pipette*, and *burette* for the measurement of volume.

1.13 Measurement of length

Activity 1.15 **To identify the units of measuring length**

Steps

1. Discuss with your partner what you think length is.
2. Suggest the SI unit of length and its symbol.
3. Name other units are used to measure length and their symbols.

Length is measured in *metres*. One metre is the distance between the two marks on a standard platinum-iridium bar kept at Paris (France).

Although the metre is the standard unit of length, it is sometimes too big to measure some distances and too small to measure others. We therefore need other larger and smaller units related to the metre to carry out some measurements.

Table 1.9 shows the SI units of length and its relationship with other larger and smaller units of length.

Unit	Symbol	Comparison with metre
1 kilometre	km	1 000 m
1 metre	m	1 m
1 centimetre	cm	0.01 m
1 millimetre	mm	0.001 m
1 micrometre	µm	0.000 001 m

Table 1.9: Units and symbols of length

Let us now discuss some of the instruments used to measure length.

Meter stick

Activity 1.16 **To make and use a metre stick**

Materials: a meter rule, a stick

Steps

1. Measure and cut out a piece of stick of length 1m
2. Use your stick to measure in full metres:
   (a) The length of your classroom.
   (b) The length of your football field.
   (c) The with of your flower garden.
   (d) The distance from your the flag post.
3. Record, compare and discuss your measurement with other groups in your class.

Metre rule

Activity 1.17 **To observe the scale of metre rule**

Materials: A metre rule

Steps

1. Hold a metre rule provided to you and note its calibration. What does each division represent?
2. Discuss the calibration of a metre rule with your colleagues in your class.

Straight distances which are less than one metre in length are generally measured using *metre rules*. Metre rules are graduated in *millimetres (mm)*. Each division on the scale represents 1 mm unit (Fig. 1.10).

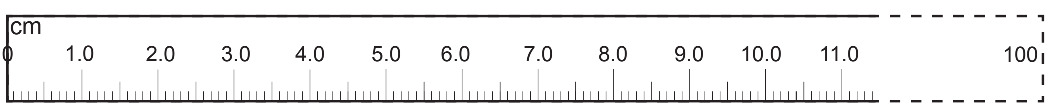


Fig. 1.10: A metre rule

Activity 1.18 To demonstrate how to use a metre rule

Materials: A metre rule, a block of wood

Steps

1. Place the metre rule in contact with the block as shown in Fig. 1.12. The zero mark on the scale is placed at the edge of the object.
2. Position your eyes vertically above at the other end of the block as shown in Fig. 1.11 position. Suggest the reason for this. Read the measurement and record it down in your exercise book.

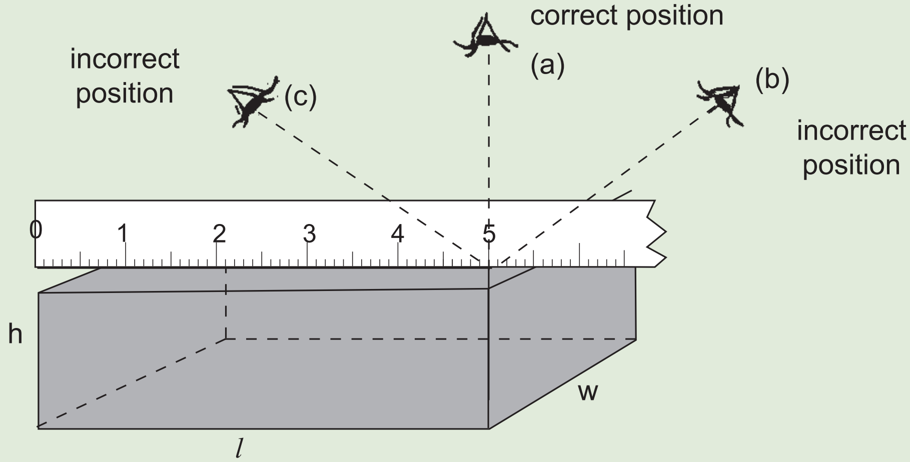


Fig. 1.11: Reading a metre rule

3. Repeat the steps this time measuring the width (w) and height (h) of the block.
4. Record your reading in tabular form as shown in table 1.10.

Length (cm)	Width (cm)	Height (cm)

Table 1.10: Result table

Note: It is not always necessary to start measuring at the zero mark of the metre rule as shown in Fig. 1.11. You may use any two points on the scale, make your readings and obtain the required length by subtraction.

Activity 1.19 To measure the length of a pencil

Materials: a meter rule, a pencil

Steps

1. Line up the zero mark of the meter stick up with the end of the pencil.
2. Note the mark exactly at the other end of the pencil. (Fig 1.12)

Fig 1.12: Measuring length of a pencil

3. Record the length of the pencil.
4. Now practice measuring the length of different objects in your classroom.
5. Compare your measurements with those of your classmates? Did everyone get the same measurements?

Vernier callipers

Activity 1.20 To observe the parts of a vernier calliper

(Work in groups)

Materials: vernier calliper

Steps

1. Look at a vernier calliper provided. Name the parts and describe their functions.
2. Observe its horizontal and rotating scales, its jaws and knobs.
3. Discuss how it measures length.

Fig. 1.13(a) shows the photograph of a vernier calliper.

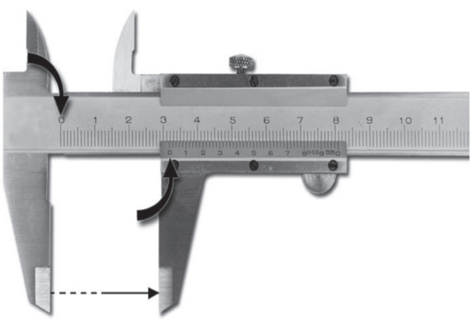


Fig. 1.13(a) Vernier calliper

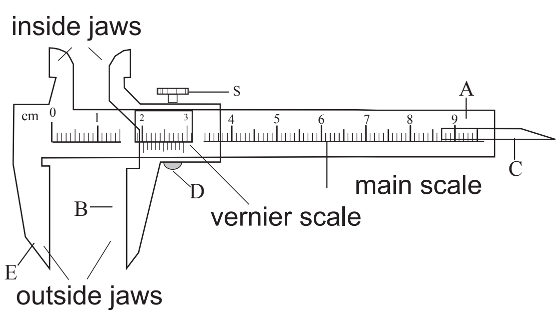


Fig. 1.13(b): Parts of a vernier callipers.

Fig. 1.13 (b) shows the parts of a vernier calliper.

The calliper consists of a steel rigid frame A, onto which a linear scale is engraved. This scale is called the *main scale* and it is calibrated in centimetres and millimetres. It has a fixed jaw E at one end and a sliding jaw *B* centrally aligned by a thin flat bar *C*. The spring-loaded button *D* is used to prevent the sliding jaw from moving unnecessarily. The sliding jaw carrying a vernier scale can move along the main scale and can be fixed in any position along the main scale by screw *S*.

The outside jaws are used to take external length measurements of objects. The inside jaws are used to take internal length measurement of an object. The sliding flat bar *C* is used to find the depth of blind holes.

Using a vernier scale

Least count of a vernier calliper

Activity 1.21 **To observe and analyse the scale on a vernier calliper**

Materials: Vernier calliper

Steps

1. Take a vernier callipers and observe its scale. How many divisions are there between 0 and 1, 4 and 5?
2. Iind out what each division represents. What is the name given to the value?

The vernier scale has a length of 9 mm. It is divided into ten equal divisions. Therefore, each division has a length of 0.9 mm. The difference between 1 division on the main scale and 1 division in the vernier scale is (1– 0.9) mm =0.1 mm. The smallest reading called the *least count (LC)* that can be read from vernier callipers is 1 mm – 0.9 mm = 0.1 mm or 0.01 cm .

The second decimal value in a reading is obtained by identifying the mark on the vernier scale which coincides with a mark on the main scale called the *vernier coincidence (VC)* and multiplying it with the least count i.e 0.01 cm.

Second decimal value = (VC × LC).

How to read the vernier callipers scale

Activity 1.22 **To read and record the reading on a vernier calliper**

Materials: cylindrical object, vernier calliper

Steps

1. Place the object to be measured between the outside jaws as shown in Fig. 1.14. Slide the jaw until they touch the rod.

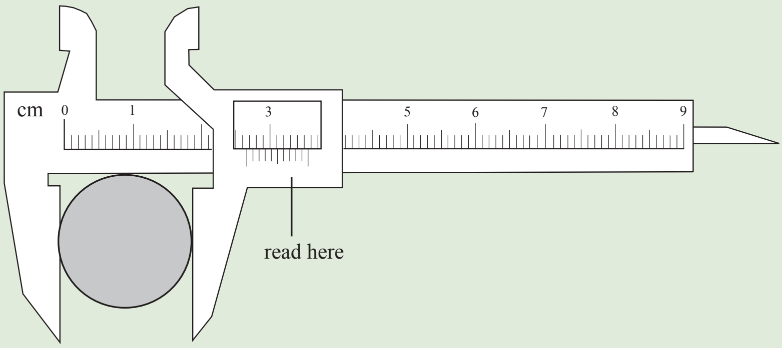


Fig. 1.14: Measurement of external diameter using vernier callipers

2. Record the readings on the main scale and the vernier scale. The main scale reading is the mark on the main scale that is immediately before the zero mark of the vernier scale.
3. Multiply the vernier scale reading by 0.01 cm.
4. Add the main scale reading (in cm) and the vernier scale reading (in cm) to get the diameter of the rod.

For instance, for the vernier shown in Fig. 1.14, the main scale reading (MSR) is 2.6 cm. However, to get the second decimal value, we make use of the vernier scale. The vernier scale mark that coincides exactly with a main scale mark gives the vernier coincidence (VC).

In this case, the 6^{th} division coincides with the main scale division.

Therefore, the external diameter of the cylindrical object is

$$\text{MSR} + (\text{VC} \times \text{LC}) = 2.6 \text{ cm} + (6 \times 0.01) \text{ cm}$$
$$= 2.66 \text{ cm.}$$

Activity 1.23 **To measure the internal diameter of a test tube using a vernier calliper**

Steps

1. Insert the inside jaws of a vernier callipers into the test tube.
2. Move the sliding jaws until the jaws just touch the inside walls of the test tube as shown in Fig. 1.15.

3. Take and record the readings on the main scale and the vernier scale. Use these readings to determine the internal diameter of the test tube.

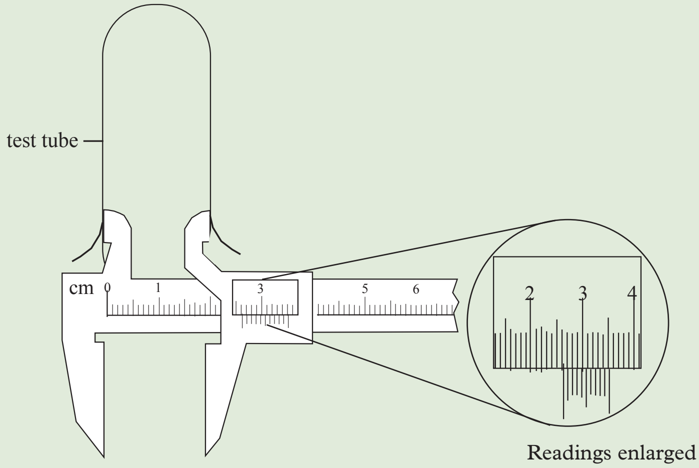


Fig. 1.15: Measurement of internal diameter using vernier callipers.

We can determine the diameter of the test tube shown in Fig. 1.15 as follows:

The internal diameter of the test tube = MSR + (VC × LC)

= 2.6 cm + (2 × 0.01) cm

= 2.62 cm

Example 1.1

What are the readings shown by the vernier callipers in Fig. 1.16(a) and (b)?

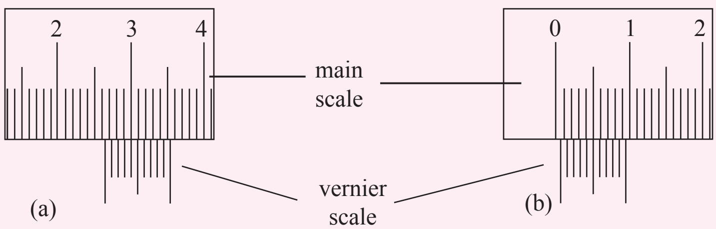


Fig. 1.16: Vernier calliper readings

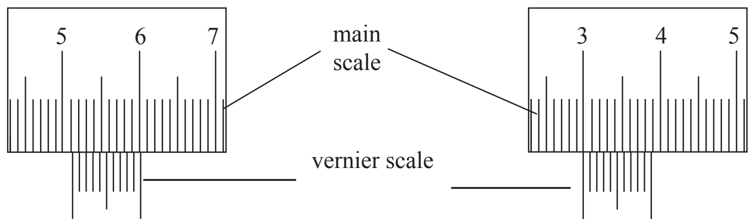
Solution

(a) Main scale reading = 2.6 cm
Vernier scale reading = <u>0.04 cm</u>
Reading = 2.64 cm

(b) Main scale reading = 0.00 cm
Vernier scale reading = <u>0.05 cm</u>
Reading = 0.05 cm

Exercise 1.4

1. Explain the advantages of using a vernier calliper over a metre rule in measuring the diameter of a small ball bearing.
2. With the aid of a well labelled diagram describe the main features of a vernier calliper.
3. What are the readings shown on the calipers in Fig. 1.17 (a) and (b)?



(a) (b)

Fig. 1.17:Vernier calliper readings

4. Micrometer screw gauge

Activity 1.24 **To observe the parts of micrometre screw gauge**

Materials: a micrometer screw gauge

Steps

1. Look at the micrometre screw gauge provided
2. Observe its horizontal and rotating scales.
3. Observe its jaws and practice how to open and close them slightly,

A micrometer screw gauge is an instrument for measuring very short length such as the diameters of wires, thin rods, thickness of a paper etc. It was first made by an astronomer called *William Gascoigne* in the 17^{th} century.

Fig. 1.18(a) shows the photograph of a micrometer screw gauge.

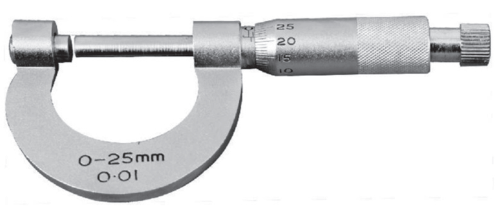


Fig. 1.18(a): Micrometer screw gauge

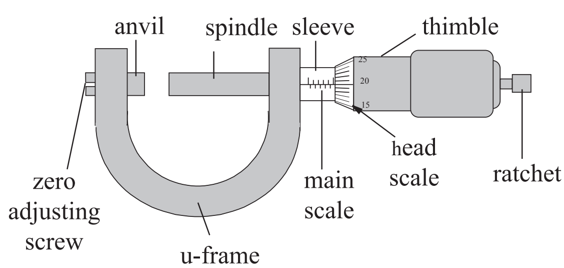


Fig. 1.18:(b) Parts of a micrometer screw gauge

Fig. 1.18(b) shows the parts of a micrometer screw gauge.

A micrometer screw gauge consists of the following:

- U-frame which holds an *anvil* at one end and a *spindle* at the other end.
- *Sleeve*, which has a linear *main scale (sleeve scale)* marked in millimetres or halve millimetres.
- *Thimble*, which has a circular rotating scale that is calibrated from 0 to either 50 or 100 divisions. This scale is called the *head scale (thimble scale)*. When the thimble is rotated, the spindle can move either forward or backwards.
- *Ratchet* which prevents the operator from exerting too much pressure on the object to be measured.
- *Zero adjusting screw* that is used to clear zero errors.

Reading a micrometer screw gauge

How to use and determine the reading on the micrometre screw gauge

Activity 1.25 **To analyse the scale on micrometre screw gauge**

Materials: a micrometer screw gauge

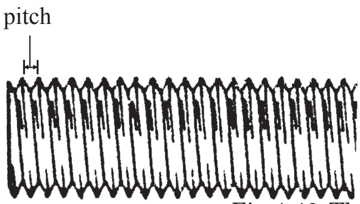
Steps

1. Take a micrometer screw gauge given to you and observe its sleeve and thimble scales.
2. Now, take a keen look on a thimble scale. How many divisions are between 0 and 100? or 0 and 50?
3. How to find the value represented by each division?

The movement of the thimble is controlled by a screw of known pitch as shown in Fig. 1.19. There are two common types of pitches on the thimble namely:

1 mm and 0.5 mm.

When the pitch is 1 mm, the thimble has 100 divisions called *head scale divisions*. In this case each division represents 0.01 mm. This is the least count (LC) of this screw gauge.



$$LC = \frac{1 \text{ mm}}{100} = 0.01 \text{ mm.}$$

Fig. 1.19: The pitch of a thimble.

Similarly, if the pitch is 0.5 mm the thimble has 50 division. Each divisions represents 0.01 mm, i.e.

$$LC = \frac{0.5 \text{ mm}}{50} = 0.01 \text{ mm.}$$

The thimble reading called *the head scale coincidence* (HSC) is the value of the mark on the thimble that coincides with the horizontal line on the sleeve. Main scale reading is taken by considering the reading of a mark on the fixed scale that is immediately before the sleeve enters the rim of the head scale.

The linear main scale on the sleeve is calibrated in millimetres or half millimetres. The micrometer screw gauge is operated by turning the thimble until the object whose measurement is required just touches the anvil and the spindle. The ratchet is then rotated to press the object gently between the anvil and the spindle. When the correct pressure has been exerted on the object, a clicking noise is heard indicating that the reading can now be taken. See Fig. 1.20.

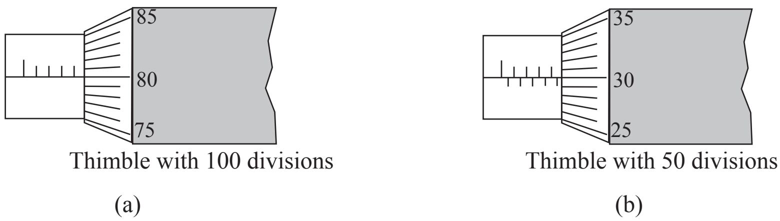


Fig. 1.20: Thimble divisions.

In Fig. 1.20(a), the least count = 0.01 mm.

The micrometer screw gauge reading

$$\begin{aligned} &= \text{MSR} + (\text{HSC} \times \text{LC}) \\ &= 4.0 \text{ m} + (80 \times 0.01) \text{ mm} \\ &= 4.80 \text{ mm.} \end{aligned}$$

In Fig. 1.20(b), LC = 0.01 mm.

The micrometer screw gauge reading

$$\begin{aligned} &= \text{MSR} + (\text{HSC} \times \text{LC}) \\ &= 4.5 + (30 \times 0.01) \text{ mm} \\ &= 4.80 \text{ mm.} \end{aligned}$$

Example 1.2

A micrometer screw gauge has a thimble scale with 100 divisions and screw pitch of 1.00 mm. Find the length of one division (least count) on the thimble scale.

Solution

100 divisions have a length of 1.00 mm

$\therefore$ 1 division has a length of $\dfrac{1.00}{100} = 0.01$ mm

Activity 1.26 To determine the diameter of a ball bearing using a micrometer screw gauge

Materials: a ball bearing, micrometer screw gauge

Steps

1. Clean the faces of the spindle and the anvil to remove any dirt.
2. Close the gap between the anvil and the spindle to check for zero error. In case of any error, remove it by rotating the zero adjustment screw clockwise or anticlockwise as the case may demand. Alternatively you may note the error as a negative or a positive value and add it to or subtract it from the final reading accordingly.
3. Turn the spindle to open a suitable gap for holding the ball bearing in between the anvil and the spindle.
4. Close the spindle to the correct tightness (Fig. 1.21).
5. Take the readings on the main scale and the thimble scale and record them down in your exercise book.

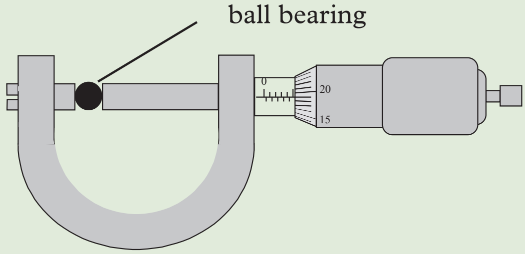


Fig. 1.21: Using a micrometer screw gauge

6. Repeat the activity by taking two more measurements. Obtain the average value.

7. Multiply the thimble scale reading by 0.01 mm.
8. Add the main scale reading (in mm) and the thimble scale reading (in mm) to get the diameter of the ball bearing.

Example 1.3

What is the diameter of the ball bearing shown in Fig. 1.22?

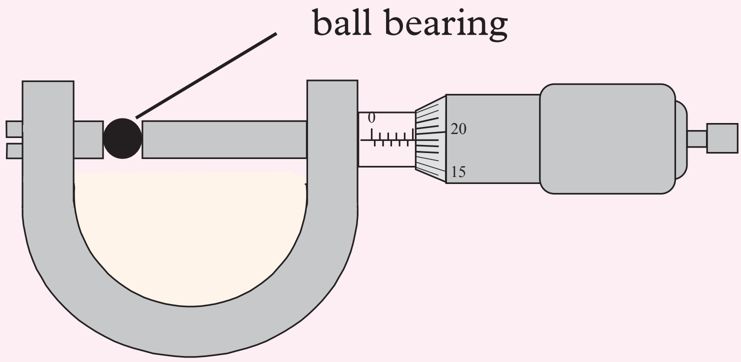


Fig. 1.22: Determining diameter of a ball bearing

Solution

Main scale reading	=	5.0 mm →	5.00 mm	
Head scale coincidence	=	19 divisions		+
Head scale reading	=	19 × 0.01 =	0.19 mm	
Full reading	=	5.0 + 0.19 =	5.19 mm	

The diameter of the ball bearing is 5.19 mm

Exercise 1.5

1. State the value of the readings shown by the micrometer screw gauges in Fig 1.23.

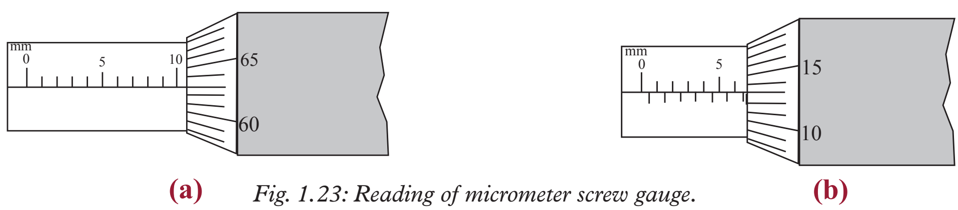


Fig. 1.23: Reading of micrometer screw gauge.

2. Draw a micrometer screw gauge showing the following reading if the screw pitch is 0.5 mm.

   (a) 18.56 mm (b) 2.36 mm (c) 5.72 mm

3. Repeat Question 2 above for a micrometer screw gauge of pitch 1 mm.

1.14 Measurement of time

Activity 1.27 **To describe the concept of time**

Materials: stopwatch, playing ground

Steps

1. Ask your partner to run from one end of the field to the other as you time the event.
2. Let him/her also time as you ran the same distance. Compare the times you took. Who took the shortest time? Explain.
3. Discuss with your partner what you think time is, its SI unit, symbol and how to use the stopwatch.

Hey!!!

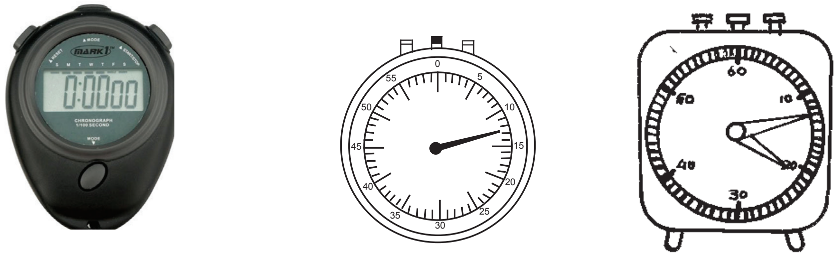
Co-curriculum activities and physical exercises are very crucial and beneficial to you as a student. Always participate in different disciplines that are offered in your school.

From Activity 1.27, you should have established that time is a measure of duration taken by an event. The SI unit of time is the second and its symbol is *s*.

Stopclocks and watches

All living things have an inbuilt biological clock which seems to control the rhythm of their life cycle. For example, the cock will crow only at specific time intervals. Regardless of where we are located or what we are doing, we are always aware of the idea of passage of time. This passage of time is noticed in many ways, for example by the heartbeat, the sun, seasons, etc. The measurement of time is based on rhythm.

Time is measured using either analogue or digital watches and clocks (Fig. 1.24). Analogue watches and clocks (Fig. 1.24(b) and (c)) are controlled by oscillations of a balance wheel and hairspring or electrical oscillations of a quartz crystal.



(a) A digital stopwatch (b) a stopwatch (c) a stop clock

Fig. 1.24: Stop watches and a stop clock

Table 1.11 shows units of time and their relationships with the seconds.

Unit	Symbol	Comparison with SI unit
1 hour	h	3 600 s
1 minute	min	60 s
1 second	s	1 s
1 millisecond	ms	0.001 s
1 microsecond	μs	0.000 001 s

Table 1.11: Units of time and their relationship with the second

Example 1.4

How many seconds are there in 1 week?

Solution

1 week = 7 days
1 day = 24 h
1 h = 60 min
1 min = 60 s

1 week = $7 \times 24 \times 60 \times 60$
= 604 800 s

Digital stopwatch can measure very small time intervals. It can display, hours, minutes, seconds and milliseconds.

Using a digital stopwatch

Timing the reading of words

Activity 1.28 **To measure and record the time taken to read words**

Materials: stopwatch

Steps

1. Start the stopwatch and time how long it takes your partner to read a certain sentence e.g.
    - Stop environmental pollution!
    - Our environment is our livelihood!
    - HIV/AIDS is incurable!
    - Avoid unprotected sex!
2. Stop the watch, reset and repeat the activity about four times. Find your average time for reading the sentence.

You should have observed that the longer the sentence, the longer the time taken to read it. The average time for reading a sentence is more accurate than each individuals time recorded for the same event.

Activity 1.29 To time the heart beat

Materials: stopwatch

1. Place your palm on the side of your chest and feel your heartbeat.
2. Start the stopwatch.
3. By feeling and counting your heartbeats, determine the number (n) of heartbeat in 60 s.
4. Determine the time interval between your two heartbeats as $\frac{60}{n}$.

When breathing normally, you should obtain 72 heart beats in one minute (60s). Hence the interval between your two heart beat should be $\frac{60 \text{ s}}{72} = 0.833$ s.

Example 1.5

The heart of an obese student was beating at 85 beats per minute. Find the time interval for one beat. What can you advice the person (Hint: the normal heartbeat rate is 72 beats per minute).

Solution

85 beats takes 60 seconds

1 beat will take ?

$$\frac{1 \times 60 \text{ s}}{85} = 0.706 \text{ s}$$

The time for one heartbeat is 0.706 s. The person should visit a doctor for checkup.

Health Matters

Always have a medical check up, exercise your body and eat properly to avoid most lifestyle diseases.

Exercise 1.6

1. Define the term time and state its SI unit.

2. A student used the stopwatch shown in Fig. 1.25 to measure the time taken by an athlete to cover 100 m. What is the time taken by the athlete?

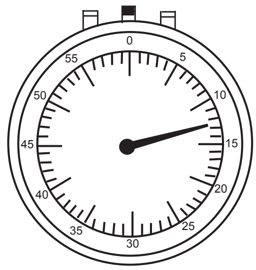


Fig. 1.25:A stopwatch measuring time

3. The stopwatch in Question 2 was accidentally dropped and its pointer pin became loose such that when the stopwatch is started, the pointer pin swifts backwards by 1 division. What is the actual reading of the stopwatch shown in Fig. 1.26?

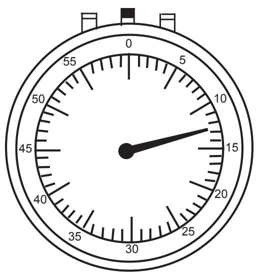


Fig. 1.26: Stopwatch measuring time

4. A wheel of a car rotating uniformly makes 400 revolutions in one minute.

   How long will the wheel take to make one revolution?

5. Describe an experiment to measure the time interval for one heartbeat.

1.15 Measurement of derived quantities

Measurement of area

Activity 1.30 **To define area and its unit of measurement.**

Materials: a ruler, a square solid, a rectangular solid

Steps

1. Measure the lengths and widths of the square and rectangular solids and record down their measurements.
2. For each item, multiply the two dimensions measured in step 1. What value do you obtain?
3. Suggest what area is and its SI unit?
4. Suggest how to determine the areas of regular and irregular solids?

In your discussion, you should have learnt that area is the measure of the extent of a surface. The SI unit of area is square metre (m^2). Area is a derived quantity. Table 1.12 shows the unit of area, its symbol and its relationship with the SI unit of area (m^2).

Unit	Symbol	Comparison with m^2
1 square kilometre	km^2	1 000 000 m^2
1 square metre	m^2	1m^2
1 square centimetre	cm^2	0.000 1 m^2
1 square millimetre	mm^2	0.000 001 m^2

Table 1.12: Units of measuring area and their symbols.

Example 1.6

Convert 97.5 mm^2 into m^2

Solution

1 000 000 mm^2 =1 m^2

$$99.5 \text{ mm}^2 = \frac{97.5 \times 1}{1000\ 000}$$

0.0000975 or 9.75×10^{-5} m^2

Example 1.7

Convert 100 cm^2 into m^2

Solution

$$1 \text{ m}^2 = 10\ 000 \text{ cm}^2$$

$$100 \text{ cm}^2 = \frac{100}{10\ 000} = \frac{1}{100} = 0.01 \text{ m}^2$$

Area of regularly shaped objects

The area of a regularly shaped objects may be obtained by measuring the relevant dimension(s) and then applying the appropriate formula.

Table 1.13 shows some of the formulae used in the measurement of area.

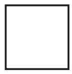
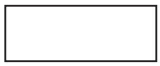
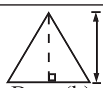
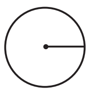
Name	Shape	Formula (Area)
Square		$A = L \times L$
Rectangle		$A = L \times W$
Triangle		$A = \frac{1}{2}(b \times h)$
Circle		$A = \pi r^2$

Table 1.13: Formulae used in measurement of area

Example 1.8

The dimensions of the top of a small coffee table are 40 cm by 30 cm. Calculate the area of the top of the table in (a) m^2 (b) mm^2

Solution

(a) Area $= L \times W$

$= 40\text{ cm} \times 30\text{ cm}$

$= 1\ 200\text{ cm}^2$

$\therefore A = \frac{1200}{10\ 000} = 0.12\text{ m}^2$

or $A = 40\text{ cm} \times 30\text{ cm}$

$= \frac{40}{100}\text{ m} \times \frac{30}{100}\text{ m}$

$= 0.12\text{ m}^2$

(b) Area $= L \times W$

$= 40\text{ cm} \times 30\text{ cm}$

$= 1\ 200\text{ cm}^2$

$= 1\ 200 \times 100\text{ mm}^2$

or $A = 40\text{ cm} \times 30\text{ cm}$

$= (40 \times 10)\text{ mm} \times (30 \times 10)\text{ mm}$

$= 400 \times 300\text{ mm}^2$

$= 120\ 000\text{ mm}^2$

$= 120\ 000\text{ mm}^2$

Exercise 1.7

1. Define the term area.
2. Explain clearly how you would determine the surface areas of the following:
   (a) A laboratory bench.
   (b) A cylindrical object.
3. A cylinder has a diameter of 4.2 cm. How many times would a thread of 132 cm be wound around the cylinder?
4. A page of a book measures 14.5 cm × 21.4 cm. What is its area in square millimetres?
5. The diameter of a cylindrical pencil is 9 mm. Calculate the cross-sectional area in square centimetres.

1.16 Measurement of volume

Activity 1.31 To define volume and state its SI units

Materials: beaker, water

Steps

- Now, pour water into the beaker and read the level of water. What does the reading represent? Explain.
- Suggest your members what volume is and its SI units. What are the other smaller and larger units that are used to measure volume?

From Activity 1.31, you should have established that volume is the amount of space occupied by a substance. The reading obtained when water is poured in the beaker represents the volume of water. The SI unit of volume is cubic metres(m^3). Like area, volume is also a derived quantity. Table 1.14 shows the SI unit of volume and its relationship with other units of volume and capacity.

Unit	Symbol	Comparison with m³
1 cubic kilometres	km^3	1000 000 000 m^3
1 cubic metres	m^3	1 m^3
1 cubic centimetres	cm^3	0.000 001 m^3
1 litre	l	0.001 m^3
1 millilitre	ml	0.000 001 m^3

Table 1.14: Units of measuring volume and their symbols.

Example 1.9

A car uses 1 litre of petrol to cover a distance of 13 km. How long, in metres, would such a car cover with 30 cm^3 of petrol?

Solution

1 litre = 1 000 cm^3

1 km = 1 000 m

13 km = 13 000 m

1 000 cm^3 covers 13 000 m

$\therefore$ With 30 cm^3, it would cover $\frac{13\ 000 \times 30}{1\ 000} = 390$ m

Volume of regular shaped solids

The volume of a regularly shaped solid may be determined by measuring the required dimensions and then applying the appropriate formula. Table 1.15 shows some of the solids and the formulae to find their volumes

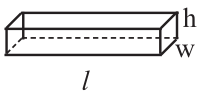
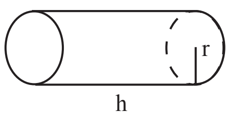
Name	Shape	Formula
Cuboid		$V = l \times w \times h$
Sphere		$V = \frac{4}{3}\pi r^3$
Cylinder		$V = \pi r^2 h$

Table 1.15: Formulae for finding volume of regular solids

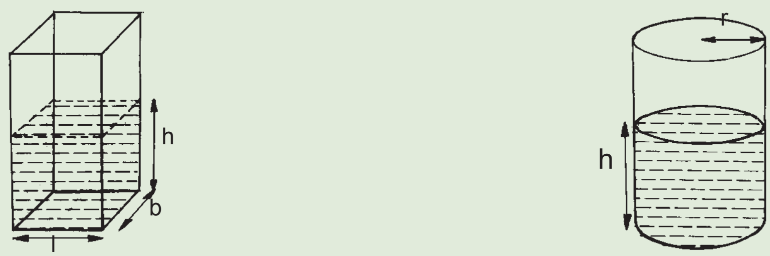
Volume of liquids

Activity 1.32 **To calculate a volume of a liquid in a container**

Materials: rectangular container, a cylindrical container, water

Steps

1. Pour some water into a rectangular container as shown in Fig. 1.27(a). Measure length, l breadth, b and height, h and calculate the volume of liquid inside the container.
2. Repeat the activity using the same amount of the liquid with a cylindrical container as shown in Fig. 1.27(b).



(a) (b)

Fig. 1.27: Measurement of volume of liquids

3. Measure the radius r and the height h then determine the volume of the liquid using the appropriate formulas.
4. Compare the two volumes to see if they are the same.

From Activity 1.32, you should have established that the volume of water in a rectangular container is equal to the cylindrical container i.e

$$v = l \times b \times h = \pi r^2 h$$

Instruments for measuring volume of liquids

Activity 1.33 **To identify instruments for measuring volume**

Materials: measuring cylinder, burette, pipette, reference books, internet

1. Identify the unit marked on each instrument
2. Now, take each instrument provided at a time and study their scales carefully.

From Activity 1.33, you should have discovered that instruments for measuring volume include measuring cylinders, burettes and pipettes. These instruments are already calibrated (marked) in the units of volume (cubic centimetres, cm^3) or capacity (millilitres, m*l*).

(a) Measuring cylinder

Measuring cylinders hold different volumes or capacities. They have a scale marked either in cm^3 or m*l*. (1 cm^3 = 1 m*l*). They measure the contained column of the liquid. It is for this reason that they are graduated from zero upwards.

How to use a measuring cylinder

Pour some coloured water into a measuring cylinder. Observe the shape of the liquid surface. Sketch the shape of the liquid surface. What do you notice? You will notice that the liquid surface is curved. The curved liquid surface is called *meniscus*. Read the level of the bottom of the meniscus with your eyes at the horizontal level (Fig. 1.28).

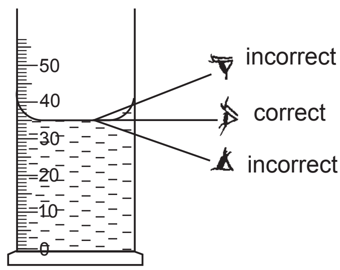


Fig. 1.28: How to use a measuring cylinder

(b) Burette

A burette consists of a long graduated glass tube fitted with a tap which opens and closes easily. Burettes are mostly used when a known volume of a liquid is to be run off. The scale is graduated in cm^3 or m*l* and runs from zero downwards since the volume required is run off from the bottom (Fig. 1.29).

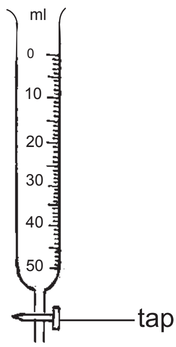


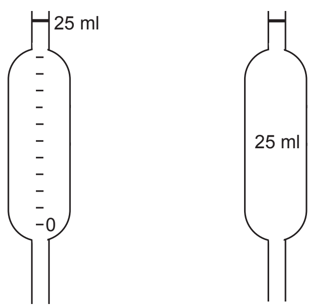
Fig. 1.29: A burette

How to use a burette

Pour a liquid into the burette with the help of a funnel. Make sure that the level goes well beyond the zero. Open the tap and allow the level to come to the zero mark. (This is to ensure that even the lower part of the tap is filled with the liquid). Run off the required volume of the liquid by opening the tap.

(c) Pipette

Pipette like a burette, it is used to run off known volume of a liquid. There are two types of pipettes commonly used in school laboratories. They are: *graduated pipette* and *one mark pipette* (Fig. 1.30).



(a) Graduated pipette (b) One mark pipette

Fig. 1.30: Types of pipettes

The graduated pipette can deliver various amounts of known volumes of a liquid. The one mark pipette delivers only one known volume of a liquid, e.g. 25 m*l* for a 25 m*l* pipette.

How to use a one mark pipette

Dip a 25 m*l* pipette in a beaker containing clean water. Suck in the water to a level above the mark. Close the mouth of the pipette with your thumb and slowly allow the liquid level to drop to the one mark. Run off the liquid into a measuring cylinder. Compare the volume delivered by the pipette and the volume read from the measuring cylinder. The two volumes should be the same.

Volume of solids by displacement method

Activity 1.34 **To determine the volume of a regularly shaped solid using a measuring cylinder**

Materials: metre rule, marble, measuring cylinder, water

Steps

1. Measure the diameter *r* of the marble using a metre rule and calculate its volume V_1 using the formula $V = \frac{4}{3}\pi r^3$.
2. Partly fill a measuring cylinder with water and record the initial volume of the water V_1. Carefully lower the marble into the water in the measuring cylinder (see Fig. 1.31). Record the new volume of the water V_2.
3. Find the volume of the water displaced, $(V_2 - V_1)$. Compare this volume with the volume of the marble calculated using the formula.

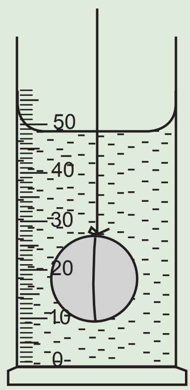


Fig. 1.31: Volume by displacement method

You will notice that:

The volume of the displaced water = volume of the marble.

The activity shows that solids displace their own volume of the liquid. The method of finding the volume of a solid by displacing a liquid is called *displacement method*.

Activity 1.35 **To determine the volume of an irregularly shaped solid using a Eureka can**

(Work in groups)

Materials: Eureka can, irregular stone, water, measuring cylinder

Steps

1. Fill a Eureka can with water until some of it over flows through the spout.
2. Once the overflow stops, put the measuring cylinder at the mouth of the spout.
3. Tie the irregular solid with a string and lower the solid carefully into the can. Make sure the solid is completely immersed.

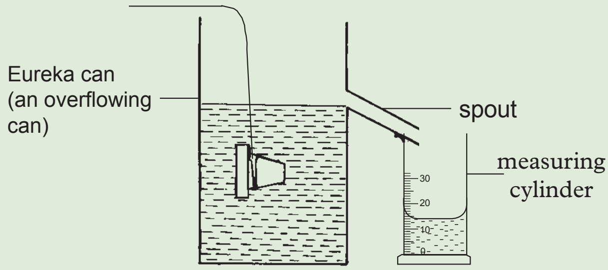


Fig. 1.32: Measuring volume using a Eureka can

4. Collect and measure the volume of the water displaced (Fig. 1.32).

From Activity 1.35, you must have noted that the volume of the solid is equal to the volume of the water displaced.

Exercise 1.8

1. Define volume and state its SI unit.
2. A tank full of a liquid has a volume of 0.6 m^3. Find the volume of the tank in:
   (a) litres **(b)** cm^3 **(c)** m*l*
3. A metal block measures 5 cm by 4 cm by 10 cm. Calculate:
   (a) The volume of the block.
   (b) The number of blocks each measuring 2 cm by 1 cm by 5 cm that have the same volume as that of the metal block.
4. A beaker of radius 5 cm contains water to a height of 10 cm.
   (a) What is the volume of the water in the beaker?
   (b) When a stone is completely immersed in the beaker, water rises to a height of 19 cm. What is the volume of the stone?
5. Give one advantage of using burette over a one mark pipette in measuring the volume of a liquid.

6. Explain why burettes are more accurate than measuring cylinders in measuring volume.
7. What is:
   (a) the minimum volume of a liquid that can be measured by the measuring cylinder shown in Fig. 1.33?
   (b) the volume of the liquid in the measuring cylinder?
8. The tap of a burette is adjusted such that water comes out in drops (Fig. 1.34). What would be the reading on the burette if 60 drops of water fall from the burette? Take the average volume of the drop to be 50 mm^3.

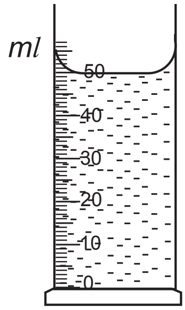


Fig. 1.33: Measuring cylinder

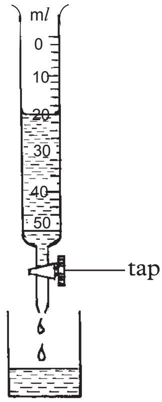


Fig. 1.34: Drops of water from a burette

1.17 Measurement of mass

Activity 1.36 **To compare massess using non-standard measures**

Materials: a brick, a jug full of water

Steps

1. By lifting a brick and a jug full of water each at a time, determine which is heavier.
2. What is the disadvantage of using such a method to measure mass?
3. What would be the remedy?

From Activity 1.36, you must have noted that, one cannot be accurate when determining how heavy an object is using non standard measures like hands. This calls for the need to use a standard measure.

Mass is the amount of matter in a substance. Its SI unit is kilogram (kg). The standard kilogram is the mass of a block of platinum iridium alloy kept at the office of weights and measures in Paris. Other masses are measured by comparing them directly or indirectly with this mass. Table 1.16 shows the relationship between the SI unit of mass (kg) and other larger and smaller units of mass.

Unit	Symbol	Comparison with kg
1 tonne	t	1 000 kg
1 kilogram	kg	1 kg
1 gram	g	0.001 kg
1 milligram	mg	0.000 001 kg

Table 1.16: Units of measuring mass and their symbols

Example 1.10

Convert 39.6 mg into kilograms

Solution

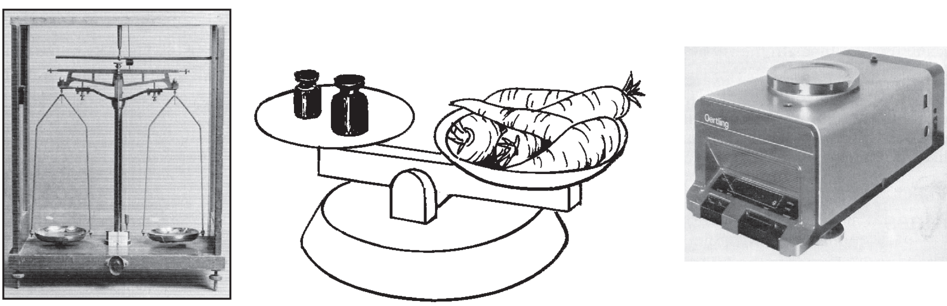
$$1 \text{ mg} = \frac{1}{1000} \text{ g} = \frac{1}{1\ 000\ 000} \text{ kg}$$

$$\text{Therefore, } 39.6 \text{ mg} = \left(\frac{1}{1\ 000\ 000} \times 39.6\right) \text{ kg}$$

$$= 0.000\ 039\ 6 \text{ kg}$$

Balance for measuring mass

There are many kinds of balances used for measuring mass (Fig. 1.35).



(a) beam balance (b) traditional pan balance (c) electronic balance

Fig. 1.35: Different types of balances

In the laboratory, the mass of an object can be measured using a *beam balance* and a set of standard masses (Fig. 1.36).

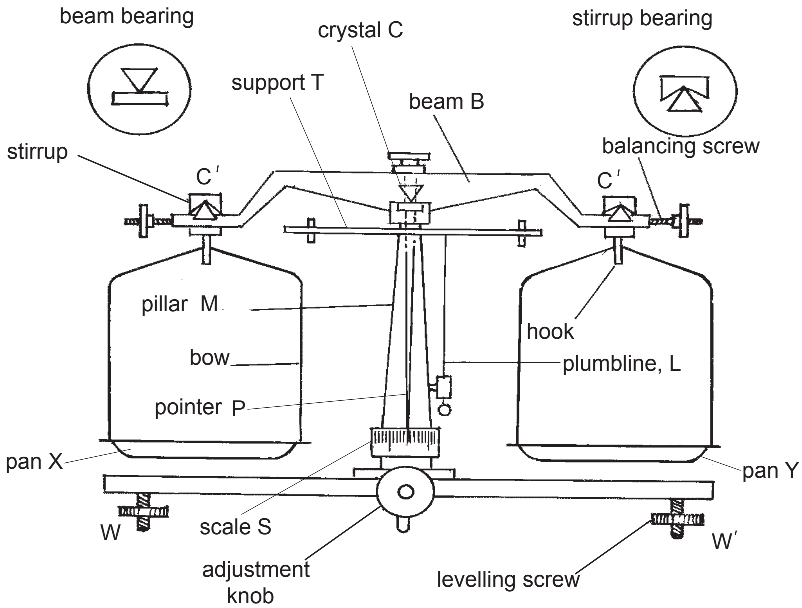


Fig. 1.36: A beam balance

The beam balance has an beam B and two containers (X and Y). The first container holds the load while the other container holds the metal that has a fixed weight. The beam is zeroed before using. This involves making sure that the pointer P is at the middle of the scale S and the plumbline L is just touching pillar M. This is done by adjusting the screws W and W' respectively. When the beam balances, the masses on the scale-pans are equal. The mass to be measured is placed on one scale-pan which is then balanced by using known or standard masses on the other scale pan. After weighing, the beam is gently lowered so that it rests on the support T, which takes the load off the delicate wedges.

1.18 Density

Definition of density

Activity 1.37 **To define density and identify its SI units**

You were introduced to density in Primary 5.

1. Remind your partner the meaning of density.
2. Discuss with your partner the SI units of density based on the definition.

Density is defined as mass per unit volume. From the definition, the formula for calculating density is as follows:

$$\text{Density} = \frac{\text{Mass of substance}}{\text{Volume of substance}}$$

The derived SI unit for density is kilogram per cubic metre, kg/m^3, also written as kg/m^3. Density may also be measured in grams per cubic centimetre,

g/cm^3, or g/cm^3. The relationship 1 000 kg/m^3 = 1 g/cm^3 is used for conversion of units of density.

The symbol for density is the Greek letter ρ read as Rho, while mass and volume are abbreviated (m) and (V) respectively. Using these symbols, the formula for density is $\rho = \frac{m}{v}$

Different substances have different densities as indicated in Table 1.18 below.

Substance	Density in kg/m^3	Density in g/cm^3	Substance	Density in kg/m^3	Density in g/cm^3
Aluminum	2 700	2.70	Sand (varies)	2 600	2.60
Brass (varies)	8 500	8.50	Steel (varies)	7 800	7.8
Copper	8 930	8.93	White spirit	850	0.85
Glass (varies)	2 600	2.60	Zinc	7 100	7.10
Gold	19 300	19.3	Iron	7 500	7.50
Ice (at 0°c)	920	0.92	Invar	8 000	8.00
Lead	11 300	11.3	Cork	180	0.18
Mercury	13 600	13.6	Air	1.293	0.001 293
Methylated spirit	800	0.80	Hydrogen	0.899	0.000 089 9
Platinum	21 500	21.50	Pure water	1000	1.0

Table 1.18: Densities of different substances

Example: 1.11

An object of volume 0.004 23 m^3 has mass 36 kg. Determine its density in kg/m^3. From table 1.18, identify the substance from which the object is made.

Solution

(a) $\rho = \frac{m}{V}$

$= \frac{36 \text{ kg}}{0.00432 \text{ m}^3} = 8\ 510.6 \text{ kg/m}^3$.

(b) The object is made from brass.

Example 1.12

The density of mercury is 13.6 g/cm^3. What volume will have a mass of 200 g.

Solution

ρ =13.6 g/cm^3

m = 200 g

We know that $V = \frac{m}{\rho}$ therefore $V = \frac{m}{\rho} = \frac{200}{13.6} = 14.7 \text{ cm}^3$

Example 1.13

What mass of gold has a volume of 2.5 cm^3? (Take the density of gold as 19.3 g/cm^3).

Solution

Density of gold = 19.3 g/cm^3, Volume (V) = 2.5 cm^3

$$\rho = \frac{m}{V} \Rightarrow m = \rho V$$
$$= 19.3 \times 2.5$$
$$= 48.25 \text{ g}$$

Comparing densities of substances

Activity 1.38 **To compare densities of different substances**

Materials: Drinking glass, water, stone

Steps

1. Pour water into a drinking glass and place a stone on the surface of water. Observe and explain what happens to the stone.
2. Repeat step 1 with a piece of wood, small piece of copper metal and a cork. Observe what happens in each case.
3. Compare the known densities of the objects you have used with that of water. What do you observe? Explain.

From activity 1.38, we observe that;

(i) The stone sinks to the bottom of the glass.

(ii) A piece of wood floats on the surface of water.

(iii) A piece of copper metal sinks to the bottom water.

(iv) A cork floats on the surface of water.

If the density of an object is greater than the density of water, the object sinks in the water. For example, a stone is more dense than water.

If density of an object is less than the density of a liquid, the object floats in the liquid.

A piece of cork is less dense than water; the cork floats on water.

Activity 1.39 **To compare densities of fresh and rotten eggs**

Materials: fresh and rotten eggs, water, a drinking glass

Steps

1. Pour water in a glass and place a fresh egg on the surface of the water. (See Fig. 1.37(a)) Observe and explain what happens to the egg.

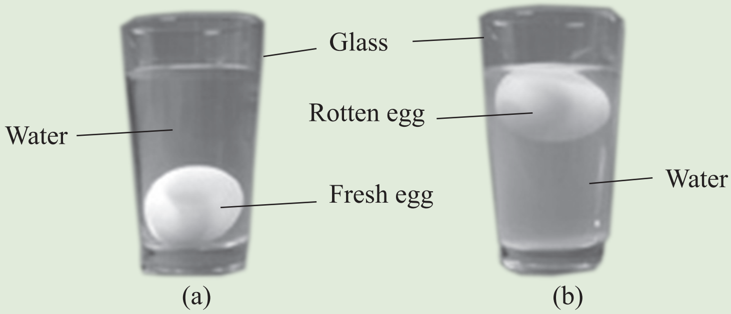


Fig. 1.37: To compare densities of fresh and rotten eggs

2. Repeat step 1 using a rotten egg. Observe and explain what happens to the egg. (See Fig. 1.37(b))

From Activity 1.39, we note that:

A fresh egg sinks in water, therefore, it is more dense than water.

A rotten egg floats on water; thus it is less denser than water.

Therefore, we can predict whether a body can sink or float in water if we know its density.

Exercise 1.9

1. Define the following terms:
   (a) Mass **(b)** density.
2. Convert each of the following to their SI units.
   (a) 6434.2 g **(b)** 0.0000046 t
   (c) 40065 μg

3. Fig. 1.38 alongside shows an irregular object of mass 56 g immersed in water. Given that the volume of water in the measuring cylinder was 10.0 cm^3, calculate the density of the object in g/cm^3.
4. The volume of methylated spirit is 0.8 g/cm^3. Calculate the volume of 20 grams of the liquid.
5. A substance has mass, volume and density as its properties. Which properties may change if a lump of sugar is crushed?

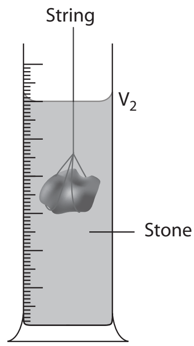


Fig. 1.38:Volume of irregular object

Unit Summary and new words

- Science is the systematic study that uses observation and experimentation to describe and explain natural phenomena.
- Physics is a science that deals with the study of matter.
- There are various branches of physics: mechanics, optics, electromagnetics etc.
- Physics creates technology.
- There are numerous career opportunities for example being a physics teacher and engineering.
- Length is the distance between two points. The SI unit of length is the metre, m. It is measured using a metre rule, tape measure etc.
- Time is the duration between any two events. Its SI unit is the second, *s*. It is measured using a clock/watch.
- Mass is the quantity of matter in a substance. Its SI unit is the kilogram, kg. It is measured using a beam balance.
- Length, time and mass are fundamental quantities.
- Area and volume are the derived quantities of length.
- Volume may be measured using a measuring cylinder, burette, pipette, etc.
- Density is the ratio of mass to volume i.e. Density = $\frac{\text{Mass}}{\text{Volume}}$. SI unit of density is kilogram per cubic metre (kg/m^3).

Unit Test 1

1. Define the term Physics.
2. Explain why Physics is a science.
3. Discuss the relationship between physics and society.
4. State the career opportunities that physics opens for you.
5. Describe the scientific investigation processes.
6. Distinguish between a fundamental (base) quantity and a derived quantity. Give one example of each.
7. Name three fundamental quantities and their SI units.
8. Give a reason why it was necessary to establish SI units.
9. How many micrometres are there in 4 cm?
10. Express the following in millimetres:
    (a) 2.7 m **(b)** 26.9 cm **(c)** 356 μm.
11. Name the instruments you would use to measure each of the following:
    (a) the length of a football field.
    (b) the height of a 20 litre jerrican.
    (c) the circumference of your waist.
12. A sea vessel carries 2 megatonnes of cargo. What is this mass in kg?
13. Explain how you would measure the external diameter of a measuring cylinder.
14. Describe briefly how you would measure:
    (a)the volume of a single drop of water from a burette.
    (b)the time taken by an ant to cover a distance of 2 m.
15. Drops of water coming from a crack in a water tap are collected at regular intervals as shown in Fig. 1.39(a).
    (a) What is the volume of the water collected?
    (b) Fig. 1.39 (b) shows the time taken to fill the measuring cylinder. What is the time taken to collect this volume?
    (c) The measuring cylinder used has a capacity of 25 ml. What is the time taken to fill the measuring cylinder?

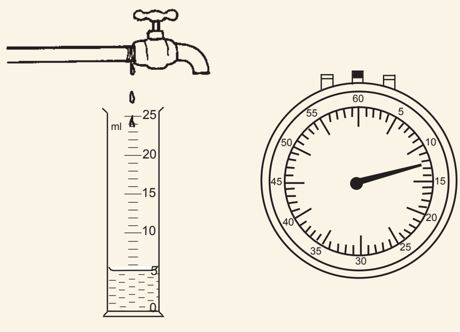


Fig. 1.39: Measuring volume of water

Conserve water always! Repair damaged taps to avoid water loss.

16. Estimate the volume of air in your classroom.
17. A solid cube of aluminium has sides 10 cm long.
    (a) Calculate its volume.
    (b) What mass in kilogram of aluminium has a mass of 100 g? Use the table of densities on page 54.
18. A Eureka can of cross sectional area 60 cm^2 is filled with water to a height of 10 cm. A piece of steel is lowered carefully into the can as shown in Fig. 1.40 then removed. If the height of the water dropped to 7 cm, after overflowing, determine the volume of steel metal.

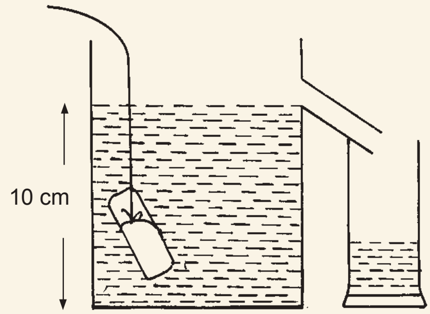


Fig. 1.40: Measuring volume using Eureka can

19. An aquarium measuring 1 m by 0.8 m by 0.5 m is filled with water of density 1 000 kg/m^3. Calculate the mass of water contained in the aquarium.

20. 1 kg of lead and 1 kg of aluminium are each made into a spherical ball. Which one will occupy more space? Explain step by step how you arrived at your answer (Use table 1.13 showing densities of common substances).

21. What is the length of the glass rod shown in Fig. 1.41?

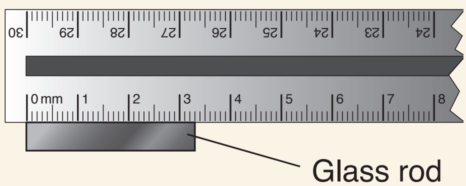


Fig. 1.41: Measuring length of a glass rod

22. Describe how you would determine the volume of an irregular object such as a small stone.

23. How would you determine the circumference of a test tube using a cotton thread and a metre rule? State any precautions that need to be taken.

24. What is the mass of air in a room measuring 5 m × 10 m × 10 m? (Take the density of air to be 1.293 kg/m^3).

UNIT 2 Qualitative analysis of linear motion

Key Unit Competence

By the end of this unit, I should be able to describe objects in motion in one dimension using the principles of kinematics.

Unit outline

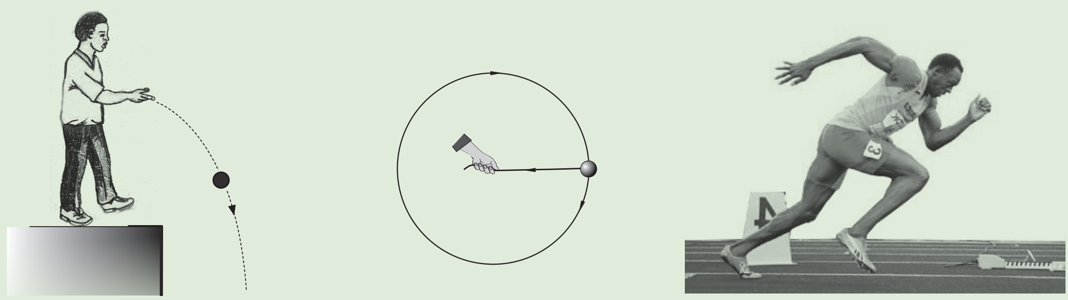
- Define distance, displacement, speed, velocity and acceleration.
- Definition of motion and types of linear motion.
- Distinguish between instantaneous and average speed, velocity and acceleration.
- Draw and analyse graphs of distance against time, displacement against time, speed against time, velocity against time and acceleration against time.
- Formulae of linear motion.
- Measurement of g (acceleration due to gravity).

Introduction

Activity 2.1 To identify different kinds of motion

Steps

1. Observe and describe the following types of motions of bodies in terms of direction(Fig. 2.1).



(a) *Throwing a stone over a cliff* **(b)** *Whirling a stone* **(c)** *100 m race*

Fig 2.1: Different types of motion

2. Suggest on what linear motion is.

In our daily lives, we come across various objects moving from one point to the other. The objects are said to be in motion. People, animals and machines are from time to time involved in motion in different directions. Motion in a straight line is called linear motion(see Fig. 2.1 (c)).

In this unit, we are going to study linear motion. We shall pay attention to the time taken, distance covered, speed, velocity and acceleration of the motion and their relationships.

There are two types of linear motion namely: uniform motion and non-uniform motion.

Uniform motion

In this motion, the speed of the moving remains the same or constant.

Non-uniform or uniform accelerated motion

In this motion the speed of an object changes at a constant rate, a good example is the free fall.

2.1 Distance and displacement

Activity 2.2 **To compare the lengths of a straight line and a curved one**

Materials: playing ground, tape measure

Steps

1. Mark points A and B on the playing ground far way from each other.
2. Starting from point A, make full strides towards point B in a straight line. How many strides do you get?
3. Repeat the activity but this time taking any curved path from point A to B. Between the straight and the curved paths, which one is longer ?
4. Now, measure the total length from points A to B using a surveyor tape measure. What length do you get? What is the SI unit of length?
5. Brainstorm on what distance and displacement are and their SI units.

In your discussion, you should have noted the following:

Distance

Distance is *the total length of the path followed by an object, regardless of the direction of motion*. It is a scalar quantity and measured in units of length. The *SI unit* of distance is the *metre (m)*. Long distances may be measured in kilometres (km) while short distances may be measured in centimetres (cm) or millimetres (mm).

It should be noted that in determining the distance between two points, the direction at any point along the path is not considered. The direction along the path may keep on changing (Fig. 2.2) or remain constant (Fig. 2.3).

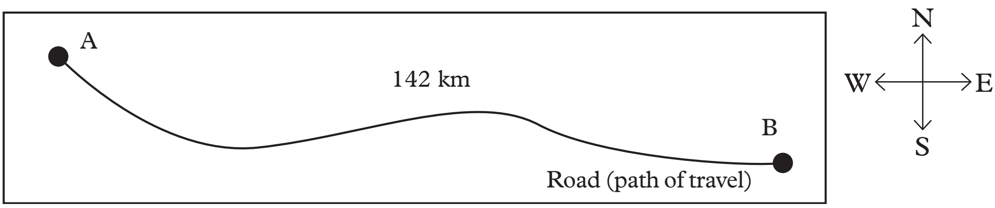


Fig. 2.2: Distance between points A and B is 142 km (direction keeps on changing)

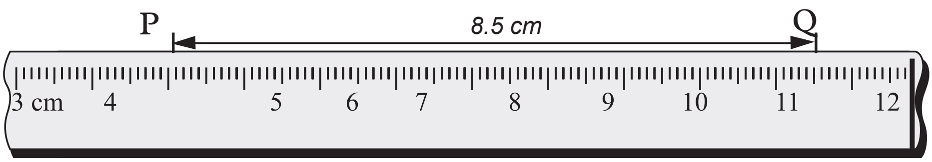


Fig. 2.3: Distance between points P and Q is 8.5 cm (direction is constant)

Displacement

Displacement is the object's overall change in position from the starting to the end point. It is the shortest distance along a straight line between two points in the direction of motion. The *SI unit* of displacement is the *metre* (m).

To fully describe displacement, you need to specify how far you have travelled from where you started and in what direction you have travelled. For example, point A is 100 kilometres Northwest of point B. In diagrams, an arrowhead indicates the direction of motion (Fig. 2.4). Displacement is a vector quantity.

displacement = distance in a stated direction from a reference point

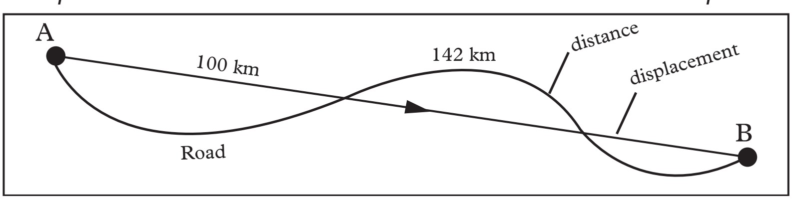


Fig. 2.4: Displacement between points A and B is 100 km

Difference between distance and displacement

Activity 2.3 **To distinguish between distance and displacement**

Materials: a tennis ball, rigid wall

Steps

1. Stand 2 m from a rigid wall.
2. Throw a tennis ball perpendicularly to a vertical wall.
3. Catch the ball when it bounces back.
4. Determine the distance and displacement covered by the ball.
5. Compare the two values.

In Activity 2.3, you will find that the distance is 4 m while displacement is 0 m.

Suppose a boat starts at point A moves 40 km East to point B followed by 30 m North to point C as shown in Figure 2.5.

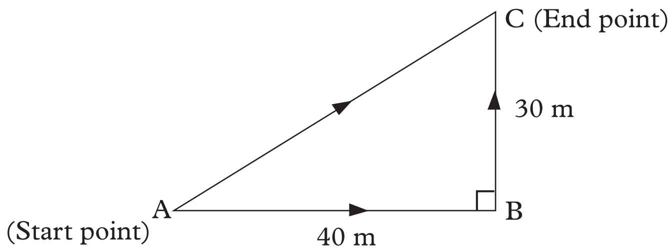


Fig. 2.5 Path followed by a boat

From Fig 2.5, point B is 100 Km SE of point A (magnitude and direction).
It should be noted that the distance can be greater or equal to the displacement in magnitude.

We can determine its distance and displacement covered as follows:

Distance = AB + BC = 40 m + 30 m = 70 m

Displacement = AC = $\sqrt{AB^2 + BC^2} = \sqrt{40^2 + 30^2} = 50$ m.

Road Safety

Activity 2.4 **To determine the shortest path when crossing the road and the safety measures to observe**

Steps

1. Fig 2.6 shows a sketch of a road. Redraw it in your exercise book.

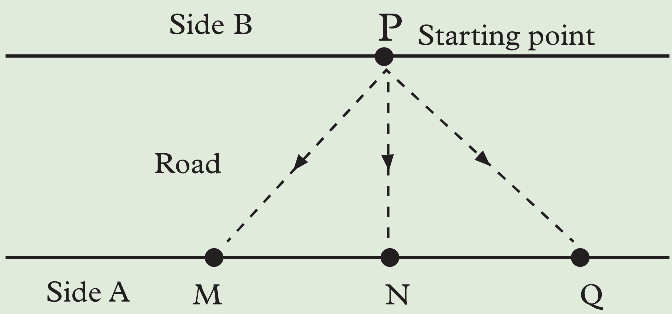


Fig. 2.6: Sketch of a road.

2. Three Senior one students: Peter, Jane and John were standing at point P on side B of the road where a school bus was packed. They crossed the road to points M, N and Q respectively on side A of the road. They took the routes shown by the dotted lines. Whose route was shortest? Discuss with your partner.
3. Suggest a reason why the shortest distance (displacement) is very important to the safety of a person crossing a road.
4. What are the safety precautions a person should observe before and when crossing a road.

In your discussion, you should have observed that route PN is the shortest. It is safer and move convenient to take this route than routes PM or PQ because it takes a shorter time to cross the road thus reducing the chances of being involved in an accident on a busy road.

The following are some of the safety measures one should take before crossing a road:

1. Always cross the road where there is a zebra-crossing.
2. Before you cross at a zebra-crossing, look right, left, then right again and if there are no oncoming vehicles then walk across. Do not run. Always remember it is better to be late but arrive safely.
3. Do not make abrupt decision to cross a road. Always put all your concentration on the road when crossing it.

2.2 Speed

Activity 2.5 **To establish the formula for speed**

A car takes 20 s to travel a distance of 600 m between points A and B while a bicycle takes 300 s to travel the same distance.

1. Using a simple mathematics approach, find the distance travelled by the:
   (a) car in one second.
   (b) bicycle in one second.
2. Using the result in step 1, which of the two means of transport is faster than the other.
3. What is the name and SI unit of the quantity obtained in 1?
4. Write the formula for finding the quantity you have identified in step 3.

In your discussion, you should have established that the distance *moved by a body per unit time is called speed*. In this motion, direction is not considered. Thus,

$$\text{Speed} = \frac{\text{distance moved}}{\text{time taken}}$$

The SI unit of speed is metres per second (m/s). Other units of speed such as kilometres per hour (km/h) and centimetres per second (cm/s) are also in common use.

When a body covers equal distances in equal time intervals, it is said to move with *uniform speed*.

Activity 2.6 **To establish the formula for distance covered and time taken**

Discuss with your partner how to determine:

(a) Distance covered by a body given its uniform speed and time it takes.
(b) Time taken by a body to cover a known distance given its uniform speed.

From your discussion, you must have found the following:

Distance covered by a body = speed × time taken

$$\text{Time taken by a body} = \frac{\text{distance covered}}{\text{speed}}$$

Example 2.1

What is the speed of a racing car in metres per second if the car covers 360 km in 2 hours?

Solution

$$\text{Speed} = \frac{\text{distance moved}}{\text{time taken}} \qquad \text{OR} \qquad \text{Speed} = \frac{\text{distance moved}}{\text{time taken}}$$

$$= \frac{360 \text{ km}}{2 \text{ h}} \qquad\qquad = \frac{360 \times 1\,000 \text{ m}}{2 \times 3600}$$

$$= 180 \text{ km/h} \qquad\qquad = 50 \text{ m/s}$$

Instantaneous speed

Activity 2.7 **To observe variation of speed at different instances**

Steps

1. Sit on the front seat of a vehicle and observe its speedometer when in motion. How does the pointer behaves? Explain.
2. Note the speed indicated by the pointer at different points while in motion until the vehicle stops.
3. Record the speeds in a tabular form at point A to E as shown in Table 2.1

Points	A	B	C	D	E
Speed					

Table 2.1 Record of speed at different points

4. Comment on the trend of the speed from points A to E.
5. Discuss with your partner what instantaneous speed is.

As you travel in a car or bus, you notice that the speedometer of the car keeps on showing different values of speed. The speed at any given instant in your journey is called instantaneous speed.

Average speed

Activity 2.8 **To establish the formula for average speed**

(Work in pairs)

1. Discuss with your partner how you can calculate the whole journey's speed for a body if the speed keeps on changing from one point to the other.
2. What is the name given to the quantity obtained in step 1?

Quite often, the speed a body moving between two points keep on varying. Such a body is said to be move with *non-uniform* speed. The equivalent constant speed that the body would move at to cover the same distance in the same time is called avarage speed.

Average speed of a body is the total distance covered by the body over the total time taken i.e.

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

Instantaneous speed of an object should not be confused with the average speed. We can use an example of a car travelling between two points A and B to differentiate the two. The average speed of a car is the total distance AB the car travels over the total time it takes to cover the distance whereas instantaneous speed is the varying speed shown by speedometer of the car at different instants along the distance AB.

Example 2.2

A car moving along a straight road ABC as shown in Fig. 2.7 maintains an average speed of 90 km/h between points A and B and 36 km/h between points B and C.

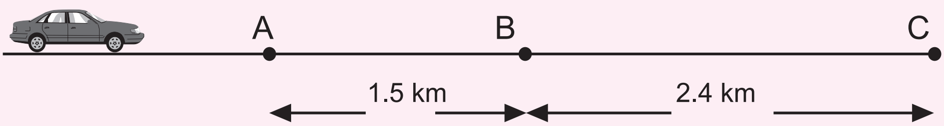


Fig. 2.7: Car moving along a straight line

Calculate the:

(a) Total time taken in seconds by the car between points A and C.

(b) Average speed in metres per second of the car between points A and C.

Solution

(a) $\text{Average speed} = \frac{\text{Total distance}}{\text{Time taken}}$

$$\text{total time between A and B} = \frac{\text{Total distance}}{\text{Average speed}}$$

$$= \frac{1.5}{90}\text{ h} = \frac{1.5}{90} \times 60 \times 60\text{ s} = 60\text{ s}$$

$$\text{Total time between B and C} = \frac{2.4}{36} \times 60 \times 60\text{ s} = 240\text{ s}$$

$$\text{Total time between A and C} = 60\text{ s} + 240\text{ s} = 300\text{ s}$$

(b) $$\text{Average speed} = \frac{\text{Total distance}}{\text{Time taken}}$$

$$= \frac{(1.5 + 2.4) \times 1\,000\text{ m}}{300\text{ s}}$$

$$= 13\text{ m/s}$$

2.3 Velocity

Activity 2.9 **To determine the speed in a specified direction**

Materials: playing ground, surveyor tape measure, stopwatch

Steps

1. Mark three points, A, B and C on a straight line on the ground (Fig. 2.8).

Fig. 2.8: Marked points on a playground

2. Stand at point B. Start making forward steps to point C, as your partner does the timing and records the time you take.
3. Repeat the activity but now start at point B and move to point A.
4. Reverse your roles with your partner and repeat the activity.
5. Taking the distance covered in the forward direction (B to C) to be positive and the one on the reverse direction (B to A) to be negative, find your speeds in each case. What does the result you have found represent? Explain.
6. Suppose you are to describe your motions to somebody who was not at the venue. What aspects of the motion must you mention so that the person distinguishes the motions from B to C and B to A?
7. What name is given to a quantity that has both speed and direction.

The speed of a body in a specified direction is called velocity or velocity is the rate of change of distance in a particular direction. Therefore,

$$\text{Velocity} = \frac{\text{distance moved in a particular direction}}{\text{time taken}}$$

Velocity is also defined *as the displacement covered per unit time* or *the rate of change of displacement.* In Activity 2.9, the result obtained in step 5 is a displacement and when divided by time we find velocity. i.e.

$$\text{Velocity} = \frac{\text{displacement}}{\text{time taken}}$$

The SI unit of velocity is metres per second (m/s).

In some cases, the velocity of a moving body keeps on changing. In such cases, it the average velocity of the body is considered.

$$\text{Average velocity} = \frac{\text{total displacement}}{\text{time taken}}$$

When stating or describing the velocity of an object, the direction of velocity should always be indicated. In doing so, we state direction say north, south, upwards, downwards, etc. A negative sign in a value of velocity is commonly used to indicate movement in the reverse direction.

Note: Just as distance and displace despite their similarities, so do speed and velocity. For instance, if we say the car is travelling 50 km/h towards north of Kigali, then we are talking about velocity. Remember that the only aspect that differentiate speed and velocity is the component of direction.

When velocity in a particular direction is constant, the velocity is referred to as *uniform velocity*. For example, Table 2.2 below shows the displacement of a car and the corresponding time taken.

Displacement (m)	0	4	8	12
Time taken (s)	0	2	4	6

Table 2.2: Values of displacement and time taken by a moving car

The velocity after every two seconds is 2 m/s, hence velocity of the car is uniform.

Example 2.3

A car travelled from town A to town B 200 km east of A in 3 hours. It then changed direction and travelled a distance of 150 km due north from town B to town C in 2 hours. (Fig. 2.9). Calculate the average

(a) speed for the whole journey.

(b) velocity for the whole journey.

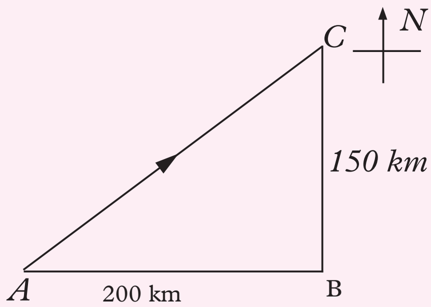


Fig. 2.9: Town A, B and C

Solution

(a) Average speed $= \dfrac{\text{total distance}}{\text{time taken}} = \dfrac{(200 + 150)\text{ km}}{(3 + 2)\text{ h}}$

$$= \frac{350}{5}\left(\frac{\text{km}}{\text{h}}\right)$$

$$= 70 \text{ km/h}$$

(b) Average velocity $= \dfrac{\text{displacement, AC}}{\text{time taken}} = \dfrac{\sqrt{200^2 + 150^2}\text{ km}}{3 + 2\text{ h}}$

$$= \frac{250}{5\text{ h}}\text{ km}$$

$= 50$ km/h, Direction is from A to C

In m/s $= \dfrac{50\ 000\text{ m}}{3\ 600\text{ s}}$

$$= 13.89 \text{ m/s}$$

Exercise 2.1

1. Distinguish between:
   (a) Speed and velocity.
   (b) Distance and displacement.
2. Rusangwanwa cycles to school 2.5 km away in 5 minutes. What is his average speed in (a) metres per second (b) kilometres per hour.
3. Nesa and Nshimiye decided to walk to a picnic site 12 km away. They walked the first 6 km at an average speed of 6 km/h and the rest at 5 km/h.
   (a) How long did the journey take?
   (b) What was their average speed for the journey?

4. The initial velocity of a motor cyclist riding on a straight road is 10 m/s. If the velocity was increasing by 5 m/s every second, find;
   (a) the velocity after (i) 1 s (ii) 2 s (iii) 5 s
   (b) the average velocity in 5 s?

2.4 Acceleration

Activity 2.10 **To determine the rate of change of velocity with time**

Materials: A long tape, carbon disk, a runway, ticker-tape timer, a trolley

Steps

1. Pass a long tape under the carbon disc of the ticker-tape timer and attach it to a trolley. Place the trolley on a horizontal runway. Ensure that the runway is friction compensated as in Fig. 2.10.

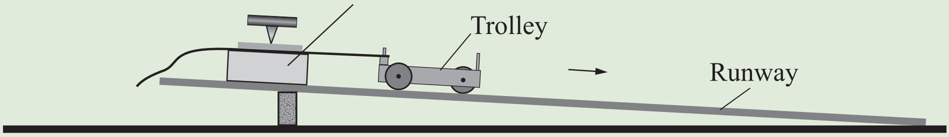


Fig. 2.10:To determine uniform velocity using a ticker-tape timer.

2. Now, increase the angle of inclination using the wooden block until the trolley is seen to be moving with increasing speed down the runway.
3. Release the trolley and start the ticker-timer. What do you notice about the separation of adjacent dots on the tape?
4. Suggest how the dots on ticker-tape will look like when the speed of trolley is reducing with time.
5. What quantity is used to refer to the change of velocity with time. Suggest its SI units.

It can be seen that the separation of the dots increases with time as shown in Fig. 2.11. Since the time between two successive dots is 0.02 s, the time between each 5 spaces length is 0.10 s.

Fig. 2.11: Ticker-tape for an accelerating body

This shows that the velocity of the trolley is not constant but changing with the time.

When the velocity of a body changes with time it is said to be *accelerating*.

Acceleration is defined as *the rate of change of velocity* i.e.

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time taken}}$$

The SI unit of acceleration is *metres per square second* or *m/s²*.

If the acceleration of a body is 4 m/s^2, it means that its velocity is increasing by 4 m/s every second. When the velocity of a body decreases, it is said to be decelerating or retarding. *Deceleration or retardation is negative acceleration*. This is usually shown with a negative sign before the value e.g – 4 m/s^2, deceleration at 4m/s^2. A body moving with uniform velocity has zero acceleration since there is no change in velocity.

When the rate of change of velocity with time is constant, the acceleration is referred to as *uniform acceleration*. Consider a body moving with velocity in time as shown in Table 2.3.

Velocity (m/s)	0	5	10	15
Time taken (s)	0	2	4	6

Table 2.3: Values of velocity (m/s) and time taken (s)

The velocity increases by 5 m/s for every 2 seconds. Thus, the body is said to be accelerating uniformly at 2.5 m/s^2.

Example 2.4

A car accelerates from rest to a velocity of 20 m/s in 5 s. Thereafter, it decelerates to a rest in 8 s. Calculate the acceleration of the car (a) in the first 5 s, (b) in the next 8 s.

Solution

(a) $\text{Acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$

$$= \frac{\text{final velocity} - \text{initial velocity}}{\text{time taken}}$$

(rest means velocity is zero)

$$= \frac{(20 - 0\ \text{m/s}}{5\ \text{s}}$$

$$= 4\ \text{m/s}^2$$

(b) Acceleration

$$\frac{\text{final velocity} - \text{initial velocity}}{\text{time taken}}$$

$$= \frac{(0 - 20)\ \text{m/s}}{8\ \text{s}}$$

$$= \frac{-20\ \text{m/s}}{8\ \text{s}} = -2.5\ \text{m/s}^2$$

or deceleration of 2.5 m/s^2

2.5 Graphs of linear motion

(a) Distance – time graphs

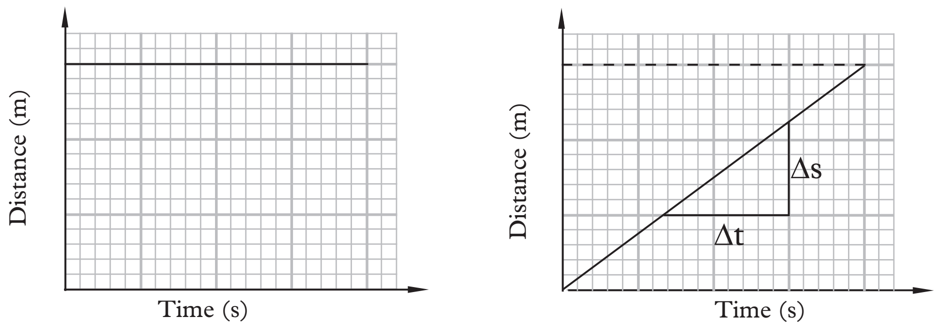
Activity 2.11 **To draw and interpret a distance-time graph**

Materials: graph papers, pencil, ruler

Steps

1. Discuss and sketch distance-time graphs for two bodies: one at rest and the other moving at a constant velocity.
2. Discuss and interpret each graph in your group.
3. Draw and analyse graphs of bodies whose speed is increasing or decreasing with time.
4. Suggest what the gradient represent in a distance-time graph.

In your discussion, you should have obtained Fig. 2.12(a) and (b) for the body at rest and one moving at a constant velocity respectively.



(a) Body at rest *(b) Moving body with constant velocity*

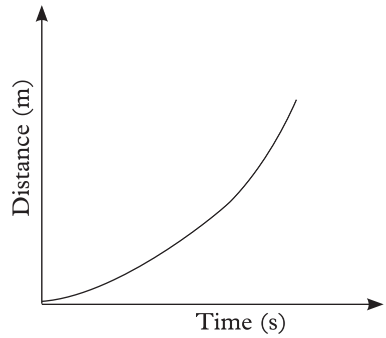
Fig. 2.12(a) and (b): Distance-time graph

The graph in Fig. 2.11(a) shows that the distance covered by the body is not changing with time. The body is therefore at rest (stationary).

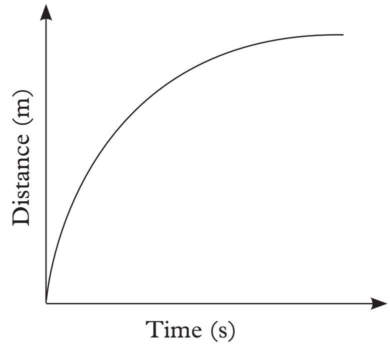
The graph in Fig. 2.11(b) shows that the distance covered by the body is increasing with time.

The gradient of the graph is $\frac{\Delta s}{\Delta t}$ and represents the speed of the object. Thus, the graph represents the motion of the body moving with constant (uniform) speed.

In some cases, the speed of an object increases or decreases with time as shown by the graphs in Fig. 2.13.



(a): Speed increasing with time



(b): Speed decreases with time

Fig. 2.13: Distance - time graph

In Fig. 2.13(a) the gradient (representing speed) is increasing, implying that the object is accelerating. Examples of real life settings where such motion is exhibited include:

- a body rolling down an inclined plane.
- a car accelerating uniformly from rest.

In Fig. 2.13(b), the speed of the object is decreasing, implying that the object is decelerating. Examples of real life setting where such motion is exihibited include

- a body thrown vertically upward.
- a body rolling uphill an inclined plane.
- a car decelerating uniformly.

Example 2.5

Fig. 2.14 shows a distance-time graph for a motorist. Study it and answer the questions that follow.

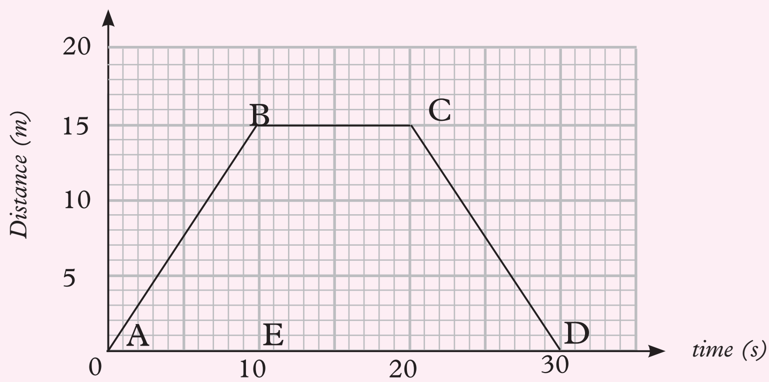


Fig. 2.14: Distance - time graph

(a) How far was the motorist from the starting point after 10 seconds?
(b) Calculate the average speed of the motorist for the first 10 seconds.
(c) Describe the motion of the motorist in regions (i) BC (ii) CD

Solutions

(a) By reading directly from the graph, distance travelled in 10 s = 15 m.
(b) Slope of the graph = speed of the motorist.

$$\text{Slope} = \frac{\text{change in distance}}{\text{change in time}} = \frac{(15 - 0)\text{m}}{(10 - 0)\text{s}} = 1.5 \text{ m/s}$$

(c) (i) In the internal BC, distance is not changing but time changes, hence the body is at rest (stationary).
(ii) In the internal CD, the motorist is moving at a constant speed towards the starting point.

(b) Displacement-time graphs

Activity 2.12 **To draw and interpret a displacement time graph**

Materials: graph papers, pencil, ruler

1. Discuss and sketch the displacement-time graph for a body:
   (a) whose displacement changes uniformly with time.
   (b) at rest.
   (c) whose rate of changes of displacement is not constant.
2. Analyse and interpret the displacemnt-time graph in 1(a), (b) and (c).
3. Compare your graphs with those of other groups in a class discussion.

In order to describe the displacement of a body, a reference point is considered. The reference point is the point when the body is at zero displacement as shown in Fig. 2.15. The body may be moving tow the left or right from the reference point.

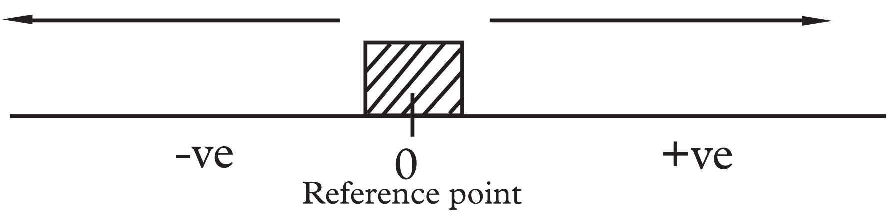
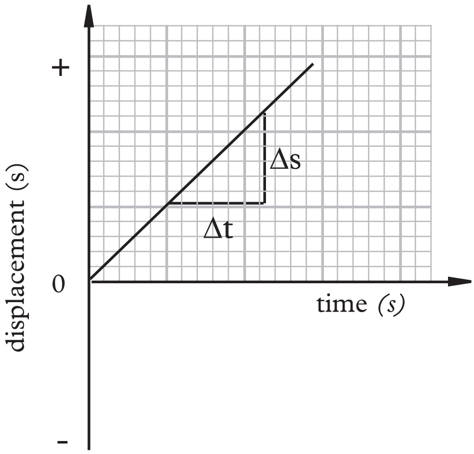
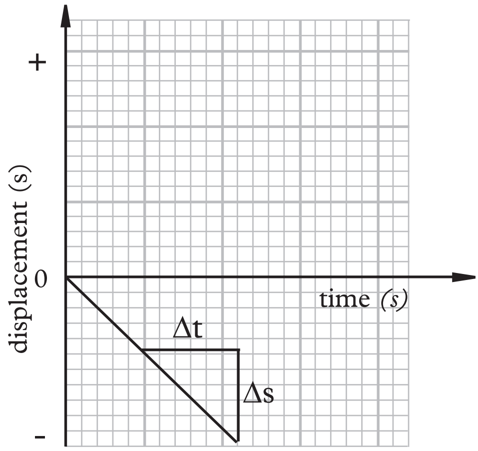


Fig. 2.15: Moving object

Let us consider a body moving in such a way that its displacement changes uniformly with time. Depending on the direction taken, two graphs can be drawn as shown in Fig. 2.16(a) and (b).



(a) A body moving forward at constant velocity

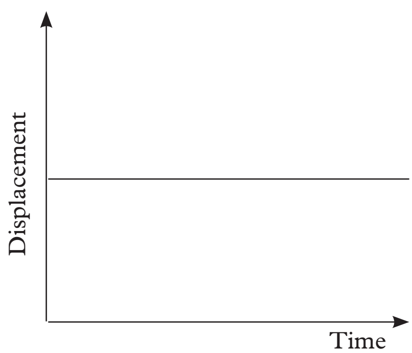


(b) A body moving reverse at constant velocity

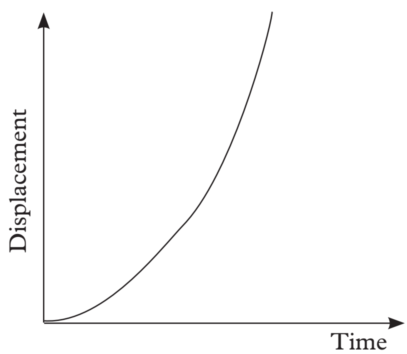
Fig. 2.16: Displacement-time graphs for moving constant velocities objects

As we have seen already, the gradient $\Delta s/\Delta t$ of a displacement-time graph gives the velocity of the body. Thus, in Fig. 2.16(a), the body is moving forward at constant velocity while in Fig. 2.16(b), the body is moving in the reverse (opposite direction) at constant velocity.

Let us now sketch displacement-time graphs for a body at rest and that whose rate of change of displacement with time (velocity) is not constant (Fig. 2.17).

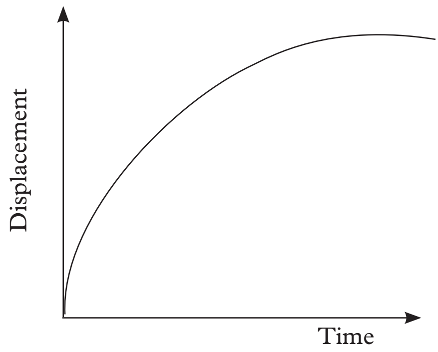


(a) Object at rest.



(b) Displacement increases non-uniformly with time.

Fig. 2.17: Displacement-time graphs



(c) Displacement decreases non-uniformly with time.

Fig. 2.17: Displacement-time graphs

In Fig. 2.17(a), the displacement does not change with time, hence the body is at rest. In Fig 2.17(b), the gradient (velocity) is increasing hence the body is accelerating. In Fig. 2.17(c), velocity (gradient) is decreasing hence the body is decelerating.

(c) Speed-time graphs

Activity 2.13 **To draw and interpret speed-time graphs**

Materials: graph papers, pencil, ruler

Steps

1. Draw and interpret speed-time graphs for a body:
   (a) at rest.
   (b) moving with uniform and non –uniform speed.
   (c) moving with increasing speed.

(i) Object at rest

At rest, the objet covers no distance since there is no movement. Therefore, the speed of the object is zero as shown in Fig. 2.18.

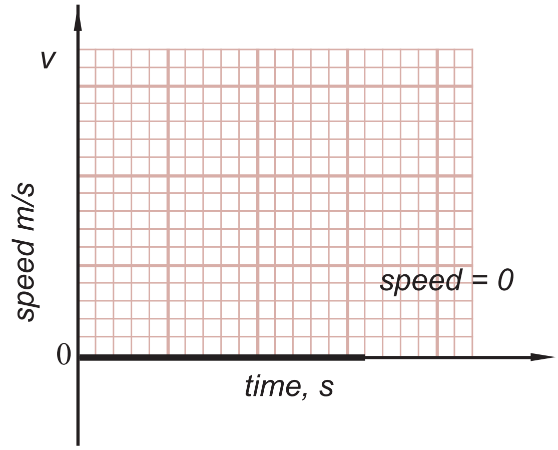


Fig. 2.18: Speed-time graph for a body at rest

The gradient in a speed time graph gives us

$$\frac{\text{Change in speed}}{\text{Change in time}} = \text{acceleration.}$$

In this case (when the object is stationary), the gradient is zero and so acceleration is zero.

(ii) A body moving with uniform (constant) speed

Fig. 2.19 shows the motion of a body moving with the uniform speed.

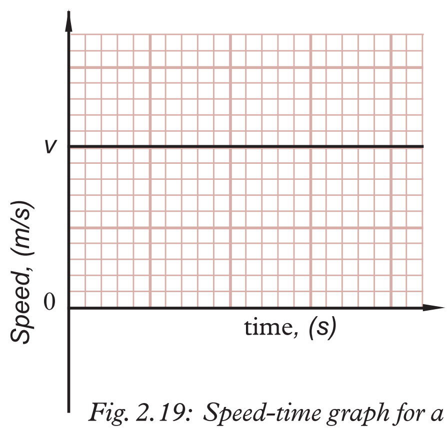


Fig. 2.19: Speed-time graph for a body in uniform speed

Gradient = 0

Acceleration in this case is zero i.e

$a = 0 \text{ m/s}^2$

(iii) A body moving with non-uniform speed (body accelerating)

When a body moves with uniform acceleration, its speed changes by equal amounts in equal interval time. The speed-time graph for a body whose speed changes unformally is a straight line as shown in Fig. 2.20.

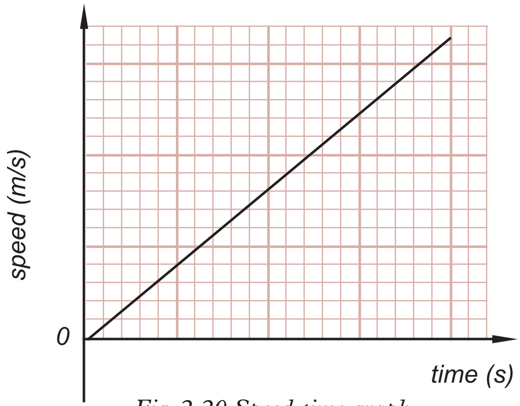


Fig. 2.20 Speed-time graph

Consider a ball thrown vertically upwards with an initial speed *u* from the top of a cliff which is *s* metres from the water level. See Fig. 2.21.

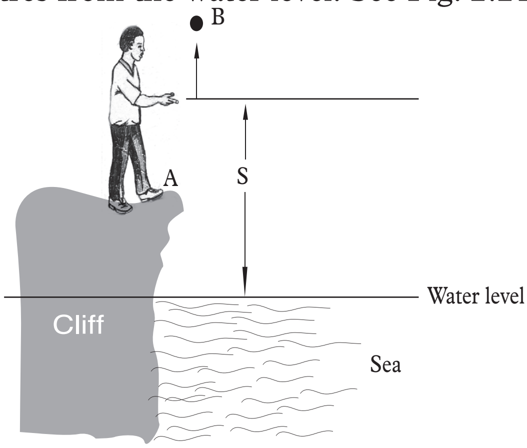


Fig. 2.21: A ball thrown upwards from a cliff

Taking the top of the cliff as the reference point and upwards as the positive direction, the motion graph is as shown is Fig. 2.22

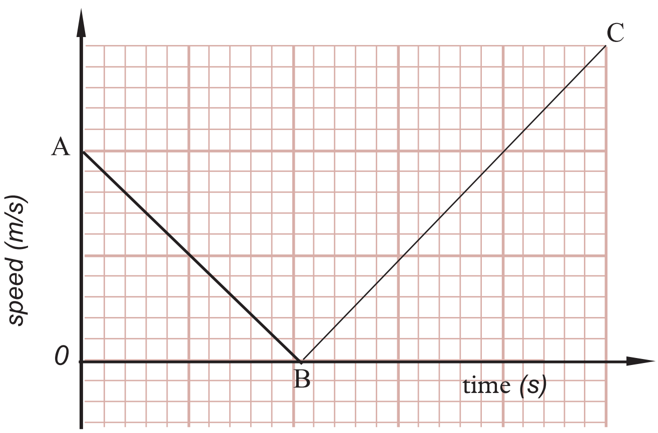


Fig. 2.22: Speed-time graph

The stone was thrown upwards and so it started either with some speed which then started decreasing to zero at the maximum height. Then the stone started dropping downwards, as its speed started increasing from zero. Notice that the stone is now moving to opposite in the negative direction (downwards in this case), (See Fig. 2.22).

Example 2.6

Fig. 2.23 shows a graph of speed against time for the motion of a car travelling from Ruhengeri to Gitarama.

Determine:

(a) the acceleration of a car in the first 4 s.

(b) the distance travelled in the first 4 s.

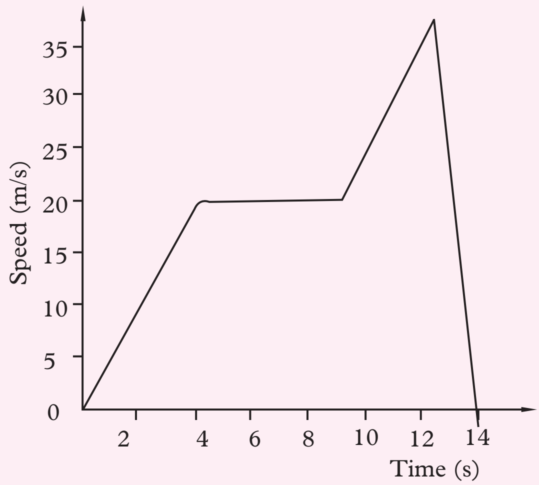


Fig. 2.23: Speed - time graph

Solution

(a) Accelaration $= \dfrac{\text{change in speed}}{\text{time taken}} = \dfrac{\Delta s}{\Delta t} = \dfrac{20\ \text{m/s}}{4\text{s}} = 5\ \text{m/s}^2$

(b) Distance travelled = Area under the graph $= \dfrac{1}{2}$ speed (m/s) × time (s)

$$= \frac{1}{2} \times 20\ \text{m/s} \times 4$$

$$= 40\ \text{m}$$

Exercise 2.2

1. Sketch the following graphs.

   (i) The speed-time graph for a body moving with uniform speed.

   (ii) The distance-time graph for a body moving with uniform speed.

(iii) The speed-time graph for a body moving with non-uniform (speed) acceleration.

(iv) The speed-time graph for a body moving with non-uniform acceleration.

(v) The speed-time graph for a ball thrown upwards and then caught again.

2. Fig. 2.24 (a) shows the distance-time graph for body A while Fig. 2.24 (b) shows the speed-time graph for body B.

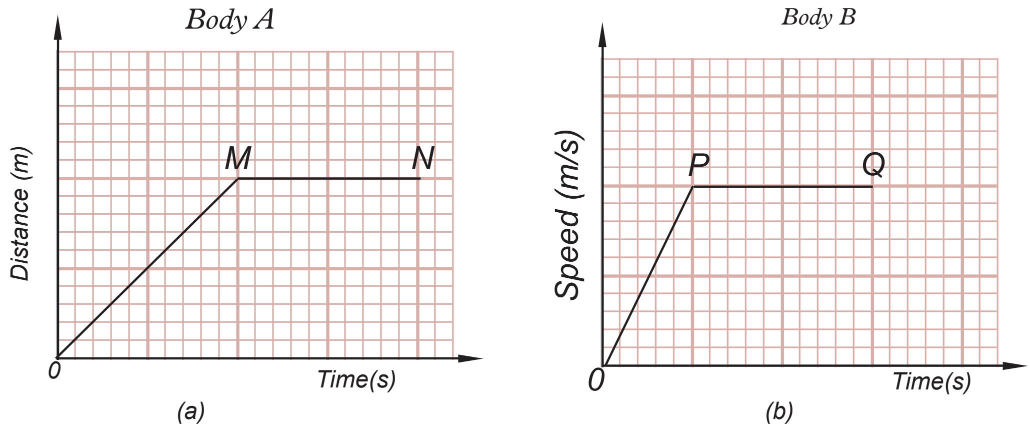


Fig. 2.24: Distance-time graphs

Describe fully the motion of the bodies in the following regions:

(a) OM **(b)** MN **(c)** OP **(d)** PQ

(d) Velocity – time graphs

Activity 2.14 **To draw and interpret a velocity-time graph**

Materials: Graph papers, pencils, ruler

Steps

1. Brainstorm on what a velocity-time graphs is.
2. Suggest what the gradient of a velocity-time graphs represents.
3. Draw and interpret velocity-time graphs for a body:
   (a) moving with a constant velocity.
   (b) accelerating from rest uniformly.
   (c) decelerating uniformly.
   (d) moving with non-uniform acceleration.
4. Suggest what the area under a velocity-time graph represent.

In your discussion, you should have learnt that a velocity-time graph tells us how the speed and direction of an object changes with time. Where there is no change in direction, a velocity–time graph looks the same as a speed-time graph. On a velocity – time graph, the gradient of the line is numerically equal to the acceleration. The gradient tells us how much extra speed is gained every second.

From Activity 2.14, you should have obtained the following line graphs:

(i) A body moving at constant velocity

The velocity-time graph for a body moving at constant velocity is shown in Fig.2.25.

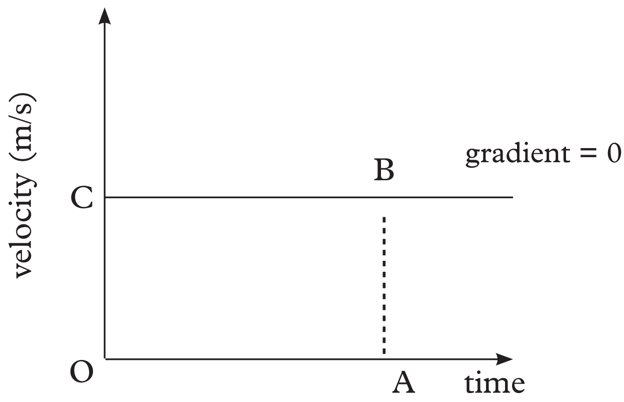


Fig. 2.25: Velocity-time graph for a body at constant speed

(ii) A body moving with steady acceleration from rest

Consider a car that started from rest and increased its velocity regularly. Its velocity-time graph is shown in Fig. 2.26.

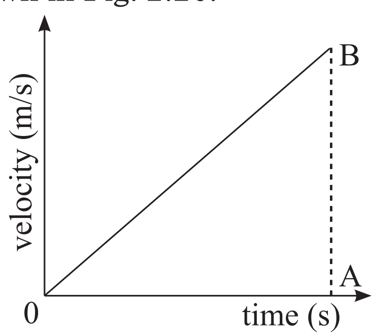


Fig. 2.26: Velocity-time graph for uniform acceleration.

The gradient of velocity time graph represents the acceleration i.e.

$$\text{gradient} = \frac{\text{change in velocity } (\Delta V)}{\text{time taken } (\Delta t)} = \text{acceleration}$$

The rate of change of velocity (acceleration) is uniform, hence the graph is a straight line.

(iii) A body decelerating uniformly

Consider a car moving at a particular velocity. If the brakes are applied such that it decelerates uniformly to rest, its velocity time-graph is as shown in Fig. 2.27

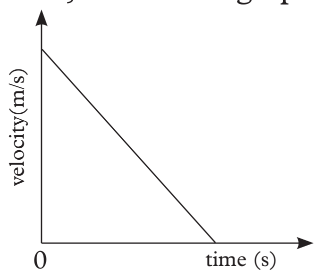
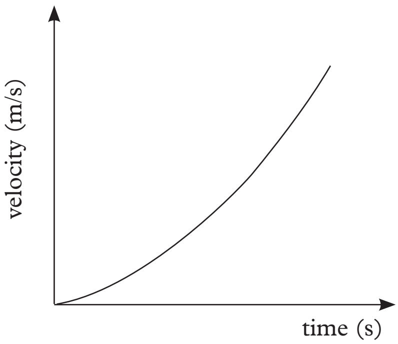


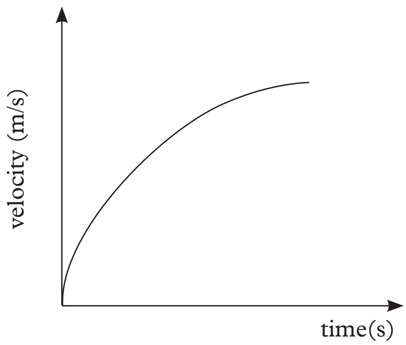
Fig. 2.27: Velocity-time graphs for uniform deceleration

(iv) A body moving with non-uniform acceleration

In some situations, acceleration is not uniform; it may be increasing or decreasing. This can be represented by the graphs shown in Fig. 2.28 (a) and (b).



(a): Increasing acceleration



(b): Decreasing acceleration

Fig. 2.28:Motion with non-uniform acceleration.

When an object is thrown upwards, it describes a curve shown in Fig 2.27(b). The graph is called trajectory.

A trajectory is the path /curve described by an object (projectile) moving through air or space under the influence of forces such as gravity, upthrust and weight.

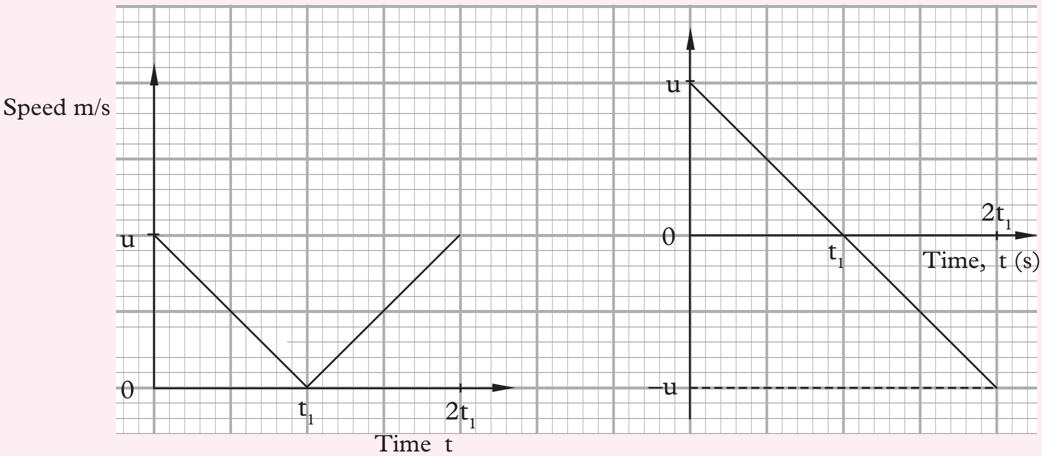
Example 2.7

A stone is thrown vertically upwards with an initial velocity *u*. Sketch its:

(a) speed-time graph.

(b) velocity-time graph for its motion up to the time it comes back to its original position.

Solution



(a) Speed-time graph of the stone (b) Velocity-time graph of the stone

Fig. 2.29: Motion of the body under gravity

The time taken to reach the maximum height is t_1.

The time taken by the body to fall back to its starting point is also t_1.

The total time of flight is $2t_1$.

Example 2.8

Table 2.4 shows the data collected to study the motion of cylist.

Velocity m/s	0	3	6	6	6	6
Time (s)	0	2	4	6	8	10

Table 2.3: Values of velocity and time

(a) Plot a graph of velocity (y-axis) against time (x-axis).

(b) Use your graph to determine the acceleration of the cyclist in the first four seconds

Solutions

(a)

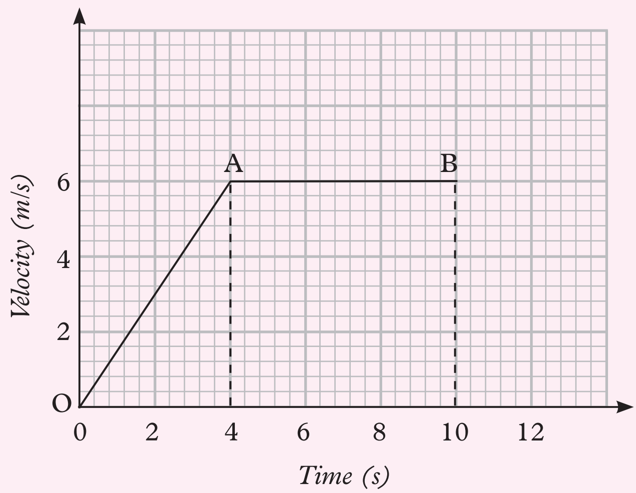


Fig. 2.30: Velocity-time graph

(b) Acceleration = slope of the graph

$$= \frac{\text{Change in velocity}}{\text{Change in time}}$$

$$= \frac{(6 - 0)\ \text{m/s}}{(4 - 0)\ \text{s}} = \frac{6\ \text{m/s}}{4\ \text{s}}$$

$$= 1.5\ \text{m/s}^2$$

Exercise 2.3

1. Define the term acceleration.

2. A bus changes its speed from 180 m/s to rest in 10 s. Calculate the:

(a) deceleration of the bus

(b) displacement of the bus

3. **(a)** Sketch a velocity-time graph for a car moving with uniform acceleration from 10 m/s to 30 m/s in 20 s.

(b) Use the graph to find the acceleration of the car and the total distance travelled by the car.

4. Fig. 2.31 shows the velocity-time graph of a car. Use the graph to find

(a) acceleration of the car.

(b) deceleration of the car.

(c) total displacement of the car.

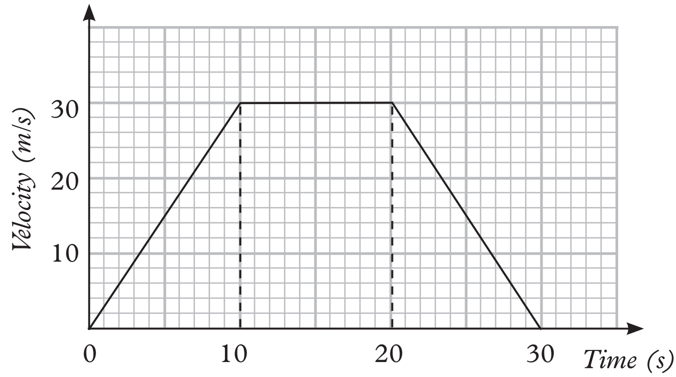


Fig. 2.31: Velocity-time graph

5. The graph in Fig. 2.32 shows the motion of a body falling freely under gravity.

(a) Determine the values of displacement(s) at t = 1, 2, 3 and 4 s.

(b) Draw a graph of velocity(v) against time (t).

(c) Use your graph in (b) to find the value of gravitational acceleration.

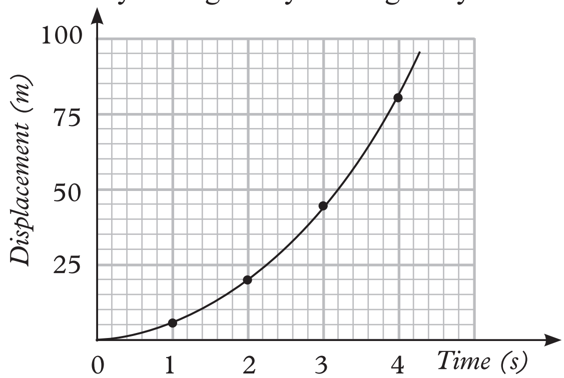


Fig. 2.32: Displacement-time graph

6. The sketches in Fig. 2.33 represent the motions of bodies in a straight line. Match each graphs with appropriately description from the ones given.

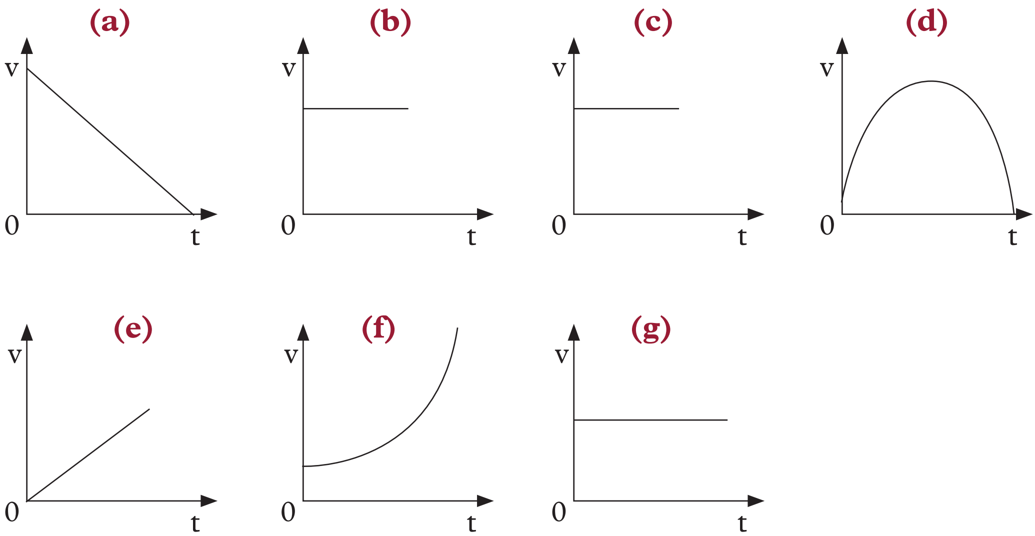


Fig. 2.33: Motion graphs

(a) Uniform acceleration of a body starting from rest.

(b) The body moves with constant velocity.

(c) Body decelerates uniformly, starting with finite positive velocity.

(d) Body accelerates from a velocity.

(e) A ball thrown to hit the ground and bounces back.

(f) Body at rest.

7. Fig. 2.34 shows the velocity-time graph for a motorcar during a short drive.

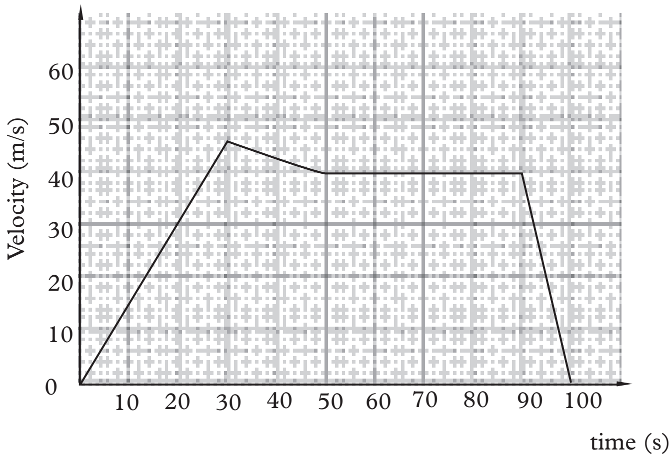


Fig. 2.34: Velocity-time graph

(a) Describe the motion of the car.

(c) Find the retardation in the interval 90 s-100 s.

8. Figure 2.35 shows velocity-time graph for a certain body.

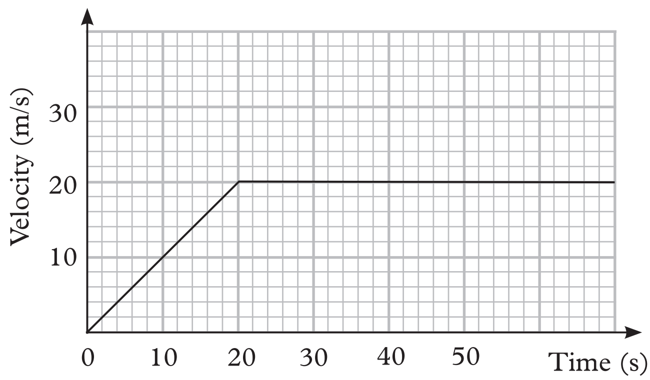


Fig. 2.35: Velocity-time graph

Find the acceleration at t = 10 seconds

9. Draw a graph of velocity against time for a car which starts with an initial velocity of 20 m/s and accelerates uniformly at 4 m/s^2 for 8 seconds, then slows down to rest in 20 seconds.

(a) How far does the car travel?

(b) What is the maximum velocity attained by the car?

(c) What is the retardation of the car as it comes to rest?

2.6 Acceleration due to gravity

Activity 2.15 **To observe the effect of earth's gravitational force**

Materials: A tennis ball

Steps

1. Throw a tennis ball vertically upwards and catch it when it comes down.
2. Describe the motion of the ball in terms of variation of velocity with time.
3. Suggest a reason why the ball falls back to you.
4. Repeat the activity using other objects such as polystyrene balls or paper balls. Consult your teacher if you have to use an object such as a stone. Take care that you are not hit by the falling objects.
5. Compare and discuss your findings with other members in your class.

You may have noticed that when an object is thrown vertically upwards, it starts with a certain speed which decreases as the object moves upwards. At some point the speed of the object becomes zero and the object starts falling back to the earth.

If an object is dropped from the top of a building or a tree, it starts from rest (with zero velocity) and its velocity increases as it falls.

These observations show that objects experience an acceleration towards the earth as they fall. This acceleration due to the pull of the earth on the objects is called *acceleration due to gravity (g)*. All freely falling objects near the earth's surface are attracted towards the centre of the earth with this acceleration. The acceleration is known as *the acceleration of free fall* i.e. when a body is just allowed to fall freely in air.

Think about this

How can a parachutist land from the sky without getting hurt yet we cannot jump from a roof-top safely?

Determination of acceleration due to gravity (g)

Activity 2.16 **To determine acceleration due to gravity**

(Work in groups)

Materials: A string, pendulum bob, stand, stop watch, metre rule.

Steps

1. Assemble the apparatus as shown in Fig. 2.36(a).
2. Displace the pendulum through a small angle θ (i.e $\theta < 10°$) and release it (Fig.2.36(b)).
3. Use a stop- watch to time 20 oscillations (complete cycles) of the pendulum.
4. Repeat the activity a second time and calculate the average time for 20 oscillations.
5. Repeat the process for at least six different lengths.
6. Record your results in a table (see Table 2.5).

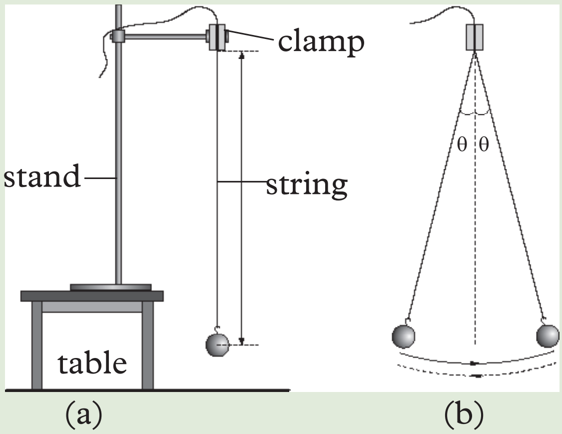


Fig. 2.36: Set-up

Length, l (m)	Time for 20 oscillations (s)		Average time t for 20 oscillations (s)	Periodic time T (s)	T^2 (s^2)
	trial 1 t_1	trial 2 t_2	$t = \frac{t_1 + t_2}{2}$	$T = \frac{t}{20}$	
0.60					
0.70					
0.80					
0.90					
1.00					
1.10					

Table 2.5: Time, distance and velocity values

7. Draw a graph of T^2 against *l*.
8. Draw the line of best fit through the points. Determine the gradient, m of the line.

It can be shown that the periodic time, T of a simple pendulum of length l is given by the equation

$$T = 2\pi\sqrt{\frac{\ell}{g}}$$

Squaring both sides of the equation gives $T^2 = \frac{4\pi^2}{g}\ell$

Comparing this equation with the general straight line equation, $y = mx + c$ shows that

$$T^2 = y,\ m = \frac{4\pi^2}{g},\ \ell = x \text{ and } c = 0$$

Therefore, a graph of T^2 against ℓ (Fig. 2.37) is a straight line with gradient $m = \frac{4\pi^2}{g}$.

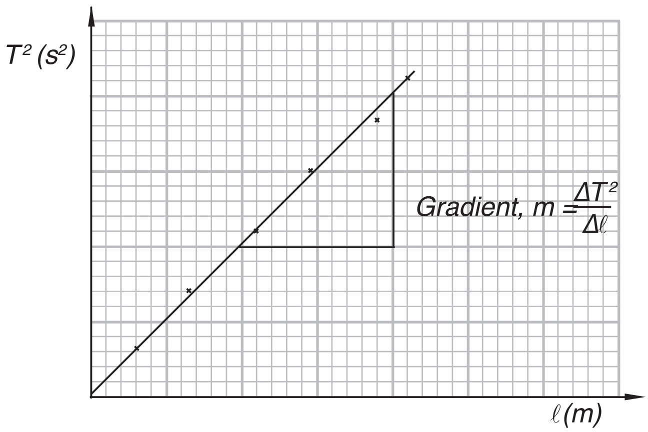


Fig. 2.37: Graph of time, T^2, against length, ℓ.

From the gradient, we get $g = \frac{4\pi^2}{m} = \frac{4\pi^2}{\text{gradient}}$.

Using the results of your experiment, calculate the acceleration due to gravity g using the above equation. Experiments have shown that g is approximately 9.8 m/s^2. However, a more convenient value of 10 m/s^2 is usually used in calculations.

Exercise 2.4

(Take acceleration due to gravity on the earth's surface as 10 m/s^2)

1. Define the term acceleration due to gravity.
2. Explain why object falls back to the earth's surface when thrown upwards.
3. An object of mass 300 g is thrown upwards with initial velocity of 10 m/s. If the acceleration due to gravity of the place is 9.8 m/s^2, find the weight of the object.

4. Describe a laboratory experiment by which you would measure the acceleration due to gravity. Show how the acceleration is obtained from your results.

Unit summary and new words

- Distance is the total length of the path travelled.
- Displacement is the shortest distance between two points in the direction of motion.
- Speed is the distance moved by the body per unit time. i.e.

$$\text{Speed} = \frac{\text{distance moved}}{\text{time taken}}$$

- A body covering equal distances in unit time intervals is said to move with uniform speed.
- Velocity is the rate of change of displacement. i.e.

$$\text{Velocity} = \frac{\text{change in displacement}}{\text{time taken}}$$

- Instantaneous velocity is the velocity of a body at a specific moment in time.
- Acceleration is the rate of change of velocity. i.e.

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{change in time}}$$

- The gradient of a velocity-time graph represents acceleration.
- The area under a velocity-time graph represents displacement.
- The gradient of a displacement-time graph represents velocity.

Unit Test 2

(Where necessary take $g = 10\ m/s^2$)

1. Define the following terms:

   (a) Distance
   (b) Displacement
   (c) Speed
   (d) Velocity
   (e) acceleration

2. Iragena and Hakizimana were discussing about velocity in their Physics class before presenting their findings to the whole class. Which of the following

is correct about uniform velocity.

A. the rate of change of acceleration with time is constant.
B. the rate of change of displacement with time is constant.
C. the rate of change of velocity with time is constant.
D. the rate of change of distance with time is constant

3. A cyclist travelling at a uniform acceleration of 2.5 m/s^2 passes through two points P and Q in a straight line. Her speed at point P is 20 m/s and the distance between the points is 100 m. Calculate her speed at point Q.

4. A car increases its speed steadily from 8.0 m/s to 30 m/s in 10 s. How far does it travel in this time?

6. Ntwali runs 100 m race in 12.0 s. Find his average velocity.

7. A racing cyclist starts from rest and accelerates uniformly to a velocity of 20 m/s in 4 s.
   (a) What is the acceleration of the cyclist?
   (b) What is the distance covered in the 4 s?

8. Uwase threw a ball vertically upwards while playing in the school field. Sketch:
   (a) a speed-time graph for the motion of the ball.
   (b) a velocity-time graph for the motion of the ball.

9. Which one of the following motion-time graphs and acceleration-time graphs represents a body moving with uniform acceleration from rest? (Fig. 2.38).

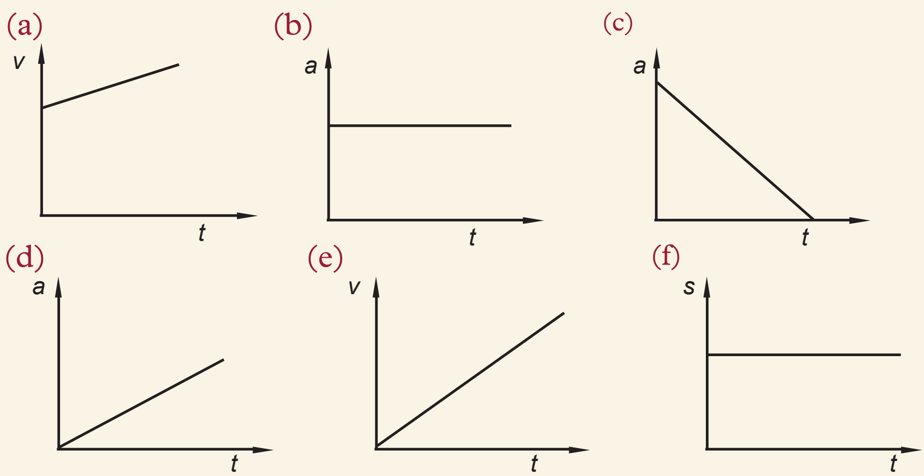


Fig. 2.38: Motion-time graphs

10. The velocity-time graph in Fig. 2.39 shows the movement of a toy car on a straight path. Use the information to find:

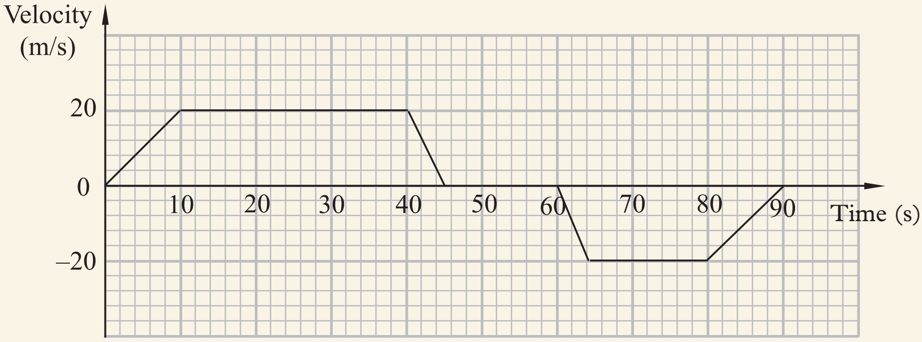


Fig. 2.39: Velocity-time graph

(a) the initial acceleration of the car.
(b) the total time the car was not moving.
(c) the total distance travelled by the car.
(d) the displacement of the car from the starting point.

11. A lift carrying people starts from the third floor and stops on the sixth floor of a building after 20 s. Sketch a velocity-time graph of the motion of the lift. Show how you would use your sketch to determine the distance between the third and the sixth floor of the building.

12. Fig. 2.40 shows the motion of a motorcyclist on a straight road. Use the information on the graph to answer the following questions.

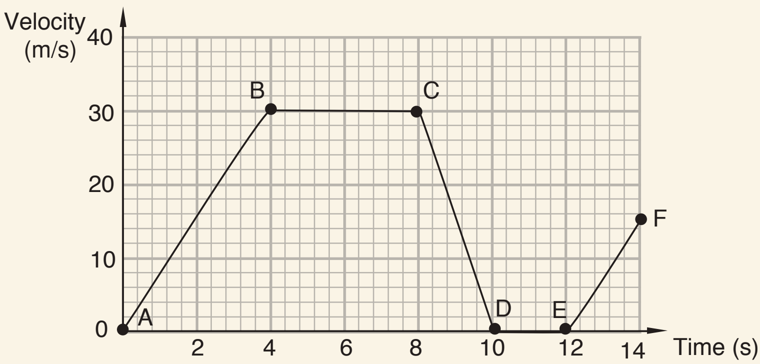


Fig. 2.40: Graph of velocity against time

(a) In which section of the graph was the cyclist accelerating most rapidly? Explain how you would determine this acceleration.
(b) Calculate the retardation of the motorcyclist from the graph.
(c) Which part of the graph shows that the motorcyclist was stationary and for how long?

(d) Use the graph to find the distance travelled by the motorcyclist before stopping.

13. Fig. 2.41 represents the velocity-time graph of a body during a period of 30 s.

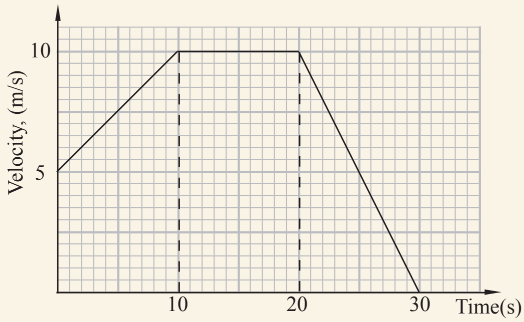


Fig. 2.41: Graph of velocity against time

(a) Use the equations of motion to find the displacement of the body in 30 s.

(b) Use the graph to determine the displacement of the body in 30 s.

(c) What is the retardation of the body?

14. Fig. 2.42 shows a displacement-time graph of the motion of a body over a period of 14 s. Use the graph to determine:

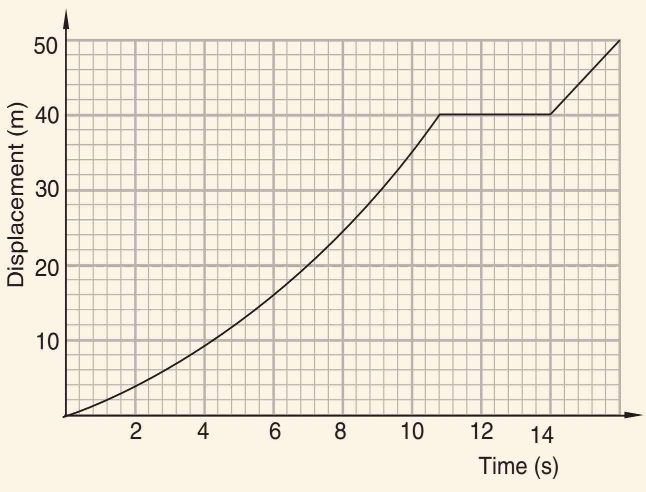


Fig. 2.42: Displacement-time graph

(a) the velocity when t = 3 s and t = 7 s.

(b) the acceleration of the body between 3 s and 7 s.

(c) the time, in seconds, the body was stationary.

UNIT 3 Force (I)

Key Unit Competence

By the end of this unit, I should be able to define, explain and describe forces and their effects.

Unit outlines

- Definition of force.
- Types of forces and difference between contact and non-contact forces.
- Representation of forces using vector diagrams.
- Addition of parallel and non-parallel forces.

3.1 Definition of force

In our daily lives, it is common to see things being pushed or pulled. Activity 3.1 gives us some of the instances where things are either being pulled or pushed.

Activity 3.1 **To demonstrate the effects of force on a body**

Materials

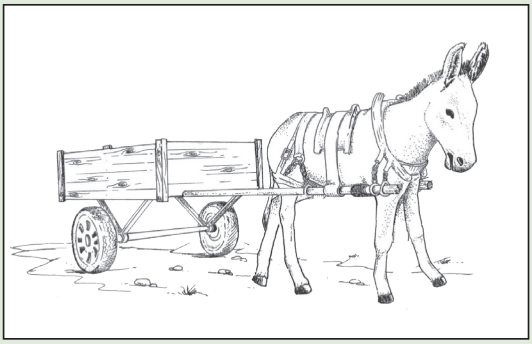
- Charts
- Rope
- A stone

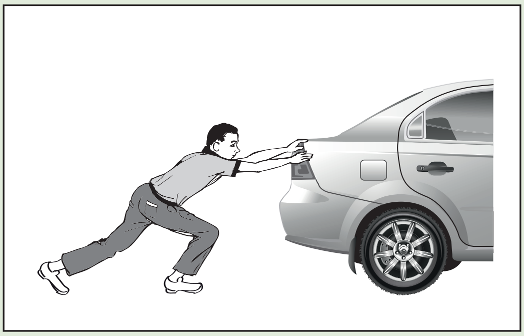
Steps

1. Push a table in your classroom slightly to displace it. Take care not to damage the legs of the table due to dragging.
2. Tie a stone or brick using a rope and pull it to other positions. (Take care not to be hurt by the stone).

Fig. 3.1 : Pushing a table

3. Now, study the pictures shown in Fig 3.2 and discuss with your class partner what is happening in each of them.





(a) **(b)**

(c) **(d)**

Fig. 3.2 : Pushing or pulling objects

4. TWhere a push or a pull is occurring.
5. List other examples where a push or a pull occurs in our daily lives.

From your discussion in Activity 3.2, you should have found that in Fig. 3.2 (a) a donkey is pulling a cart, 3.2(b) a car is being pushed to start, Fig. 3.2(c) a man is pushing a wheel chair and in Fig. 3.2(d), a woman is pushing a supermarket trolley.

These activities and many more involve either pushing or pulling. In physics, a pull or a push is called a force.

The SI unit of force is the newton (N), named after the famous physicist Sir Isaac Newton (1642 –1727).

Force is a vector quantity. It has both magnitude and direction. The magnitude is represented by a straight line while the direction is shown using an arrow as shown in Fig 3.3.

Fig. 3.3: Force exerted to the right

3.2 Types of forces

(a) Contact forces

Contact forces are those forces that act at the point of contact between two objects, in contrast to body forces. Examples of contact forces are *frictional force, tension, normal action reaction force, air resitence and upthrust*.

(i) Friction force

Activity 3.2 **To demonstrate friction in solids**

Materials

- Wooden block
- A light spring

Steps

1. Place the wooden block with the spring attached on the bench.
2. Pull a wooden block using a light spring slowly and then faster across the bench. (Fig. 3.4). Observe what happens.
3. Discuss the observations made in step 2.

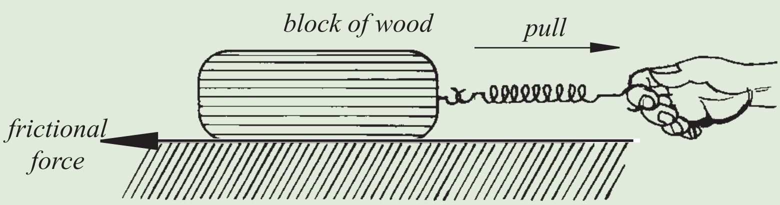


Fig. 3.4: Direction of frictional force

4. Place a pencil on the horizontal bench and give it a slight push. Observe and explain what happens.

In Activity 3.2, you should have noted that the spring extends without the wooden block moving and then it starts to move. When the pencil is given a slight push, it moves but finally comes to a stop.

In the first case, there is a force preventing the stationary block of wood from moving. In the second case, there is a force compelling the moving pencil to stop. These forces are called frictional forces. The force of friction exists whenever two bodies which are in contact, move relative to one another. If the two bodies are solids, the force is called solid frictional force. It does not matter which body is in motion.

Exercise 3.1

Do a research from internet and reference books on how to demonstrate friction in fluids i.e in liquids and gases.

(ii) Tension force

Activity 3.3 To demonstrate the existence of tension force in strings

Materials:

- A string
- A pail with water

Steps

1. Hold one end of a string and your friend the other end.
2. Let both of you pull the ends away from each other as shown in Figure 3.5. What happens to the string?

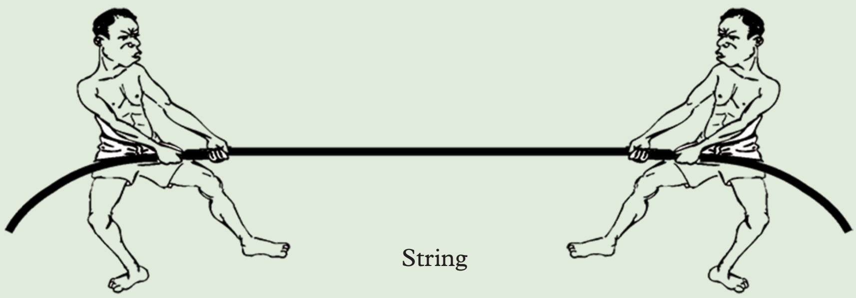


Fig. 3.5: Pulling a string

3. Discuss your observations in step 2 with your class partner.
4. Tie a string to the pail and hang it as shown in Figure 3.6.
5. Discuss with your class partner any forces acting on the string and the pail in fig 3.5.
6. Sketch a diagram to show the direction in which the forces in step 2 and 4 are acting.
7. Compare your findings in step 5 and 6 with those of other pairs in the class.

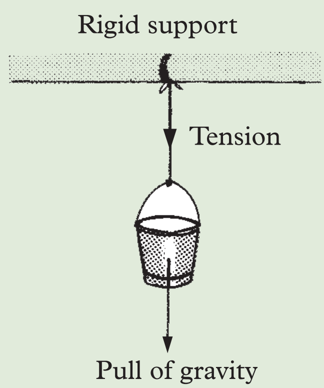


Fig. 3.6: Pail with water

In step 2, you should have felt that the string pulls inwards with a force. This force that develops in the string, cable or rope when it is being pulled tightly by forces acting from opposite end is called tension force.

The tension force can be shown on a force diagram by an arrow pointing inwards along the string marked with the letter, T. (Fig. 3.7)

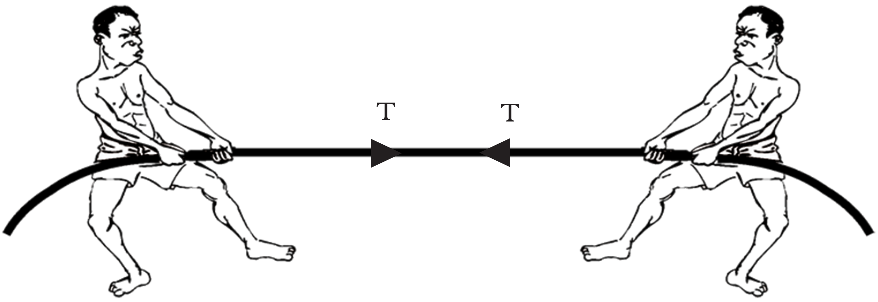


Fig. 3.7: Showing tension force

In step 5, you should have found that there are two forces acting on the setup; Tension force, which act in the string upwards and downwards and weight (pull of gravity) which act from the centre of the pail downwards. (See Fig. 3.8).

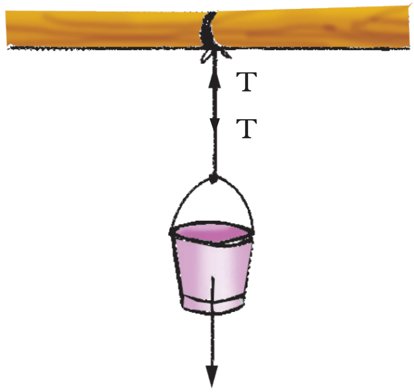


Fig. 3.8 : Tension force

Note: We will learn more on how to represent forces using vector diagram later in this unit.

Exercise 3.2

Do a research from internet and reference books on why it is important to have an idea of tension force on materials while constructing bridges and houses.

(ii) Action and reaction forces

Activity 3.4 To demonstrate action and reaction forces

Materials:

- A rigid support
- Two identical spring balances

Steps

1. Hook one end of a spring balance A to a rigid support e.g a wall. Pull the other end until the spring shows a reading (see Fig 3.9(a)).
2. Discuss with your partner what happens to the rigid support.
3. Repeat the activity by using a similar spring B instead of a rigid support.
4. Pull the two springs until the reading on spring A is the same as before (see fig 3.9(b)). What reading is shown by spring B?

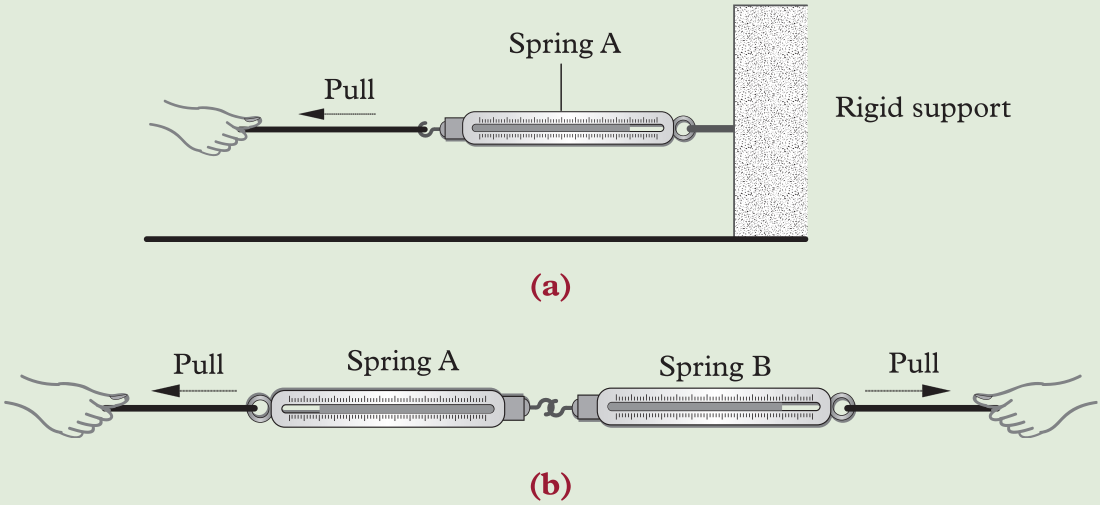


Fig. 3.9: To demonstrate action and reaction forces

From activity 3.4, you should have noted that the reading of spring A is the same as of spring B. This implies that there are two equal forces which are acting in opposite directions in the two springs.

Similarly, when spring A pulled the rigid support, the support also pulled it with an equal and opposite force. These two equal forces that act in opposite directions are called action and reaction force.

Another example that shows action and reaction force is when a book is placed on a table. The weight of the book provides action force while the table supporting the book provides reaction (Fig. 3.10)

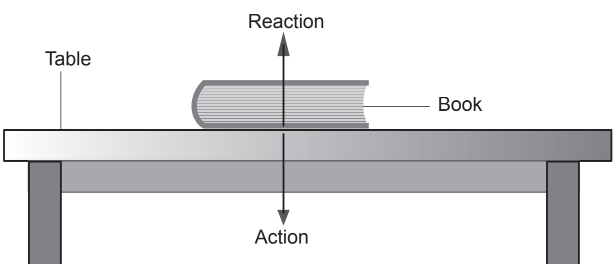


Fig. 3.10: A book on a table

Activity 3.5 **To demonstrate existence of normal reaction force**

Materials

- A bench
- A wooden block

Steps

1. Press the bench downwards with your thumb (Fig. 3.11). What do you feel? Suggest the kind of force acting on your thumb.

Fig 3.11: Thumb pressing on a table

2. Place a wooden block on the bench. Suggest the forces that are acting on the wooden block.
3. Lift one side of the bench top upwards at an angle ϴ. Ensure that the wooden block does not fall down.(see fig 3.12)

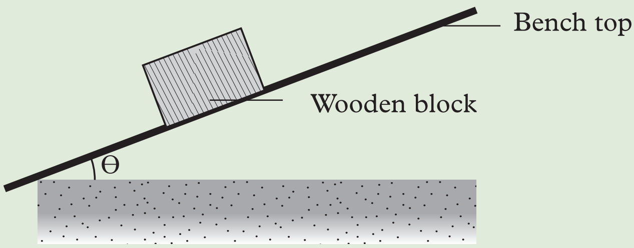


Fig 3.12: Wooden block at an angle

4. Identify the forces that are acting on the block of wood in step 3.

In step 1, you must have felt the bench pressing upwards against your thumb. The force you feel acting on your thumb by the table is called reaction force and the one acted by the thumb on the table is called action force.

This activity has shown that the reaction and action forces are always perpendicular (normal) to the surface of the body exerting the reaction (Fig 3.13)

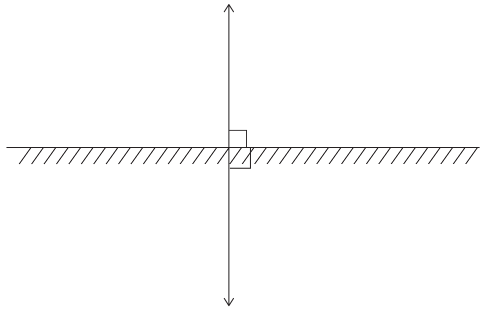


Fig. 3.13: Normal reaction and action perpendicular to the surface

Normal reaction and action also acts on the wooden block resting on the bar (step 2).

The force due to the block is called the action force, while that due to the table is called normal reaction force. Since the block is at rest the two forces must be equal though acting in opposite directions. (Fig. 3.14).

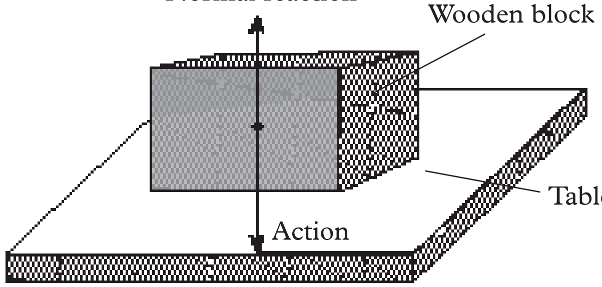


Fig. 3.14: Action and reaction forces

The forces that are acting on a wooden block when the bench top is lifted at an angle Θ are shown in Fig 3.15.

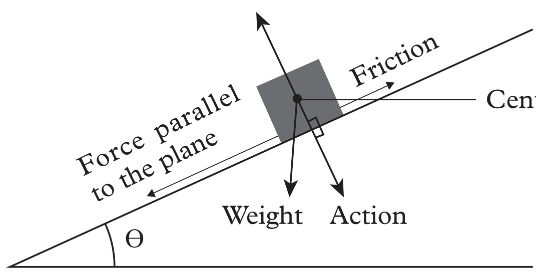


Fig 3.15: Forces acting on a wooden block at an angle

Note: The normal action force is the component of weight in an inclined body.

Exercise 3.3

Give explanation to the following observations:

(a) A balloon will start moving when the air inside it is released.

(b) A garden sprinkler starts rotating immediately the water starts to jet out of nozzles.

(c) When a gun is fired, the holder shakes as the gun tends to move backwards(recoil).

(iii) Air resistance (Friction due to air)

Activity 3.6 **To demonstrate the existence of air resistance**

Materials

- An umbrella
- A stopwatch

Steps

1. Run with an open umbrella as shown in Fig. 3.16 (a). What do you observe?
2. Record the time you take to move a given distance.
3. Repeat the activity, but this time with the umbrella closed as shown in Fig. 3.16 (b). Note the time taken to move the same distance.
4. Compare the time obtained in steps 2 and 3. What do you notice? Explain to your colleague in class.

(a) *Umbrella opened* **(b)** *Umbrella closed*

Fig. 3.16: Friction due to air

From activity 3.6, you should have noted that the time taken is more with open umbrella than the closed one. This shows that air offers hindrance to the movement. This hindrance is due to air resistance, also referred to friction due to air). Frictional force in fluid (liquids and gases) is called viscous drag.

Upthrust

Activity 3.7 To demonstrate upthrust force

Materials

- resort stand
- metre rule
- a solid mass.
- a spring balance
- beaker with water

Steps

1. Suspend a solid in air using a spring balance (Fig 3.17(a). Note its weight.
2. Push the solid upwards gradually with your hand (Fig 3.17(b). What happens to the reading of the balance? Explain.
3. Release the solid and submerge it in a fluid such as water as shown in Fig 3.17(c). What is the weight of the solid? Note it down.

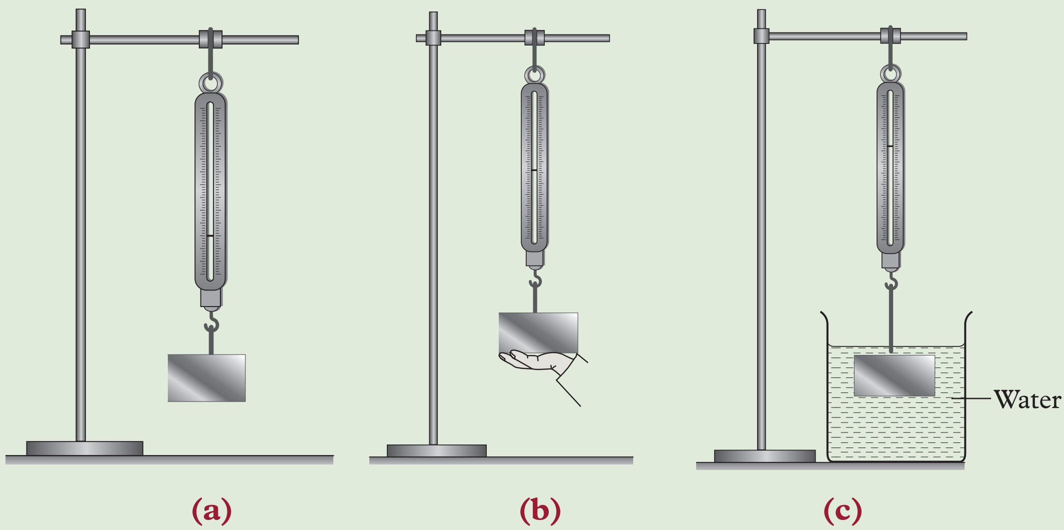


Fig. 3.17: To demonstrate upthrust force

4. Compare the weight of the solid? Note it down. Suggest the reason for your observation.

In Activity 3.7, you must have noted that the pointer of the spring balance moves upwards in both cases. However, the pointer moves upwards in step 3 due to upward force in water which acts from below the solid submerged in it. This upward force due to a fluid is called upthrust.

Exercise 3.4

Do a research on the importance of upthrust force to:

1. Divers and some animals e.g crocodiles.
2. Ship industry.

(b) Non-contact forces

A non-contact forces is a force applied to an object by another body that is not in direct contact with it. Examples of non-contact forces are *gravitational, electrostatic and magnetic force*s.

(i) Gravitational force

Activity 3.8 **To demonstrate gravitational force**

Material

- A ball

Steps

1. Hold a ball above the ground and release it. What happens to the ball?
2. Repeat step 1 but this time throw the ball upwards in the air as far as you can (do it in the field). Observe and describe the motion of the ball.
3. Discuss what made the ball to behave the way it did in steps 1 and 2.

In this activity, you should have noticed that when the ball is released, it moves down, hits the ground and eventually comes to rest. When it was thrown upwards, the ball moves up, stops momentarily and comes down.

Sir Isaac Newton made a similar observation as in step 1. He observed an apple falling from a tree and wondered why this was so (see Fig 3.18).

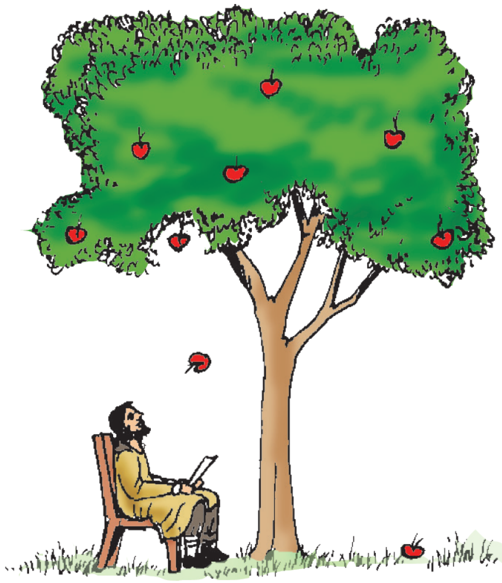


Fig. 3.18: A falling apple

After many experiments, Newton concluded that the apple he saw falling from a tree was attracted downwards by a force in the earth. He called this force of attraction gravitational force or force of gravity. The force of gravity pulls bodies towards the centre of the earth, as observed in activity 3.18 above.

Fig 3.19 shows how bodies are attracted by gravitational force towards centre of the earth.

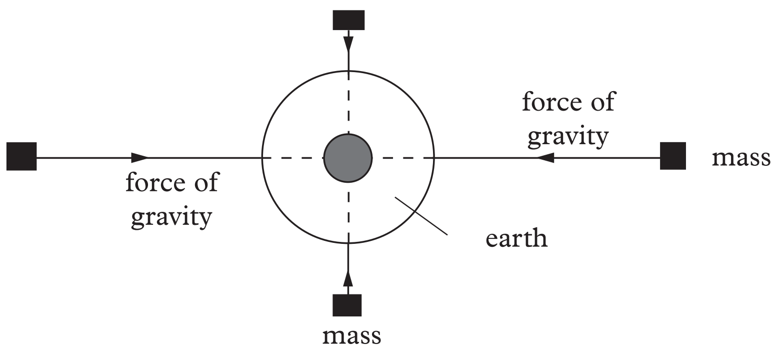


Fig. 3.19: Force of gravity pulls bodies towards the centre of the earth

Exercise 3.5

Do a research from Internet and reference books on what causes tides in oceans.

(ii) Electrostatic force

Activity 3.9 **To demonstrate electrostatic force**

Materials

- Plastic ruler/pen
- Dry piece of cloth
- Piece of paper

Steps

1. Rub a plastic ruler against a dry piece of cloth. Suggest a reason why we do so.
2. Bring the plastic ruler close to small pieces of paper (Fig 3.20). What happens to the pieces of paper? Explain.
3. Discuss with your colleagues in class your observation in step 2.

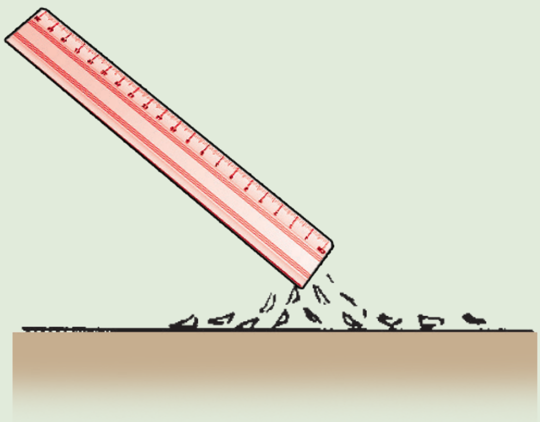


Fig. 3.20: Ruler pulling up a paper

You must have noticed that the pieces of paper were attracted towards the ruler in step 2 in Activity 3.9. The force of attraction or repulsion between static charges is called electrostatic force.

Electrostatic force is created when the plastic ruler was rubbed against a dry piece of cloth. We will learn more about electrostatic in Unit 11 of this book.

(iii) Magnetic force

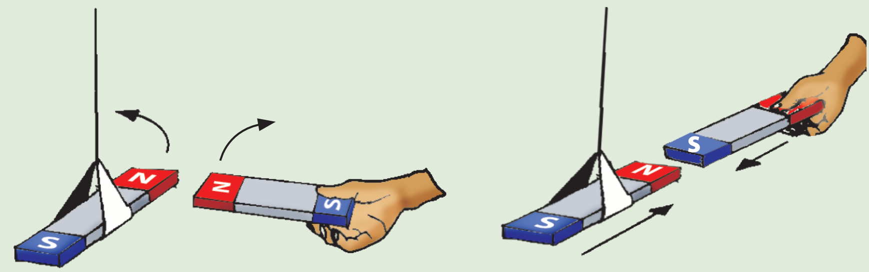
Activity 3.10 **To investigate repulsion and attraction effects of a magnetic force**

Materials

- 2 bar magnet
- Iron rod
- A thread

Steps

1. Suspend a bar magnet from a support using a light thread. Allow the bar magnet to swing freely until it comes to rest.
2. Bring a second bar magnet near it (Fig 3.21). What do you observe? Explain your observations.



(a) *Repulsion* **(b)** *Attraction*

Fig 3.21: Behaviour of two poles of bar magnets brought near one another

3. Repeat step 1 and 2 using a bar magnet and iron rod. What do you observe? Explain your observations.

In Activity 3.10, you must have observed that when like poles of the suspended magnet and the other magnet are near each other, the suspended magnet is repelled (Fig 3.21(a). However, when or unlike pole or iron rod are brought close the suspended magnet, they are attracted (Fig 3.21(b)). The repulsion and attraction between magnets is called magnetic force. Magnetic forces also exists between magnets and other materials such as iron rod. Such materials with magnetic force are called magnetic materials.

3.3 Effects of forces

The effect of a force depends on the size, nature, how and where the force is applied. The following activities illustrate the effect of forces on bodies.

Activity 3.11 To demonstrate the effect of a force on an object at rest or in motion

Materials

a ball

Steps

1. Kick the ball from its resting position. What do you observe? Explain your observation.
2. Identify the effects of forces shown in Fig. 3.22(a) and (b).

(a) Kicking a ball

(b) Catching a moving ball

Fig. 3.22: Forces changing state

A force can make a body at rest to start moving (Fig 3.22(a)) or a moving body to come to rest (Fig. 3.22(b)). It can also change the direction of motion of a body. Therefore, force can change the state of motion of a body.

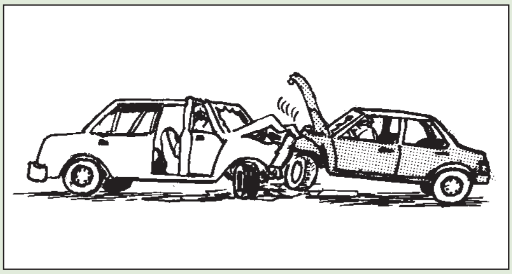
Activity 3.12 To demonstrate the effect of a force on the shape of an object

Materials

a ball

Steps

1. Sit on the ball and let your class partner observe what happens to the ball.
2. Let your class partner also sit on the ball. What do you observe. Discuss?
3. Identify the effects of forces shown in Fig. 3.23 (a) and (b).



(a) *Cars colliding.*

(b) *A girl sitting on a balloon.*

Fig. 3.23: Forces changing shape

4. Discuss other cases where the effects you have observed in step 1 are also experienced.

A force can distort or change the shape of an object. For example, stretching a rubber band or a spring when compressed by a force and squeezing a balloon. Clay and plasticine are also other examples of substances whose shapes change easily when a force acts on them.

A force due to an earthquake can also cause massive destruction such as death of people and animals. It can also cause land deformation which leads to soil erosion and consequently contribute to pollution.

Plant more trees and plough across the farm to minimise on soil erosion.

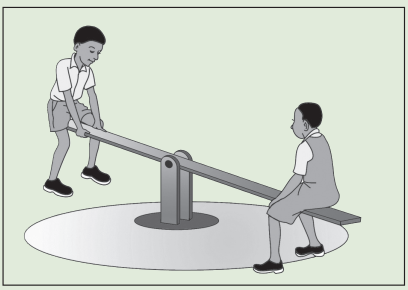
Activity 3.13 **To show that force produces a turning effect on an object**

Materials

- A seesaw
- A steering wheel

Steps

1. With your partner, try to balance on a seesaw (Fig. 3.24(a)). Now try to lift your partner on the seesaw. What do you observe?
2. Observe the activity in Fig. 3.24 (b).



(a) *Seesaw*

(b) *A steering wheel*

Fig. 3.24: Forces causing turning and rotation

3. Discuss the effects of force shown in Fig. 3.24(b).

From activity 3.13, we notice that, forces when suitably applied can make a body to turn about a point or cause a rotation. See Fig. 3.24(b).

Activity 3.14 **To demonstrate tear and wear as caused by a force**

Materials

- Different tyres

Steps

1. Take a close look at different tyres of vehicles within the school compound or roadside. What can you comment about their treads? Suggest a reason.
2. Now, compare and discuss the state and condition of the tyres shown in Fig. 3.25.

(a) **(b)**

Fig. 3.25: Conditions of tyres

3. Name the effect of the force demonstrated in Fig 3.25 (b).

From Fig. 3.25, tyre (a) has its treads still in good condition. The tyre in (b) has its treads worn out. The tyres wear and sometimes tear because of friction between the road and the tyre when in use. This shows that, forces can cause wear and tear.

In summary, the following are the effects of forces:

- Force can cause change in the state of motion of a body, i.e. force can start, stop, increase or reduce motion and change the direction of a body in motion.
- Force can change the shape of a body i.e. force can distort, stretch or compress a body.
- Force can cause turning effect. Examples are a seesaw and a beam balance.
- Force can cause rotation in the bodies e.g a steering wheel.
- Force can cause heating effect, i.e. frictional force cause heating, e.g. lighting a matchstick.
- Frictional force causes noise when rough surfaces are rubbed together.

3.4 Representation of forces using vector diagrams

Activity 3.15 **To demonstrate representation of force**

Material

- Marbles

Steps

1. Arrange the marbles on top of your desk in a straight line (Fig. 3.26).

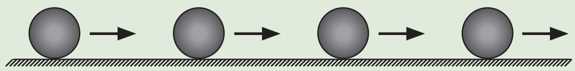


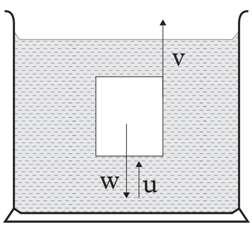
Fig. 3.26: Movement of marbles

2. Give one marble a slight push toward others and observe what happens.
3. What is your observations? suggest how forces are represented.

From Activity 3.15, you should have observed that the force on the marble made others to start moving in a particular direction.

Force is a vector quantity, that is, it *has both magnitude (size) and direction*. A vector is normally represented by a line with an arrow head ($\longrightarrow$). The length of the line represents the magnitude and the arrow head shows the direction. We therefore need a way of representing both magnitude and direction on a diagram in order to represent forces.

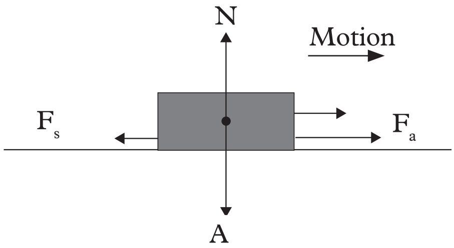
A diagram showing all the forces acting on a body in a certain situation is called a free body diagram or simply a vector diagram. A free body diagram shows only the force acting on the object under consideration, not those acting on other objects. Fig. 3.27 shows forces acting on a body.



v, is the viscous drag of the liquid.
w, is the weight of the object.
u, is the upthrust in the liquid.

Fig. 3.27: A moving object in a liquid

Fig. 3.28 shows a body moving toward right on a rough surface.



N is the normal reaction.

F_a is the applied force.

F_s is the friction force.

A is the action force or (weight).

Fig. 3.28: Normal, applied force and friction force

Fig. 3.29 shows a person pushing a wheelbarrow.

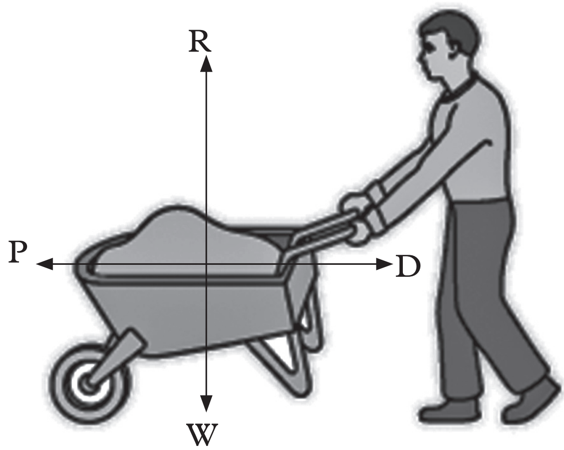


Fig. 3.29: Shows a wheelbarrow being pushed towards left

R is the reaction force of earth on the wheelbarrow. This force acts at right angle (or normally) to the ground. It is also referred to as the normal reaction force.

P is the forward force exerted by the worker on wheelbarrow.

W is the pull of earth on wheelbarrow (its weight).

D is the drag force acting on the wheelbarrow.

3.6 Weight and mass

Activity 3.16 **To determine the weight of an object using a spring balance**

Materials

- Spring balance

Steps

1. Study the spring balance provided. What does it measure?

2. Identify the units labelled on the spring balance. Which units do you think are used to measure weight?
3. Tie a small stone with a string and suspend it on a spring balance. What is the reading on the spring balance?

Weight is the measure of gravitational pull on an object. It always act from the centre of a body downwards in the direction of gravitational acceleration. The SI unit of weight is newton (N).

Weight is measured using a spring balance (See Fig. 3.30)

Fig 3.30: A spring balance

Weight and mass are related. Do you remember what we learnt on mass in unit 1 of this book? Remind your class partner.

Relationship between mass and weight

Activity 3.17 **To differentiate between mass and weight**

Material: spring balance

1. Look at the graduations of the spring balance provided to you. Deduce the relationship between the two units (i.e Newton and grams).
2. In your group, find out 1 kg is equivalent to how many newton (N).
3. Write down an expression relating weight and mass.
4. List and discuss five differences between mass and weight.
5. Compare and discuss your findings with other pairs in your class.

In your discussion, you should have come up with the following relationship

Weight = mass x gravitational field strength
$w = mg$

Hence,

$$\frac{\text{Weight (w)}}{\text{Mass (m)}} = \text{gravitational field strength (g) abbreviated as } \frac{w}{m} = g$$

$$w = mg \text{ or } m = \frac{w}{g}$$

Experimentally it has been shown that the earth pulls a mass of 1 kg with a force of 9.8 N/kg. However a convenient rounded up value of 10 N/kg is commonly used.

$$\text{Gravitational field strength (g)} = \frac{\text{Force (N)}}{\text{Mass (kg)}} = \frac{10 \text{ N}}{1 \text{ kg}}$$

$$g = 10 \text{ N/kg}$$

Differences between mass and weight

Table 3.1 shows the main differences between mass and weight.

Mass	Weight
Quantity of matter in a body.	Pull of gravity on a body.
SI unit is kilogram (kg).	SI unit is newton (N).
Constant everywhere.	Changes from place to place.
Scalar quantity.	Vector quantity.
Measured using a beam balance.	Measured using a spring balance.

Table 3.1: Differences between mass and weight

Example 3.1

A van of mass 2500 kg is authorised to carry 14 passengers. If the average mass per passenger is 50 kg, calculate the:

(a) weight of the van.

(b) weight of all passengers.

(c) total weight of the van and the passengers.

Solution

(a) $w = mg$

$w = 2\ 500 \text{ kg} \times 10 \text{ N/kg}$

$= 25\ 000 \text{ N}$

(b) $w = mg = (50 \times 14) \text{ Kg} \times 10 \text{ N/Kg}$

$= 7\ 000 \text{ N}$

(c) $w = (25\ 000 + 7\ 000) \text{ N}$

$= 32\ 000 \text{ N}$

Exercise 3.6

1. Define a vector quantity. Give two examples.
2. Distinguish between mass and weight.
3. Calculate the weight of the following. (Take g = 10 N/kg).
   (a) 300 g mass of water.
   (b) 700 kg mass of sand.
   (c) 0.05 mg mass of wool.
4. A metal bob of mass 20 g is suspended using a light thread. Calculate the tension developed in the thread. Take g = 10 N/kg

3.6 Balanced and unbalanced forces

Activity 3.18 To demonstrate balanced and unbalanced force in a tug of war

Material

- A rope
- 5 very small boys
- 5 very strong boys

Step

1. Let the 5 very strong boys pull a rope on one end and 5 small boys pull on the other end.
2. Observe and explain what happens.
3. Suppose the boys on both sides are of equal strength. What would you observe?

From Activity 3.18, you should have noticed that the rope moves to the side with the stronger boys ones who applied a greater force than the weak ones. The pulling forces are said to be unbalanced.

Incase the two teams had equal strength or force, the rope will stay in the same place. The pulling force applied is said to be balanced or at equilibrium.

Similarly, consider the following:

1. A book is placed on a table top as shown in Fig. 3.31. The gravity pulls the book vertically downward while the table support the book with a force acting vertically upwards.

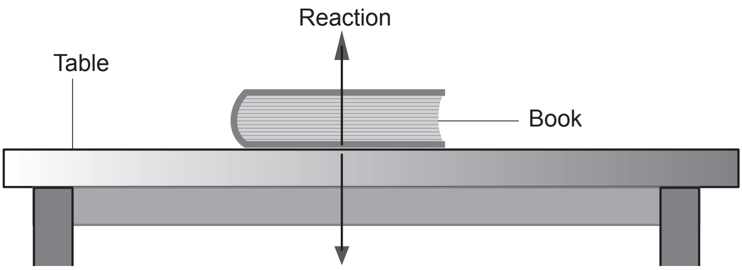


Fig. 3.31: Gravity pull downward on the book

Since the two forces are of equal magnitude and in opposite directions, they balance each other. The book is said to be in equilibrium. There is no unbalanced force acting on the book and therefore the book maintains the state of rest. Also, there is no change in motion.

2. If you compete in arm wrestling competition with someone who is just as strong as you are, and both of you are pushing as hard as you can, your arms stay in the same place. This is an example of balanced forces. The force exerted by both of you are equal, but are acting in opposite directions. The resulting force is zero hence there is no change in motion. See Fig. 3.32.

Fig. 3.32: Arm wrestling

If one of the forces is greater than the other, motion occurs towards the weaker forces. The forces are said to be unbalanced.

3.7 Addition of parallel and non-parallel forces

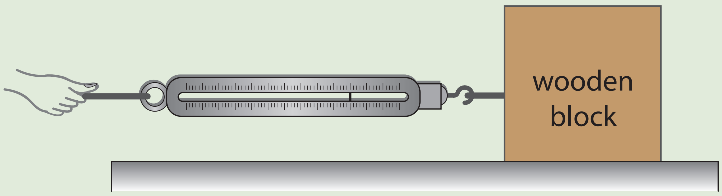
Parallel forces

Activity 3.19 **To demonstrate parallel forces**

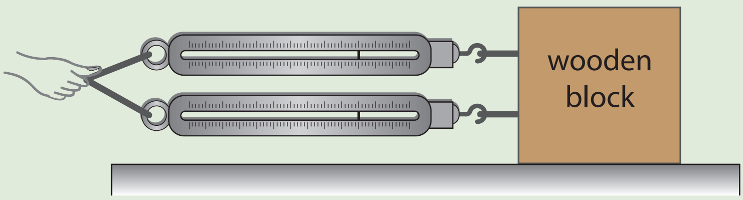
- A block of wood
- Two identical springs

Steps

1. Place a block of wood on a rough surface.
2. Pull the block using a string attached to a spring balance until the block just starts to move Fig. 3.33(a). Record the value of the force applied.
3. Repeat the activity but use two identical springs parallel to each other. (Fig.3.33(b)). Record the force applied in each of the springs.



(a) *Pulling a block using one spring*



(b) *Pulling a block using two springs*

Fig. 3.33: Measuring force using spring balance

4. Compare the value of the forces applied in steps 2 and 3. Explain the difference if any.

You should have observed that the two spring pulling together record the same value. This value is half of that recorded by the single spring.

Let the force applied by the single spring A values = y

Force applied by each one of the two spring = x

Therefore, $x + x = y$

$$2x = y$$

$$x = \frac{y}{2}$$

When several parallel forces act together on the same body in the same direction the combined or resultant force can be added by the ordinary rules of arithmetic.

If the Activity 3.19 is repeated with two equal forces pulling the wooden block at the same time but in opposite direction, one force cancels or counters the other one. If the force in one direction is taken as positive, then the force in the other direction is taken as negative.

When a number of parallel forces act on a single body, the resultant force acting on the body can be found by adding all the forces taking considerations of the directions (+ or –).

Example 3.2

Two oxen are pulling a heavy block along a floor in the same direction. One exerts a horizontal force of 800 N and the other a force of 1000 N. If the frictional force between the crate and the floor is 430 N.

(a) Draw the force diagram.

(b) Find the total horizontal force in (a) above.

(c) Find the direction of the force in (a) above.

Solution

(a)

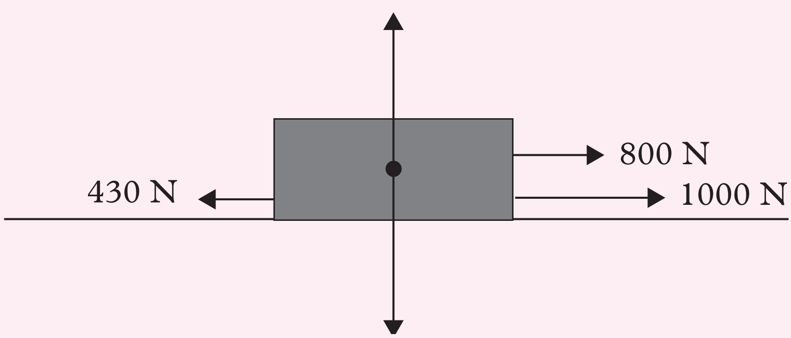


Fig. 3.34: Addition of parallel forces

(b) We shall chose the forward direction as positive since the frictional force opposes motion i.e acts backwards in the negative direction.

Force exerted by the oxen = 800 N + 1000 N

Force exerted by friction = -430 N

The total force on the crate = 800 + 1000 – 430 N

= 1370 N

The resultant force on the crate = 1370 N

(c) Since the force is positive its direction is forward.

Exercise 3.7

1. Name all the forces acting on the following:
   (a) A book resting on a table.
   (b) A book which is being pushed across a flat rough table by a student's finger.
   (c) A stone resting on a rough sloping board.
   (d) A box supported on a tall thin pillar.
2. Draw force diagrams for the cases in question 1.
3. Find the resultant of the following sets of forces:
   (a) A force of 35 N backwards and a force of 35 N forward.
   (b) A force of 120 N upwards and a weight of 150 N.
   (c) A force of 29 N upward, a force of 34 N upward, and a force of 50 N downwards.

Non-parallel forces

Activity 3.20 To demonstrate non-parallel forces

Materials

- A ring
- 3 ropes/strings

Steps

1. Tie three ropes at different points on the ring as shown in Fig 3.35.

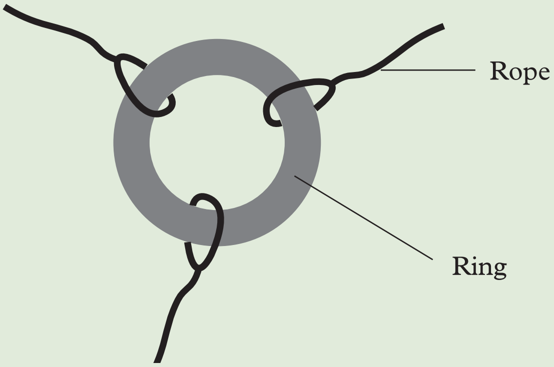


Fig. 3.35: Strings tied to a ring

2. Let three of you pull each rope in different directions. What do you observe? Explain.

When one one rope is pulled by a greater force than the rest, the other two, move towards its direction. However, when the ropes are pulled with the same force, neither of you moved to any particular direction since the forces are balanced.

These three forces in this activity acting on the ring in different directions. Such forces are called non-parallel forces.

Addition of non-parallel forces

Activity 3.21 **To illustrate addition of non-parallel forces**

Materials

- 3 - identical spring balances
- Plane paper
- A ring
- 3 - heavy wooden blocks

Part A

1. Cover the top of a table with a plane paper.
2. Hook the springs balances to wooden blocks.
3. Hook the springs to the ring by means of loose loops of the string as shown in Fig 3.36.

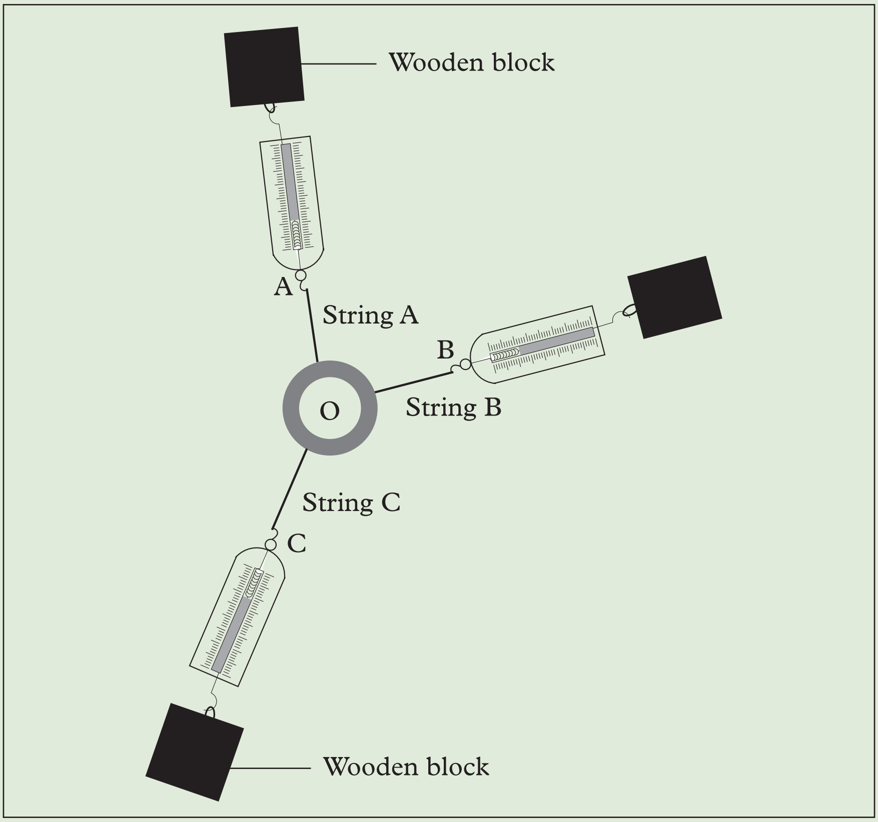


Fig. 3.36: Addition of non-parallel forces

4. Move the wooden blocks outwards until each spring balance is showing appreciable reading. Record the readings of the spring balances.
5. Tap the ring and the strings so as to be in their true position. Is the ring balanced? Give a reason. Mark the centre of the ring as point O.
6. Draw a straight line along each string. Mark points A, B and C along the lines representing the respective strings as shown in Fig. 3.36.

From Activity 3.21 part A, the ring is observed to be in equilibrium i.e. state of balance. Therefore, the total force acting upon it must be zero. This can be shown by adding together the forces exerted by spring balances A, B and C as shown in part B below.

Part B

Steps

1. Remove the set ups.
2. Produce the lines through A, B and C inwards to meet at O.
3. Using a suitable scale, mark off distances OA, OB and OC accurately and proportional to the readings you recorded for the respective springs.

4. Construct a parallelogram OBRA and draw the diagonal OR (see Fig 3.37).
5. Find the length OR and compare it with the length OC. What can you say about forces OC and OR. What is the relationship between Forces OA, OC and OR.

The magnitude force OR and OC are equal in magnitude but opposite in direction (Fig. 3.37).

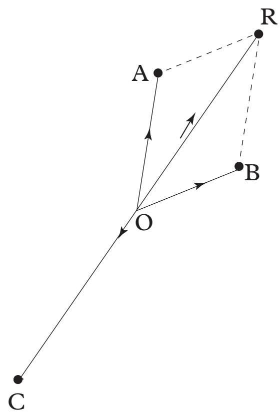


Fig. 3.37: Construction of parallelogram

This force OR represent the resultant force exerted by OA and OB. This method of obtaining the resultant of two forces is called the parallelogram law method which says that;

If two forces are represented in magnitude and direction by two sides OA and OB of the parallelogram OARB, then the resultant is represented in magnitude and direction by the diagonal OR.

Example 3.3

A wooden crate is pulled horizontally by two forces of 250 N and 150 N at an angle of 70° to each other. (Fig. 3.38). Determine the resultant force on the box.

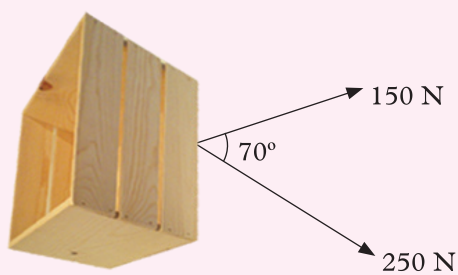


Fig. 3.38: Wooden crate being pulled by two forces

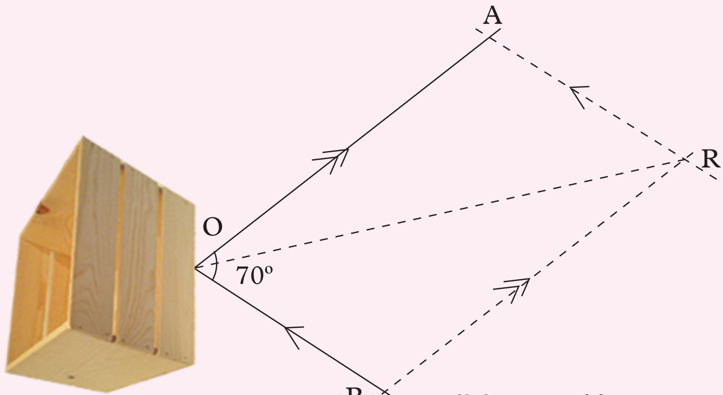
Solution

Using a scale of 1.0 cm represent 50 N

Draw a line OA to represent 250 N

Draw a line OB to represent 150 N

Let O be the common point and the angle between the two lines be equal to 70°



OA = 5.0 cm
OB = 3.0 cm

Fig 3.39: Parallelogram of forces acting on a crate

Construct the parallelogram OARB using these lines OA and OB as adjacent sides and measure the diagonal OR = 6.9 cm.
Using the scale of 1.0 cm = 50 N, we find the resultant force is 345 N.

NB: When the angle between two forces is very close to 0° or close to 180°, the parallelogram of forces folds down into a flattened form lying almost along a single straight line. The parallelogram rule of addition of slanting forces then gives the same result as the simple addition rule for parallel forces.

Equilibrium of three non-parallel forces

Consider a balloon suspended from a rigid support (Fig. 3.40).

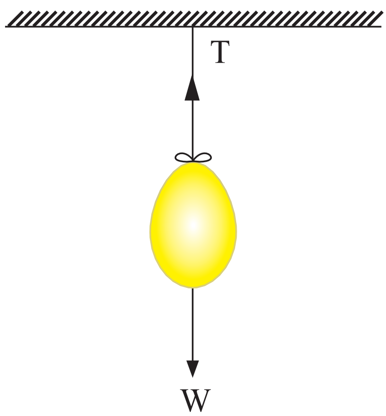


Fig. 3.40: Suspended balloon

Supposing the wind exerts a horizontal force on the balloon. The balloon moves and stops with the string making an angle with the vertical line. The balloon is in equilibrium under the force due to the wind, the force due to the ball's own weight, and the tension in the string.

The resultant of the wind force and the weight in the string is therefore equal and opposite to the tension in the string. Hence, the net resultant force is equal to zero at equilibrium.

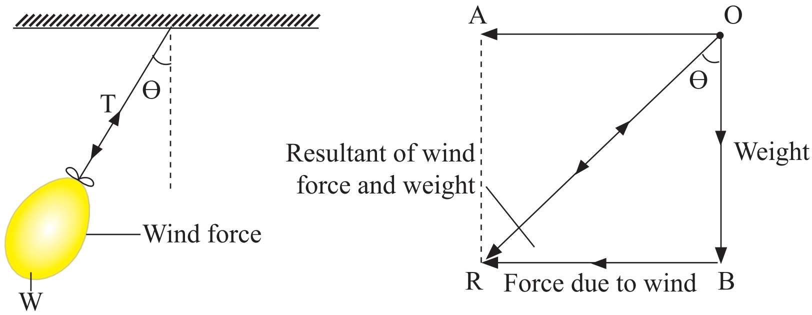


Fig. 3.41: Determining resultant force of suspended balloon

The resultant force is known to act in the same straight line as the tension in the string.

Exercise 3.8

1. State the parallelogram law.
2. Explain the term equilibrium.
3. A box is moving constantly across a rough horizontal floor, pulled by two horizontal ropes. One of the ropes has a tension of 150 N and makes an angle 20° with the direction of motion of the box. The other rope with a tension force of 90 N makes an angle 40° with the direction of motion of the box.
   - **(a)** Sketch the arrangement.
   - **(b)** By scale drawing find the resultant forward force acting on the box.
   - **(c)** Give the backward force on the box due to friction.

Unit summary and new words

- A force is a push or a pull. The SI unit of force is the newton (N).
- Unbalanced forces cause acceleration.
- Frictional force is that force that opposes relative motion between two surfaces in contact with one another.

- Weight is the gravitational pull in an object.
- A force can cause:
  - Change in the state of motion of a body.
  - Change of the shape of a body.
  - Turning effect on a body.
  - Wear and tear on a body.
- Types of forces include friction, tension, pull of gravity(weight), normal reaction force, air resistant, upthrust, action and reaction force, gravitational, magnetic and electric force.
- Contact force include tension, pull of gravity(weight), action and reaction force, air resistance etc.
- Non-contact force includes gravitational, magnetic and electrostatic forces.
- Force is a vector quantity. It has both magnitude and direction. It is normally represented by a line with an arrow ($\longrightarrow$).
- Weight is measured using a spring balance.
- Two or more forces are said to be balanced if they are equal in magnitude and act in opposite direction.

Unit Test 3

1. Define force and state its SI unit.
2. State three types of contact and non-contact forces.
3. Name the instrument which is used to measure weight.
4. A first aid kit box used at a fire accident scene has a weight of 2 500 N. What is its mass?
5. The mass, weight and density of chalk is not changed by grinding it into powder, but air friction is greater when the powder falls towards the ground. Explain.
6. Calculate the weight of the following. (Take g = 10N/kg.)
   - **(a)** 300 g mass of water
   - **(b)** 700 kg mass of sand
   - **(c)** 0.5 mg mass of wool
7. A metal bob of mass 20 g is suspended using a light thread. Calculate the tension developed in the thread. (Take g = 10N/kg.)

8. What effect of a force is shown in Fig. 3.42?

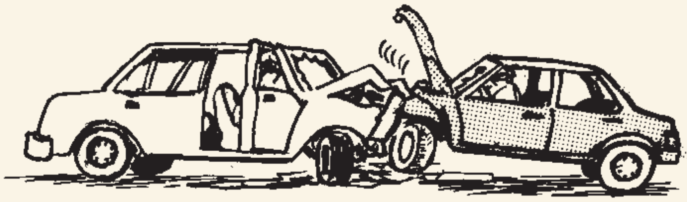


Fig. 3.42: Effect of force on a body

9. What is frictional force?

10. Find the resultant of the following forces:

(a) 150 N due East and 200 N due West.

(b) 450 N due North and 250 N due South.

11. State four differences between mass and weight.

12. Moon's gravitational pull is $\frac{1}{6}$ of the earth's gravitational pull. Calculate the weight of a body whose mass is 40 kg on:

(a) the moon's surface.

(b) the earth's surface.

13. Three strings are attached to a small metal ring. Two of the strings make an angle of 70º and each is pulled with a force of 7 N, find the force that must be applied to the third string to keep the string stationary.

14. A body is acted upon by two forces each of magnitude 50 N. Find the magnitude of the resultant force on the body when the angle between the two forces is:

(a) 0º **(b)** 45º **(c)** 90º

(d) 135º **(e)** 180º

Drive and observe all traffic rules carefully. Careless driving and breaking of traffic rules can cause death!

UNIT 4 Newton's Laws of Motion (I)

Key Unit Competence

By the end of this unit, I should be able to state Newton's laws to describe the effects of forces on objects.

Unit Outline

- Relationship between mass and inertia.
- Newton's First law (law of inertia).
- Newton's Second law (Impulse) F = ma.
- Newton's Third law (Principle of action and reaction).
- Newton's law of universal gravitation.
- Weight = mg.
- Application of Newton's law of motion on frictionless horizontal surface.
- Determination of acceleration due to gravity.

Introduction

You may have observed the following: passengers make an abrupt forward movement when emergency brakes of a car are applied, a group of people are able to push a stalled car to a high speed faster than one person, etc. These observations and similar ones are explained by Newton's laws of motion. In this unit, we shall discuss these laws of motion and their applications.

4.1 Newton's first law of motion

Activity 4.1 **To demonstrate effect of inertia**

Discuss in pairs and suggest what causes the following observations to take place:

1. A passenger lurches backwards when a bus initially at rest suddenly starts moving forward.
2. When a bus is moving very fast and suddenly negotiates a corner in one direction, the passengers lurches to the opposite side.
3. If the brakes of a fast moving bus are applied suddenly, the passengers lurch forward.

From the observation in Activity 4.1, we see that the body of the passenger is always tending to resist any action taken by the bus e.g when the bus wants to move, the body wants to remain behind; when the bus wants to stop the body wants to continue moving.
The reluctance of a body to resist change to its state of motion i.e either to remain at rest or to continue moving is known as inertia (latin word meaning laziness).

To demonstrate Inertia

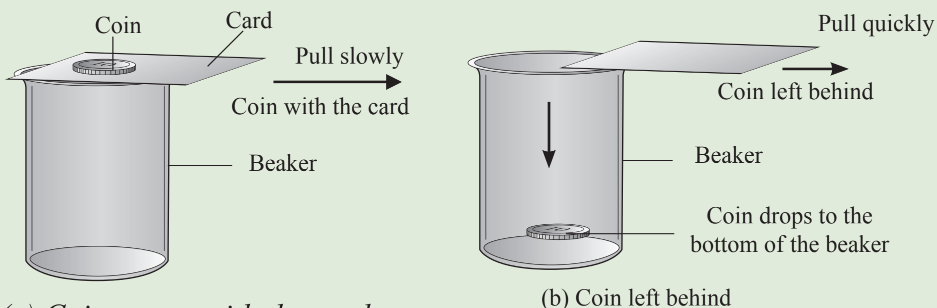
Activity 4.2 To demonstrate inertia using a coin

Materials

- A coin
- A beaker
- A smooth cardboard

Steps

1. Place a coin on a smooth cardboard and place it over a beaker. Pull the card away slowly (Fig. 4.1 (a)). Observe what happens to the coin.
2. Repeat the activity but this time pull the card away suddenly (Fig. 4.1 (b)). Observe what happens to the coin.
3. Suggest a reason why the coin behave differently in these steps.



(a) Coin moves with the card

Fig. 4.1: Card with coin pulled (a) slowly (b) suddenly

In Activity 4.2, you should have observed that when the card is pulled slowly, the coin moves together with the card Fig. 4.1(a). This is because the frictional force between the card and the coin makes the two to move together. However, when the card is pulled suddenly, the coin is left behind and drops vertically down into the beaker (Fig. 4.1(b)). This is because the coin resists motion and does not move with the card and hence drops vertically downwards into the beaker.
The coin resists to change its state of rest but due to lack of support from below, falls into the beaker.

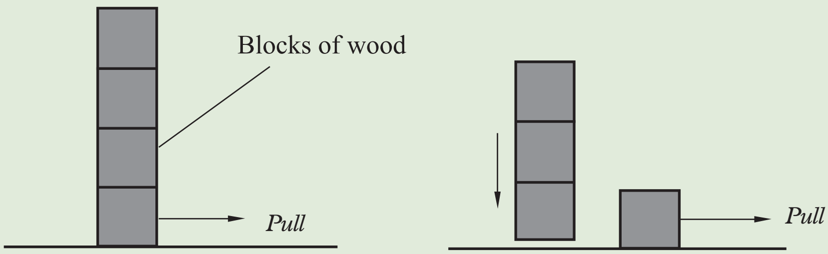
Activity 4.3 To demonstrate inertia using a wooden block

Materials

- Four wooden blocks
- Smooth surface
- String

Steps

1. Place a pile of wooden blocks on a table. Tie the block with a string. Pull the lower block slowly and note what happens (Fig. 4.2 (a)). Discuss and suggest a reason for this.
2. Repeat the activity but this time pull the lower block suddenly (Fig. 4.2 (b)). Write down your observation.
3. Suggest a reason for this observation. Why does the pile behave differently in step 1 and 2.



(a) The lower block pulled slowly (b) The lower block pulled suddenly

Fig. 4.2: Pulling the blocks of wood

In Activity 4.3, you should have observed that the whole pile moves when the lower block is pulled slowly (Fig.4.2(a)). When pulled suddenly, the lower block moves leaving the other blocks behind. In the second case, the pile of blocks above the lowest ones resist sudden movement hence drops down on the table (See Fig. 4.2(b)).

Activity 4.4 To demonstrate inertia using a mass suspended with a string

Materials

- Three 200 g masses
- Pieces of strings

Steps

1. Hang a mass as shown in Fig. 4.3 (a).
2. Pull the lower string below the block slowly (Fig. 4.3 (b)). Note what happens to the two strings. Suggest a reason for your observation.
3. Repeat the activity but now pull the lower string suddenly (Fig. 4.3 (c)). Write down your observation.

4. Discuss your observations in steps 2 and 3 and suggest a reason why the strings behaved differently.

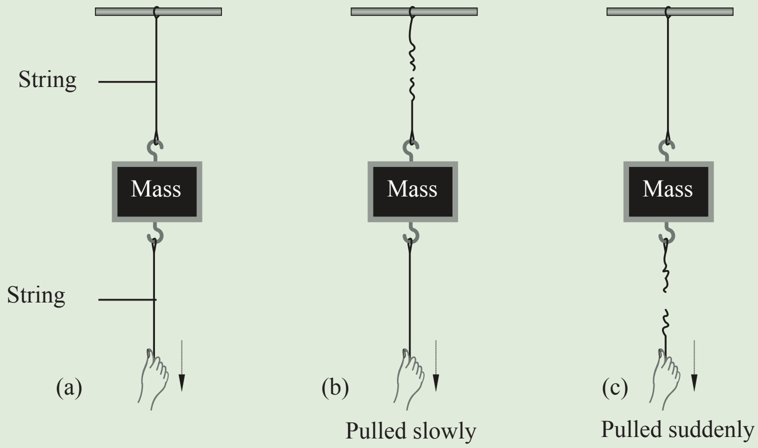


Fig. 4.3: String pulled

In Activity 4.4, when the lower string is pulled slowly, the upper string breaks (Fig. 4.3(b)). This is because the force applied is gradually exerted on the two strings. The upper string experience a greater force than the lower one due to the block's weight. However, when pulled suddenly, the lower string breaks. In this case, the upper string resist the sudden change hence only the lower string breaks (See Fig. 4.3(c)).

Activity 4.5 To illustrate the law of inertia using a trolley

Materials

- A wooden block
- A trolley
- A runway

Steps

1. Place a wooden block on a trolley. Allow the trolley to move down a friction compensated runway as shown in Fig. 4.4 (a).

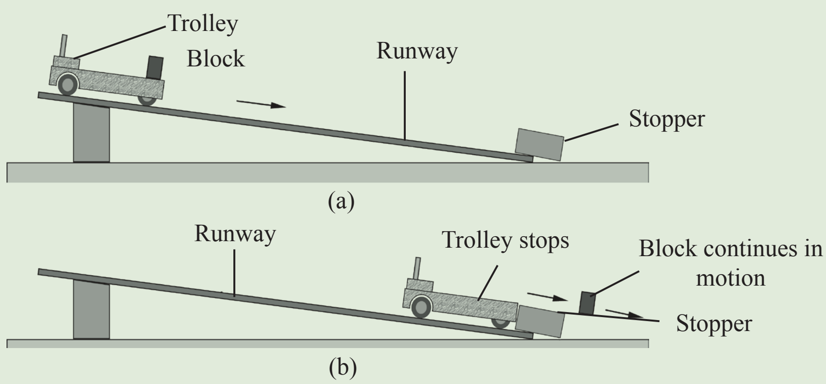


Fig. 4.4: A body is reluctant to stop moving

2. Note what happens to the wooden block once the trolley is stopped suddenly Fig. 4.4 (b).
3. Suggest a reason for the behaviour of the block.

The wooden block slides off the trolley and continues moving in the same direction the trolley was moving (Fig. 4.4 (b)) i.e. wooden block is reluctant to stop moving.

Mass and inertia

In this section, we will discuss the relationship between mass of a body and its inertia. The following activity will help us establish their relationships.

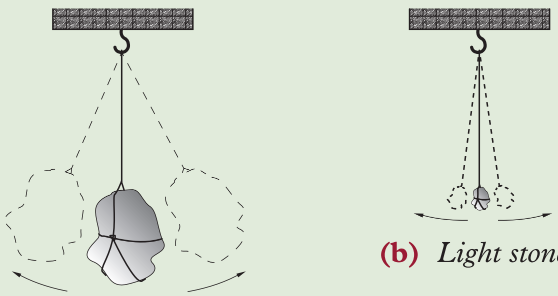
Activity 4.6 **To investigate the relationship between mass and inertia**

Materials

- String
- heavy stone
- hook
- light stone

Steps

1. Suspend the heavy stone using the strings as shown in Fig. 4.5.
2. Push the heavy stone towards one side. Release the stone to swing (Fig. 4.5. (a)) and then try to stop the stone from moving.
3. Repeat the activity with the light stone. (Fig.4.5 (b)).



(a) *Heavy stone* **(b)** *Light stone*

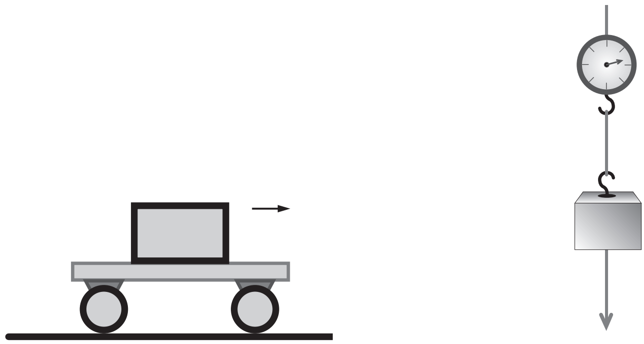
Fig. 4.5: Relationship between mass and inertia.

4. Which stone is easier to start moving and to stop moving? Suggest a reason for this.

The lighter stone in Activity 4.6 is easier to start moving and to stop moving. The heavier stone is more difficult to start or stop moving i.e, it requires a larger force to do so.

This activity shows that the mass of a body is a measure of its inertia. A body with a large mass has a greater inertia and vise versa.

If Activity 4.6 is repeated in a place where there is no gravitational pull e.g. interplanetary space, the same results are obtained. The mass of a body in this case is called inertial mass (Fig. 4.6(a)). When the mass of a body is pulled by the force of gravity the mass is called gravitational mass (Fig. 4.6 (b)).



(a) *Inertial mass* **(b)** *Gravitational force*

Fig. 4.6: Inertia and gravitational mass

Statement of Newton's first law of motion

Activities 4.2 to 4.5 shows that bodies tend to resist change to their states of motion i.e they exhibit inertia.

These observations were summarised by Sir Isaac Newton in his first law of motion, called the law of inertia. The law states that:

Newtons first law of motion

A body continues in its state of rest or uniform motion in a straight line unless compelled by some external force to act otherwise.

From this law we can define a force as that quantity which produces motion of a body at rest or that which alters its existing state of motion.

Exercise 4.1

1. Explain the term inertia.
2. State three practical applications of inertia law.
3. Explain the following experiences.
   (a) When one alights from a moving bus, he/she is more likely to fall unlike when alighting from a stationary one.
   (b) When a car suddenly stops, the passengers are jerked forward.
4. An umbrella kept upside down can be dried by rapidly closing and opening it. Explain.
5. Explain why safety belts are worn in cars.

6. An object of large mass is suspended by means of a string A from the ceiling. Another similar string, B, is attached to the bottom of the object. Explain which string would break when string B is pulled,

   (a) slowly

   (b) suddenly

7. Place a coin on a cardboard which is on a table as shown in Fig. 4.7. Move the cardboard backwards and forward several times, moving the cardboard very slowly in one direction and very quickly in the other. Explain your observation on the movement of the coin.

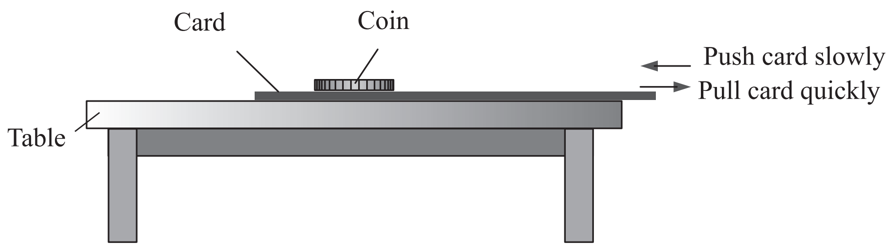


Fig. 4.7: A card being pulled on the table

8. Differentiate between inertial mass and gravitational mass.

4.2 Newton's second law of motion

As we already learnt in Unit 3 of this book, one of the effects of a force is that it changes the state of motion of an object i.e, it causes a body at rest to move or if moving, to accelerate (increase its speed) or decelerate (decrease in speed). We also learnt in that $a = \frac{v - u}{t}$ in Unit 2.

But what is the relationship between the net force (F) acting on the body,the acceleration (a) it produces on the object and the mass (m) of the object?

Activity 4.7 **To investigate the relationship between net forces (f), acceleration (a) and mass (m)**

Materials

- Footballs

Steps

1. Kick a football in two ways: In case one, kick it with a small force on a smooth path towards your partner. Fig 4.8.

2. In the second case, kick the same ball with a greater force on the same path. In which case does the ball gain a greater acceleration? Explain.

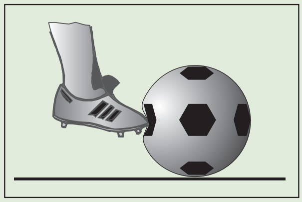


Fig 4.8: Kicking a ball at rest

3. Take two balls of different masses e.g 1 kg and 2 kg balls. Kick them each at a time on the same path with the same force. Which ball gains a greater acceleration?
4. Discuss the observations in steps 1, 2 and 3 and deduce a relationship between force, mass and acceleration of the ball.

Sir Isaac Newton made similar observations to those in Activity 4.7 and summarized them in what is now called Newton's second law of motion. It states that;

Newtons second law of motion

The acceleration (a) of an object is directly proportional to net (resultant) force(F) acting on it and inversely proportional to its mass; and the acceleration takes place in the direction of the resultant force.

$$F \propto \frac{m(\Delta s)}{t}.$$

This law is mathematically represented as follows;

$$a \propto \frac{F}{m}.$$

This means, $a = k\frac{F}{m}$ where k is a constant.

Experiments have shown that the value of k =1. Hence,

$$a = \frac{F}{m}.$$

By cross multiplication we get $\boxed{F = ma}$

If mass is 1 kg and acceleration is 1 m/s^2, then the force is 1 N. This is the definition of 1 newton i.e 1 newton is the force that will accelerate a mass of 1 kg at the rate of 1 m/s^2.

Thus, F = ma implies that:

(i) When the resultant force acting on a body is increased, the acceleration produced on the same body increases in the same proportion and vice versa (when the mass is constant).

(ii) The same resultant force produces a smaller acceleration on a body of a greater mass than when it acts on a body of a smaller mass.

Example 4.1

A truck of mass 2.5 tones accelerate at 7.5 m/s^2. Calculate the force generated by the truck's engine to attain this acceleration.

Solution

$F = ma = 2.5 \times 1\,000 \text{ kg} \times 7.5 \text{ m/s}^2$

$= 18\,750 \text{ N}$

Example 4.2

An object of mass 4 kg accelerates to 5 m/s^2. Calculate the resultant force.

Solution

$$F = ma$$
$$= 4 \text{ kg} \times 5 \text{ m/s}^2$$
$$= 20 \text{ N}$$

Example 4.3

Calculate the acceleration produced by a force of 20 N on an object of mass 300 kg.

Solution

$$a = \frac{F}{m} = \frac{20 \text{ N}}{300 \text{ kg}}$$

$$= 0.066\,7 \text{ m/s}^2$$

Example 4.4

A car of mass 900 kg is towed by a breakdown truck along a level road. The truck accelerates at 0.6 m/s^2. (Fig, 4.10). Calculate the tension in the rope.

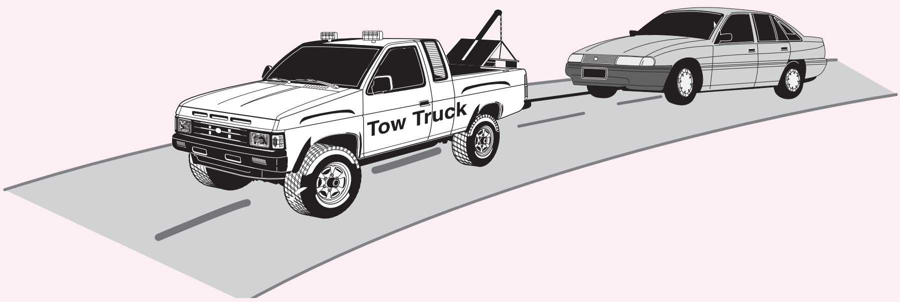


Fig. 4.10: Breakdown truck towing a car along a level road

Solution

Tension = resultant force using acceleration

Resultant force, F = ma

$= 900 \text{ kg} \times 0.6 \text{ m/s}^2$

$= 540 \text{ N}$

Tension = 540 N

Exercise 4.2

1. (a) State Newton's second law of motion.
   (b) Use Newton's second law of motion to derive to the equation F = ma.
   (c) Define the unit of force; 'the newton' using F = ma
2. A trolley is pulled by three elastic cords in parallel. The acceleration is found to be 15 m/s^2. The elastic cords are then arranged in series and pulled (Fig. 4.11). If the elastic cords are stretched by exactly the same amount of force, find the acceleration of the trolley assuming there are no frictional forces.

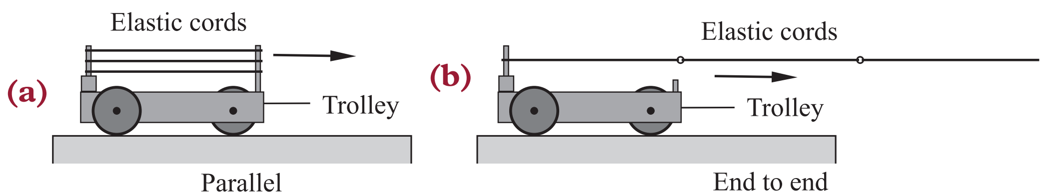


Fig. 4.11: Trolley being pulled by elastic cords

3. Find the force that is needed to make a mass of:
   (a) 6 kg to accelerate at 10 m/s^2,
   (b) 30 g to decelerate at 12 cm/s^2,
   (c) 8 kg to accelerate at 6 m/s^2.
4. Describe an experiment to investigate how the force applied on an object is related to the acceleration it produces. Draw a diagram that you would use, stating the observations expected and explaining how you would use these observations to obtain the relationship between force and acceleration.
5. Find the force that should be applied to an object of mass 8.0 kg to make it accelerate by 20 m/s^2.
6. A football of mass 500 g attains acceleration of 25 m/s^2. Find the average force exerted on the ball.
7. A force of 15 N makes a body of mass 3.0 kg to move. Calculate the average acceleration of the body.
8. A car of mass 800 kg moving with an acceleration of 20 m/s^2 crashes into a wall. Find the average force exerted by the car.

4.3 Newton's third law of motion

Activity 4.8 **To demonstrate reaction and action act in opposite directions**

Materials:

- Skating shoes
- Rigid wall

Steps

1. Put on the skating shoes and touch the brick wall with your hand (Fig. 4.12).
2. Push the wall. What happens?
3. Discuss with your partner your observations. Suggest a reason for what happened.

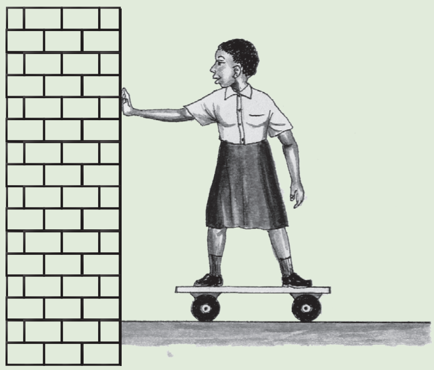


Fig. 4.12: Demonstration action and reaction

In your discussion, you must have noticed that when you push a rigid wall, you move in the opposite direction i.e the wall pushes you back. The force applied on the wall is called action force and the one applied back by the wall is called reaction force. Action and reaction force act in the opposite direction as shown in Activity 4.8.

Activity 4.9 **To demonstrate that action and reaction forces are equal and act in opposite direction**

Apparatus

- Two identical balance springs
- A rigid support

Steps

1. Hook one end of a spring balance A to a rigid support.
2. Pull the other end until the spring shows a reading (Fig. 4.13 (a)). Explain what the wall could be doing at the same?
3. Repeat the activity but use a second similar spring B instead of the wall (Fig. 4.13 (b)).

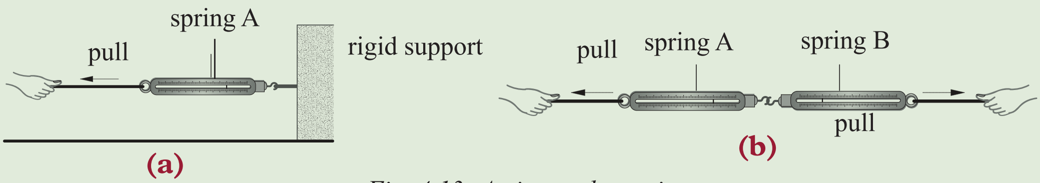


Fig. 4.13: Action and reaction

4. Pull the two springs until the reading on spring A is the same as before.
5. What reading is shown by spring B? Suggest a reason for this observation.

In Activity 4.9, you must have observed that the reading in spring B is the same as in spring A. The two forces are equal in size but are in opposite direction. This shows that when spring A is pulled to the wall, the wall also pulled the spring A with an equal and opposite force.

In Unit 3, we defined a force as a push or a pull. In reality when one body pulls or pushes a second body, the second body also pulls or pushes the first body respectively with the same force. The first body exerts a force called action force on the second body. The second body responds by exerting a force called reaction force on to the first body.

Other examples of action and reaction

1. A book placed on a table provides the action, while the table supports the book by providing a reaction force (Fig. 4.14).

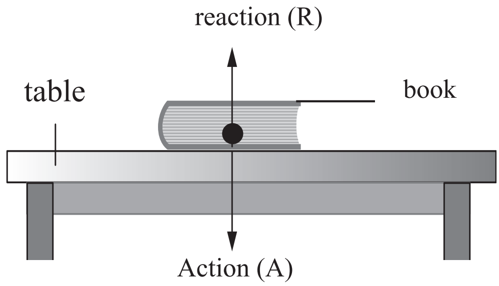


Fig. 4.14: A book resting on a table

2. Charged bodies show two equal but opposite forces (Fig. 4.15).

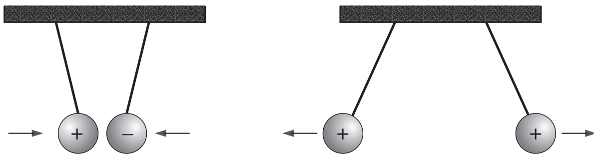


Fig. 4.15: Equal but opposite forces

3. Tug of war (Fig. 4.16).

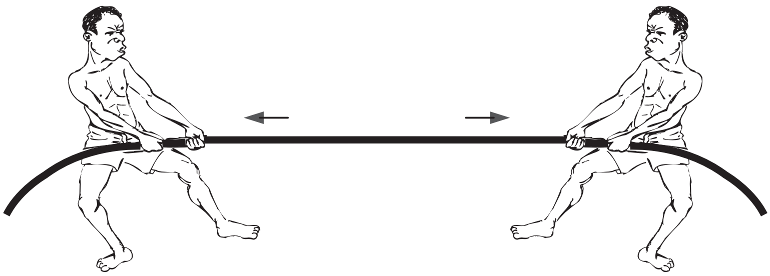


Fig. 4.16: Example of action and reaction

All these observations can be summarised by what is called **Newton's third law of motion.**

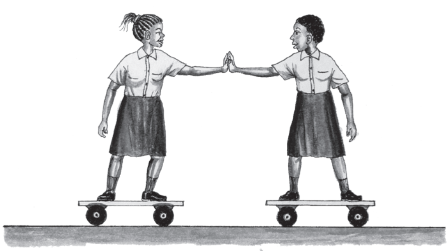
It states that *whenever a body exerts a force on another body, the other body exerts an equal but opposite force on the first body*.

This is sometimes stated as, *to every action there is an equal and opposite reaction*.

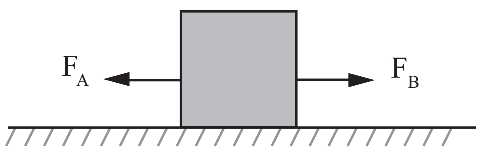
Note

The two forces, action and reaction, act on two different objects. For example in Fig. 4.14 the action force A acts on the table while the reaction force R acts on the book. Consequently, the two forces, although equal and opposite, do not cancel each other i.e. they do not produce a zero resultant force.

Consider two girls standing on trolleys and pushing each other (Fig. 4.17 (a)). The pushes cause both girls to move away in opposite directions. Compare this with two equal and opposite forces acting on the same body (Fig. 4.17 (b)). The two forces cancel each other and the body remains at the same place.



(a) Forces do not cancel each other



(b) Forces cancel each other

Fig. 4.17: Action and reaction forces

Some common experiences due to Newton's third law of motion

Activity 4.10 **To describe the applications of Newton's third law of motion**

Describe at least three other cases in real life where action and reaction are exhibited.

You should have identified some of the following:

1. When running or walking, a person exerts a backward force on the ground. The ground exerts a forward push on the person. This makes walking possible.
2. When a gun is fired, the bullet travels in one direction while the gun recoils backwards (Fig. 4.18). Although the two forces are equal and opposite, the bullet's velocity is greater than that of the gun.

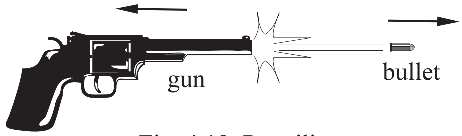


Fig. 4.18: Recoiling

3. A balloon will always move in the opposite direction when the air inside it is released. This is the principle that rockets and jet engines use. The force (action) of the air coming out exerts an equal and opposite force (reaction) on the balloon making it move.
4. The water sprinkler works on action and reaction principle (Fig. 4.19).

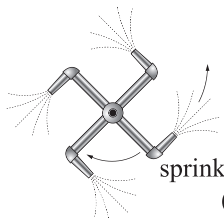


Fig. 4.19: Water sprinkler

The sprinkler rotates in the direction opposite to that of the water jet.

Exercise 4.3

1. For each of the following forces, describe the reaction, giving its direction and stating where it acts.
   (a) The push of a boot on a football.
   (b) The push (backwards) of a swimmer on water.
   (c) The pull of gravity on a mango resting on a table.

2. State Newton’s third law of motion. Explain how this law is applied in the propulsion of rockets.
3. Give an explanation to the following:
   (a) A gun recoils when it is fired.
   (b) A fireman moves backwards when a water hose he is aiming at a fire is suddenly turned on.
4. A mini bus accelerates uniformly from rest to 30 m/s in 10 s. Find
   (a) Acceleration.
   (b) Force the back of a passenger of mass 60 kg would exert on the seat.
5. Explain how garden a shown in sprinkler (Fig. 4.20) works.

4.4 Newton's Universal Law of Gravitation

A story is told that one day Isaac Newton was sitting under an apple tree, and an apple fell on his head. This led him to think hard and conclude that there must be a force of attraction that pulled the apple to the earth. He called this force gravity.

Activity 4.11 **To investigate the Newton's universal law of gravitation**

Materials

A small stone

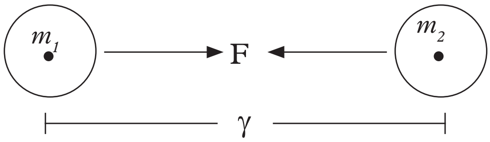
Steps

1. Throw the stone upwards and also observe what happens. Expain your observation.
2. Do a research from the internet and books on.
   (a) The Newtons's universal law of gravitation What does it state?
   (b) How are planets able to orbit one another
3. Throw the piece of wood horizontally and observe what happens to the piece of wood. Explain your observation.
4. Do research on why planets move around the sun from books and Internet.

Newton discovered that, the gravitational force of attraction was not limited to objects falling to the earth but it exist between any two objects in the universe and depends on the mass of the two objects and the separation distance between them. He summarised his observation in a law that is now referred to as Newton's Universal Law of Gravitation.

> The law states that any two bodies in the universe attract each other with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

Consider two bodies of masses m_1 and m_2 separated by a distance r as shown in Fig 4.21



(The separation distance r is from the centres of masses of the two objects)

Fig 4.21: Two bodies at a distance

According to Newton's universal law of gravitation, the force (F) of attraction between the two objects is given by

$$F \propto \frac{m_1 m_2}{r^2}$$

Hence, $F = \frac{Gm_1m_2}{r^2}$ where G is a constant called the universal gravitational constant.

Note that the constant G is the same everywhere in the universe.

We can obtain the units for G as follows:

$$F = \frac{Gm_1m_2}{r^2} \Rightarrow G = \frac{Fr^2}{m_1m_2} \Rightarrow \frac{Nm^2}{kg^2}$$

Alternatively we use m^3s^2/kg

The value of a constant, G is approximately equal to 6.673×10^{-11} Nm^2/kg^2

From the equation, $F = \frac{Gm_1m_2}{r^2}$, we obtain the other quantities as follow:

$$\text{Mass of object 1, } m_1 = \frac{Fr^2}{Gm_2}$$

$$\text{Mass of object 2, } m_2 = \frac{Fr^2}{Gm_1}$$

$$\text{Distance between two objects, } r = \sqrt{\frac{Gm_1m_2}{F}}$$

Example 4.5

Determine the force of gravitational attraction between a student of mass 60 kg and the earth if the student is standing on the earth surface a distance of 6.4×10^6 m from the centre of the earth.(mass of the earth = 5.98×10^{24} kg, $G = 6.67 \times 10^{-11}$ Nm²/kg²)

Solution

$m_1 = 60$ kg, $m_2 = 5.98 \times 10^{24}$ kg, $r = 6.4 \times 10^6$ m, $G = 6.67 \times 10^{-11}$ Nm²/kg²

$$F = \frac{Gm_1m_2}{r^2} = \frac{6.67 \times 10^{-11}\ \text{Nm}^2\text{kg}^{-2} \times (60\ \text{kg}) \times (5.98 \times 10^{24}\ \text{kg})}{(6.4 \times 10^6\text{m})^2}$$

$$= \frac{2393.196 \times 10^{-11} \times 10^{24}}{40.96 \times 10^{12}}\ \text{N}$$

$$= 58.4276 \times 10^{(-11+24-12)}\text{N} = 584.276\ \text{N}$$

Example 4.6

A communication satellite of mass 300 kg orbits (go round) the earth at a height 35 000 m. Given that mass of earth = 5.97×10^{24} kg, radius of earth = 6.4×10^6 m and $G = 6.67 \times 10^{-11}$ Nm²/kg², find

(a) how far the satellite is from the centre of the earth?

(b) the earth's force of attraction onto the satellite.

Solution

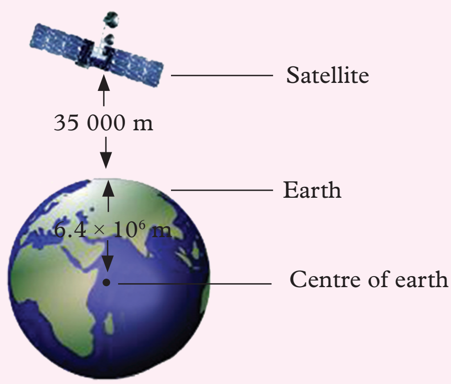


Fig 4.22: A communication satellite

(a) Distance of satellite from the centre of the earth = Radius of earth + Distance of the satellite from the surface of earth.

$= 35\ 000$ m $+ 6.4 \times 10^6$ m

$= 35\ 000$ m $+ 6\ 400\ 000$ m

$= 6\ 435\ 000$ m or 6.435×10^6 m

(b) To determine force of attraction between the earth and satellite

$m_1 = 5.97 \times 10^{24}$ kg, $m_2 = 300$ kg, $r = 6.435 \times 10^6$ m, $G = 6.67 \times 10^{-11} Nm^2/kg^2$

$$F = \frac{Gm_1m_2}{r^2} = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 3 \times 10^2}{(6.435 \times 10^6 \text{ m})^2} \text{N}$$

$$= \frac{119.459 \times 10^{15}}{41.409225 \times 10^{12}} = 288.48 \text{ N}$$

Example 4.7

Kampire is 28 kg and is standing 1.2 metres away from Mugisha. What is the mass of Mugisha if a gravitational force of attraction of 3.2×10^{-8} N is acting on each of them? (Assume $G = 6.67 \times 10^{-11}$ Nm^2/kg^2)

Solution

$m_1 = 28$ kg, $m_2 = ?$, $r = 1.2$ m, $F = 3.2 \times 10^{-8}$N, $G = 6.67 \times 10^{-11}$ Nm^2/kg^2

$$F = \frac{Gm_1m_2}{r^2} \Rightarrow m_2 = \frac{Fr^2}{Gm_1} = \frac{3.2 \times 10^{-8} \times (1.2)^2}{6.67 \times 10^{-11} \times 28} \text{ kg}$$

$$= \frac{4.608 \times 10^{-8}}{186.76 \times 10^{-11}} \text{ kg}$$

$$= 0.02467 \times 10^3 \text{ kg}$$

$$= 24.67 \text{ kg}$$

Example 4.8

What is the separation distance between a stone block of mass 20 kg and another one of mass 35 kg if a gravitational force of attraction of 3.6×10^{-9} N acts between them.

Solution

$m_1 = 20$ kg, $m_2 = 35$ kg, $r = ?$, $F = 3.6 \times 10^{-9}$ N, $G = 6.67 \times 10^{-11} Nm^2/kg^2$

$$F = \frac{Gm_1m_2}{r^2} \Rightarrow r = \sqrt{\frac{Gm_1m_2}{F}} = \sqrt{\frac{6.67 \times 10^{-11} \times 20 \times 35}{3.6 \times 10^{-9}}} \text{ m}$$

$$= \sqrt{\frac{4.669 \times 10^{-8}}{3.6 \times 10^{-9}}} \text{ m}$$

$$= \sqrt{12.96} \text{ m}$$

$$= 3.6 \text{ m}$$

Exercise 4.4

In this exercise use: Mass of the earth = 5.98×10^{24} kg, Radius of the earth = 6.4×10^{6} m, Mass of the sun = 1.989×10^{30} kg, Radius of the sun = 6.9858×10^{8} m, Distance from the sun to the earth = 1.496×10^{10} m, Mass of the moon = 7.348×10^{22} kg, Radius of the moon = 1.7374×10^{6} m, $G = 6.67 \times 10^{-11}$ Nm²/kg²

1. What is the gravitational force of attraction between the earth and a car of mass 1500 kg resting on the surface of the earth?
2. Determine the earth's force of gravitational attraction on a satellite of mass 500 kg orbiting the earth at a distance 40 000 km above the surface of the earth.
3. If the gravitational force of attraction of the earth on the moon is 2.14×10^{20} N, what is the distance of the moon from the earth?
4. A gravitational force of attraction of 4.4×10^{-10} N exists between a cow of mass 800 kg and a goat when both are 18 m apart. What is the mass of the goat.
5. What is the separation distance between a man of mass 85 kg and a woman of mass 95 kg if the gravitational force of attraction between them is 2.58×10^{-7} N.

Unit summary and new words

- Newton's first law of motion states that a body continues in its state of rest or uniform motion in a straight line unless compelled by some external forces to act otherwise.
- Newton's second law of motion states that the acceleration of an object is directly proportional to the net force acting on the object and inversely proportional to its mass and takes place in the direction of the force. This law is summarised as F = ma.
- Newton's third law of motion states that for every action , there is an equal and opposite reaction.
- Newton's law of universal gravitation states that any two bodies in the universe attract each other with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.
- This law is summarised as

$$F = \frac{Gm_1m_2}{r^2}$$

Where, F = the force of attraction between the two bodies.

r = the separation distance of the two bodies.

G = the universal gravitational constant equal to $6.673 \times 10^{-11} Nm^2/kg^2$.

m_1 and m_2 are the respective masses of the the two bodies.

Unit Test 4

In this unit test use: Mass of the earth = 5.98×10^{24} kg, Radius of the earth = 6.4×10^6 m, Mass of the sun = 1.989×10^{30} kg, Radius of the sun = 6.9858×10^8 m, Distance from the sun to the earth = 1.496×10^{10} m, Mass of the moon = 7.348×10^{22} kg, Radius of the moon = 1.7374×10^6 m, G = $6.67 \times 10^{-11} Nm^2/kg^2$.

1. **(a)** Explain why Newton's first law is also called the law of inertia.

   (b) Describe an experiment to illustrate the Newton's first law of motion.
2. Explain why a balloon with air moves immediately the air inside is released?
3. State Newton's universal law of gravitation.
4. Akaliza is 57 kg while Mazimpaka is 62 kg. The two are standing at a distance from each other in their class. If the gravitational force of attraction between them is 3.21×10^{-8} N, find their separation distance.
5. What is the gravitational force of attraction between the;

   (a) Sun and the earth.

   (b) Earth and the moon.
6. The gravitational force between two objects of equal mass when they are 15 m apart is 1.94×10^{-8}N. What is the mass of each object.
7. Two wardrobes of masses 1.6×10^2 kg and 2.3×10^2 kg exert an attraction force of 3.4×10^{-6} N between them. What is the distance separating them?
8. What is your mass? What is the earth's gravitational force of attraction on you when you are standing on the ground?

UNIT 5 Centre of Gravity

Key Unit Competence

By the end of this unit, I should be able to determine the position of centre of gravity of a body.

Unit outline

- Definition of centre of gravity and centre of mass.
- Determination of centre of gravity of regular and irregular objects.
- Effects of the position of centre of gravity on stability of objects.

Introduction

In our day to day experiences, we may have come across statements such as "that object is not stable on the table" or "that overloaded *bus* is not stable on the road". Have you ever asked yourself what factors control the stability of an object? In this unit, we will study one of those factors.

Activity 5.1 To locate the centre of gravity of a book

Materials: Exercise book

Steps

1. Take your exercise book and try to balance it horizontally on your finger as shown in Fig 5.1.

Fig. 5.1: Balancing a book

(a) What do you observe?
(b) Why do you think the book balances at only one point?
(c) What do you think is special about the point where the book balances?
2. Discuss with your colleagues your observations and thoughts in 1(a),(b) and (c).

By going through the following discussions, you will be able to answer questions 1(a) to (c) in Activity 5.1.

5.1 Centre of gravity and centre of mass of a body

In one of his experiments, Sir Isaac Newton showed that bodies experience a force of gravity exerted on them by the earth. This force of gravity is always directed towards the earth's centre and is called the *weight of the body*. How is this weight distributed throughout the body? The answer to this question is found in the following activity.

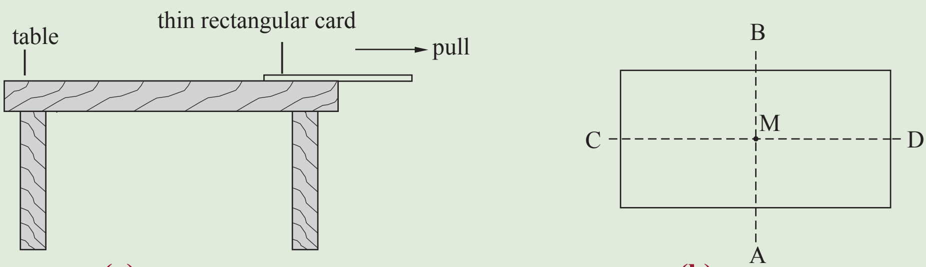
To investigate where the weight of a body acts from

Activity 5.2 To find the centre of gravity of a regular body

Materials: A table, thin rectangular card

Steps

1. Place a thin rectangular cardboard near the edge of the bench top.
2. Pull the card slowly away from the bench until it is just about to topple over then released as shown in Fig. 5.2 (a).
3. Using a ruler, mark and draw the line AB along which the card balances.
4. Repeat the activity with the other side of the card, mark and draw the line CD along which the card balances. The lines AB and CD intersect at a point M (Fig. 5.2(b)).



(a) (b)

Fig. 5.2: Location of a point where the weight of the body acts

4. Now, try to balance the card with the point M placed at the tip of your fore finger. What do you notice. Suggest reason for this observation.

From Activity 5.2 you should have observed that the cardboard balances horizontally at point M only. This shows that although the mass of the cardboard is distributed over the whole body, there is a particular point, M, where the whole weight of the cardboard appears to be concentrated. When pivoted at this point the cardboard balances horizontally. This point, M, is called *centre of gravity* of the cardboard.

The centre of gravity of a body is the point from which the whole weight of the body appears to act.

The centre of gravity of an object is constant i.e. at the one location when a body in a place with uniform gravitational field strength.

However, the centre of gravity of a body moves to a different location when the body is placed in a region with non uniform gravitational field strength.

Centre of mass of an object on the other hand is the point where all the mass of the object is concentrated.

Since the mass of an object is constant and is not affected by pull of gravity, the location of the centre of mass of an object is constant i.e. does not change.

In places like on earth where the gravitational field strength is uniform, the centre of mass and the centre of gravity coincide i.e. are at the same point.

However, the two centres are at different locations for the same object if the object is placed in a place with non-uniform gravitational field strength.

5.2 Centre of gravity (c.o.g) of regular lamina

Activity 5.3 **To locate the centre of gravity of a regular lamina**

Materials: manila paper, ruler, pencil

Steps

1. Discuss what a lamina is.
2. Using your geometrical instruments, draw and cut from a manila paper pieces that are exactly rectangular, square, circular and isosceles triangle.
3. Practically locate their centres of gravities by drawing.
4. Balance them at their centres of gravity on the tip of your pencil.

In your discussion, you should have learnt that a *lamina* is a body whose thickness is very small compared with the other dimensions of the body. A thin cardboard like the one used Activity 5.2 is a lamina. The cover of a book is a lamina. The set square or protractor in your mathematical set are all examples of laminae.

Experiments have shown that bodies with *uniform cross section area* and *density* have their centres of gravity located at their *geometrical centres.* For example, a metre rule of uniform cross-sectional area and density has its centre of gravity located at the 50 cm mark.

Fig. 5.3(a) - (d) shows the centre of gravity (c.o.g) of rectangular, square, triangular, and circular laminae.

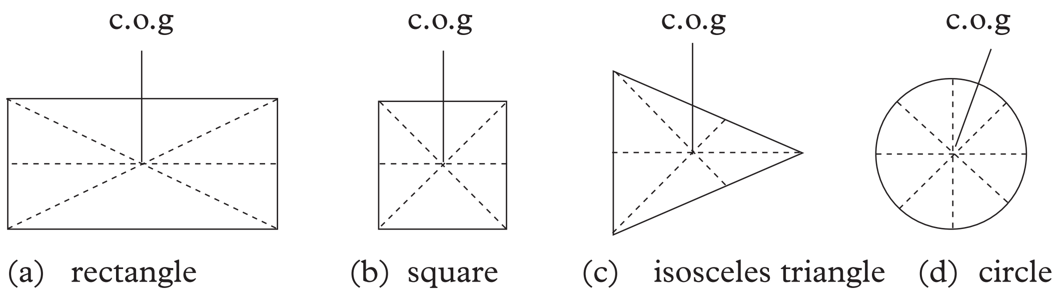


Fig. 5.3: c.o.g. of regular lamina

5.3 Centre of gravity (c.o.g) of irregular lamina

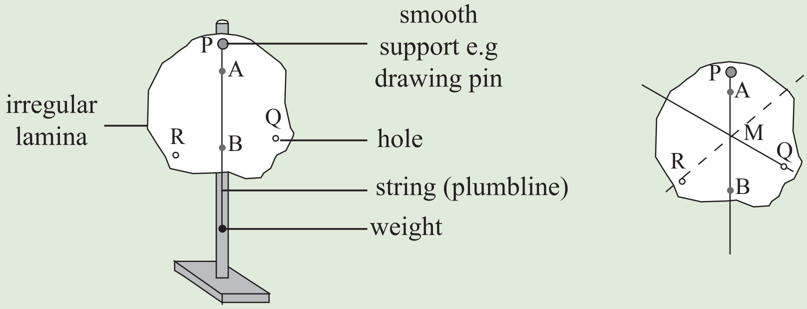
Activity 5.4 **To determine the centre of mass of an irregular lamina using a plumbline**

Materials: An irregular lamina, plumbline, a drawing pin

Steps

1. Make three holes P, Q and R on an irregularly shaped lamina as close as possible to the edges and far away from each other. The holes should be large enough to allow the lamina turn freely when supported through a drawing pin.
2. Suspend the lamina on the clamp using the drawing pin through each hole at a time.
3. Suspend a plumbline (a thin thread with a small weight at one end) from the point of support, P as shown in Fig. 5.4(a), and draw the line of the plumbline on the lamina by marking two points A and B far apart and joining them.
4. Repeat the steps with the support Q and mark the point M where the two lines intersect.

5. Check the accuracy of your method by suspending the lamina at R. What do you observe? Explain.



(a) **(b)**

Fig. 5.4: Locating centre of mass of a lamina using a plumbline

The plumbline pass through M (Fig. 5.4 (b)). Check the results again by balancing the lamina about point M. What do you observe?

The lamina balances horizontally at point M. Point M is the centre of gravity of the lamina.

This activity proves that *when a body is freely suspended it rests with its centre of gravity vertically below the point of suspension.*

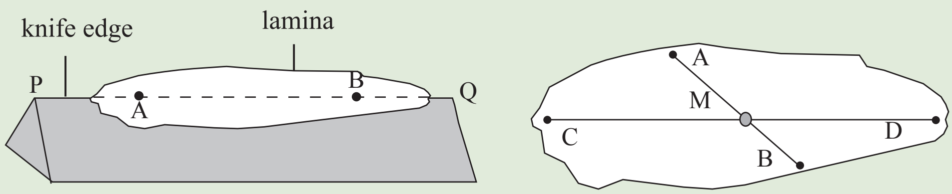
Activity 5.5 To demonstrate how to locate the centre of gravity of an irregular object using a straight edge

(Work in groups)

Materials: An irregular lamina, a prism

Steps

1. Balance a lamina on the edge PQ of a prism as shown in Fig. 5.5(a). Mark the points A and B on the lamina and join them.
2. Repeat the activity for another position and note the points C and D on the lamina. Join C and D.



(a) **(b)**

Fig. 5.5: Locating the centre of mass of a lamina using a straight edge

3. Label the point of intersection of lines AB and CD as point M.
4. Try balancing the lamina at point M on a sharp pointed support. What do you observe? Explain.

From Activiy 5.5, you should have observed that the lines AB and CD intersect at M; the centre of gravity of the lamina.

5.4 Effect of position of centre of gravity on the state of equilibrium of a body

Activity 5.6 **To define and describe three states of equilibrium**

Materials: Internet, reference books

Steps

1. Conduct a research from books and the internet on the meaning of equilibrium in regard to forces acting on an object.
2. Identify the three states of equilibrium an object can be in.
3. Describe each of the three states of equilibrium.

In your discussion, you should have noted that, the state of balance of a body is referred to as the *stability* of the body. Some bodies are in a more stable (balanced) state than others. The state of balance of a body is also called its *state of equilibrium*. Activities 5.7, 5.8 and 5.9 will help us distinguish between the different states of equilibrium.

Activity 5.7 **To investigate the relationship between the position of c.o.g and stability of an object**

Materials: plastic thistle funnel, bench

Steps

1. Place the funnel upright with the wider mouth resting on the bench (Fig 5.6).
2. Displace the funnel slightly upwards as shown in Fig 5.6 (b) and then release it. What do you observe?

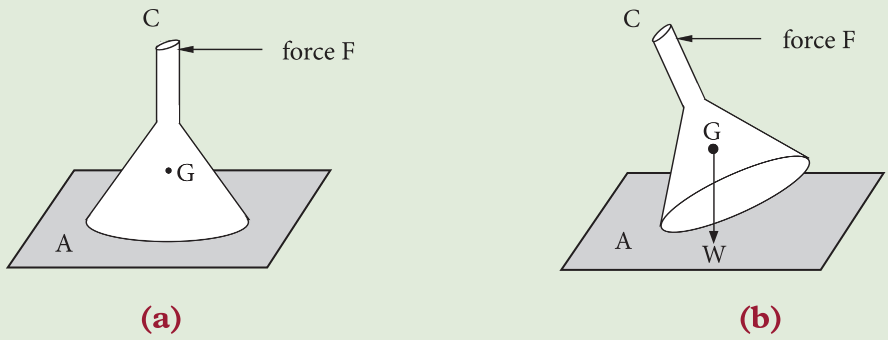


Fig 5.6: To show stable state

3. Explain the behaviour of the funnel in terms of the changes in the position of centre of gravity.

When a body is resting with its centre of gravity at the lowest point, it is very stable. When displaced slightly; its centre of gravity is raised and when it is released, the object falls back to it original position to keep its centre of gravity as low as possible. This type of equilibrium is known as stable equilibrium. Thus, the funnel in Activity 5.7 Fig. 5.6 (a) was in stable equilibrium.

Activity 5.8 To demonstrate unstable equilibrium

Materials: Plastic thistle funnel, bench

Steps

1. Place the funnel upright with the narrower mouth resting on the bench as shown in Fig 5.7 (a).
2. Displace the funnel slightly with your finger. What do you notice?

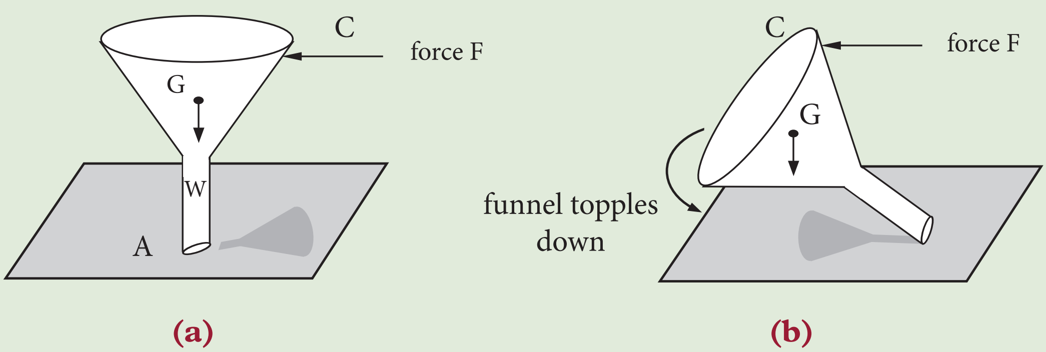


Fig 5.7: To show unstable state

3. Explain the behaviour of the funnel in terms of the change in position of its centre of gravity in this activity.

Our finances!!

Note that we have used a plastic thistle funnel instead of a glass one. The latter has high chances of breakings.

Any time we break a laboratory apparatus, we think of its effects on the school finances as it has to be replaced. Sometimes we may be required to pay ourselves hence affect the finances of our parents.

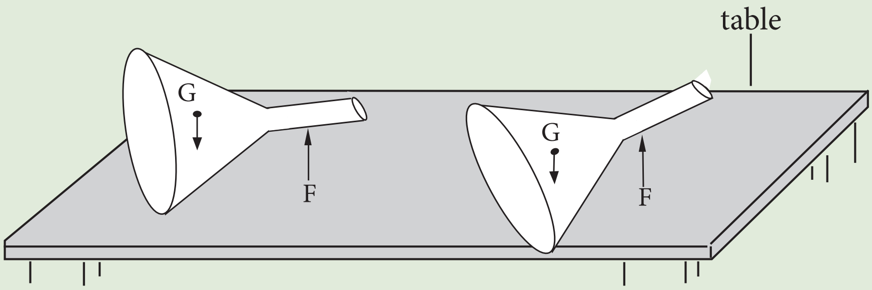
When an object is resting with its centre of gravity at a very high position from the base support, it is unstable. When displaced slightly, it continues to fall up to the lowest possible position in order to lower its centre of gravity. This state of stability is known as unstable equilibrium. The funnel in Fig 5. 7(a) Activity 5.8 was in unstable equilibrium.

Activity 5.9 To demonstrate neutral equilibrium

Materials: Plastic thistle funnel, bench

Steps

1. Place the funnel horizontally as shown in Fig 5.8 (a).
2. Displace the funnel gently by tapping it with a finger. What do you observe?



(a) **(b)**

Fig. 5.8: To show neutral state

3. Explain the behaviour of the funnel in terms of the change in position of the centre of gravity when displaced slightly.

When an object is resting such that the position of its centre of gravity remains at the same vertical position even when the object is displaces, it is said to be in neutral equilibrium. The funnel in Fig 5.8 (a) in Activity 5.9 was in neutral equilibrium.

Activity 5.10 **To investigate the relationship between position of centre of gravity of a body and its stability**

Material: playing ground

1. Assume that he/she is a bus (preferably the lighter student) and the other to be heavy goods to be transported (preferably the heavy one).
2. Let the bus carry the heavy goods on his/her shoulders from one end of the playing ground to another. Observe what happens.
3. Let the disabled students (if any in the class) observe the stability of your movement in step 2 and record down the observations.
4. Now, let the other student (the heavy good) be the bus and repeat step 2. Observe and explain what happens.
5. Discuss and compare observations made in steps 2 and 4 with you partner and report to the whole class.

Caution: Be careful you may fall down when carrying your partner and cause injury to yourself or your partner.

From your discussion, you should have noted that when the lighter student was carrying the heavier one, they were unstable, hence they tended to or fell down at some point. However, when they interchanged and the heavier one was carrying the lighter one, they walked confortable because they were stable.

Therefore, a body is more stable when its heavy part is as low as possible since it lowers the position of the centre of gravity. If the heavy part of the body is at high position or if the light part of the body in high position is made heavier than the lower position, the body becomes unstable and thus likely to topple over and can cause accident like in the case of a vehicle carrying heavy luggage at its roof top.

Exercise 5.1

1. Identify the centre of gravity of each of the following figures.

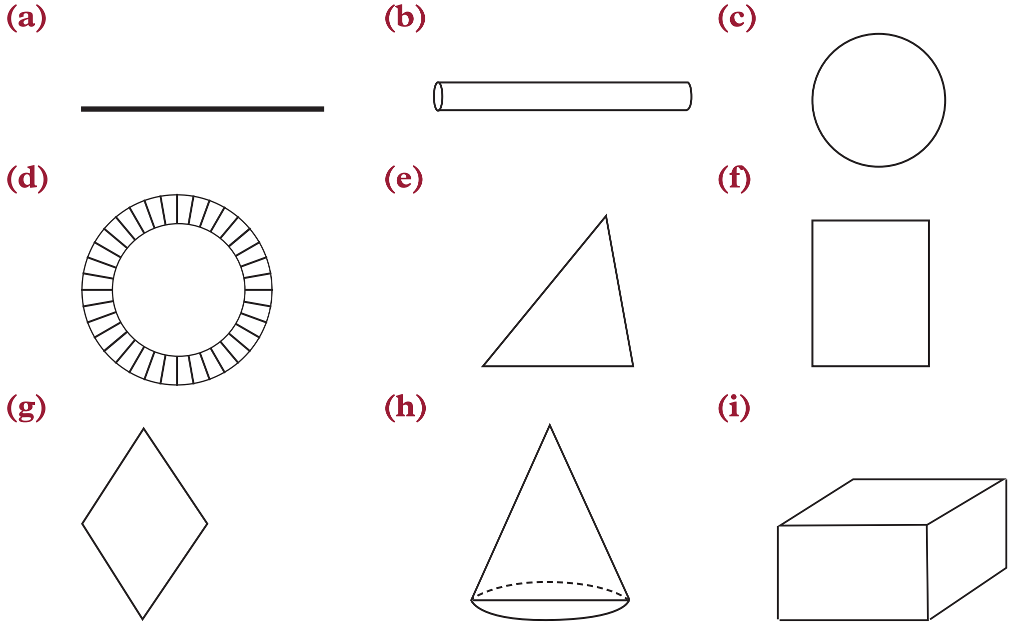


Fig 5.9: Various types of figures

2. Fig 5.10 shows a Bunsen burner at different states of equilibrium.

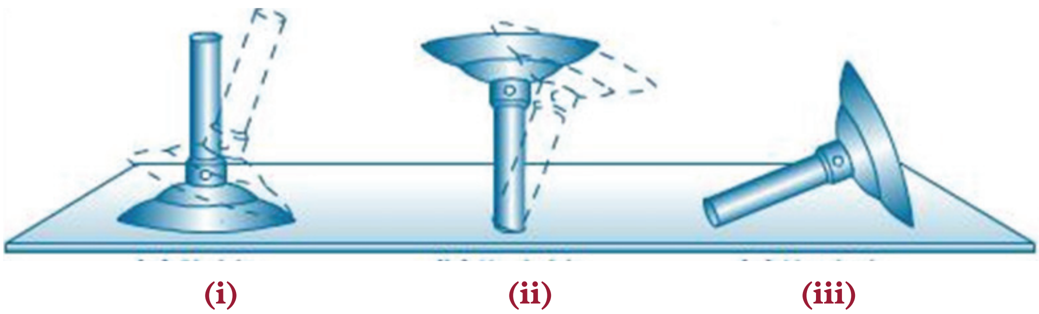


Fig 5.10: Bunsen burner at different states of equilibrium

   (a) Name the states in which the Bunsen burner is at in (i), (ii) and (iii).

   (b) Describe each state named in (a) above.

3. With aid of a diagram, describe how you can determine the centre of gravity of an irregular plane sheet of metal.

4. State and explain the states of equilibrium in Fig 5.11.

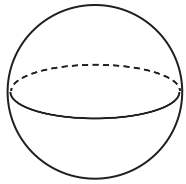


Fig 5.11: A sphere

5.5 Factors affecting the stability of a body

Activity 5.11 **To investigate factors that affect the stability of a body**

Steps

1. Repeat Activities 5.7 and 5.8.
2. Compare the observations in two activities and deduce one factor that affects stability of the funnel.
3. Now, repeat Activity 5.9. What happens to the funnel when the vertical line through the centre of gravity falls outside the base of the funnel? Deduce one factor that affect stability of the funnel in step 1.
4. Compare the observations in Activities 5.8 and 5.9 and deduce another factor that affects stability of the funnel.

Activities 5.7 and 5.8 show that the funnel is more stable when its c.o.g is at a very low position and vice varsa. In addition, the activities show that the wider the base the more stabke a body is.

Activity 5.7 further shows that the funnel becomes unstable when the vertical line drawn through the centre of gravity falls outside the base that supports the body.

In summary, a body is more stable if:
1. the centre of gravity is as low as possible.
2. the area of the base is as large as possible, and
3. the vertical line drawn from the centre of gravity falls within its base.

5.6 Some applications of the position of centre of gravity

Activity 5.12 **To describe the applications of the position centre of gravity**

Materials: reference books, Internet

Steps

1. Conduct a research from Internet and reference books on the applications of position of centre of gravity.
2. In your research also find out:
   (a) Why a bird toy is balances on its beak.
   (b) Why it is not advisable to stand on a small boat on the surface of the water.
   (c) Why one leans to the opposite direction when carrying a load.
   (d) Why the bus chasis is made heavier than the other parts of the bus.
   (e) How a tight-rope walker balances himself/herself.
3. What do o you have the same explanations?
4. Have a class presentation on your findings from your research.

In your research and discussion, you should have learnt the following:

1. The balancing bird is a toy that has its centre of gravity located at the tip of the beak. The bird balances with the its beak resting on one finger or any other support placed underneath the beak, and the rest of the body in the air. This is because it is designed with its centre of gravity at that point (Fig 5.12).

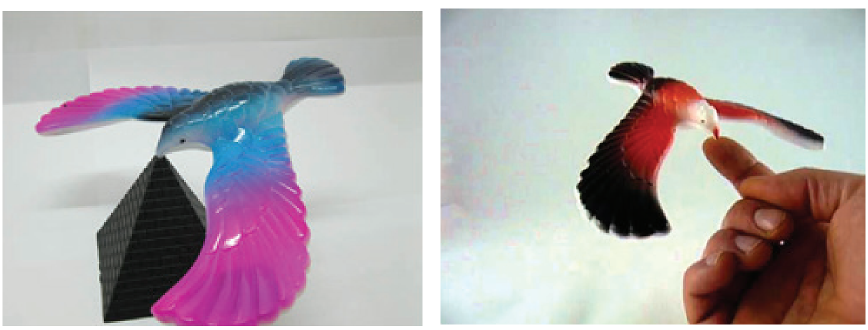


Fig. 5.12: Balancing bird toy

2. People in a small boat are advised neither to stand up nor lean over the sides

while in the boat. This is because when they stand, they rasie the position of the centre of gravity making the boat unsatble and more likely to tip over (See Fig 5.13).

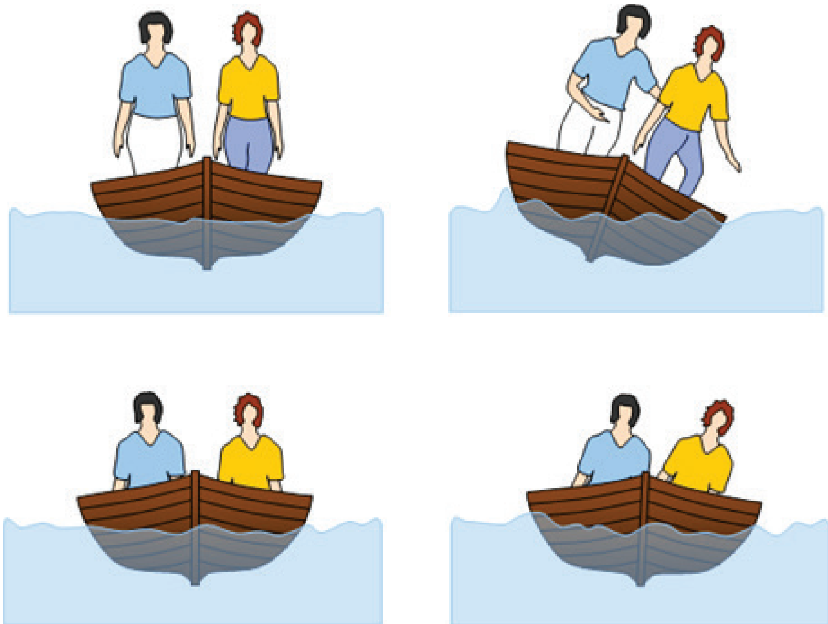


Fig. 5.13: People in a boat

3. A person normally lean to the opposite direction when carrying heavy loads with one hand e.g. a bucket full water. This helps to maintain the position of the c.o.g to within the base of the person inorder to maintain stability (See Fig 5.14)

Fig. 5.14: Leaning while carrying heavy load

4. Most buses have their cargo in compartment in the basement instead of the roof rack in order to keep the centre of gravity of the buses as low as possible (Fig. 5.15).

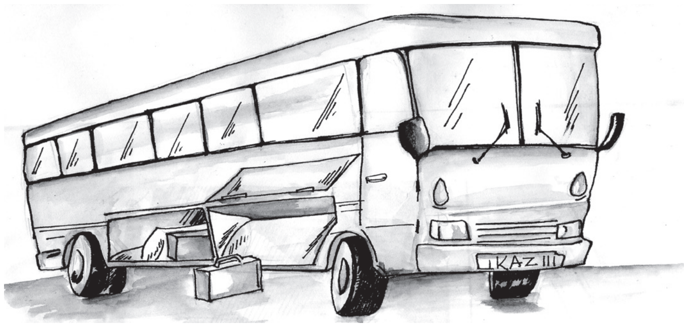


Fig. 5.15: Buses carry their cargo below passengers' level.

5. A tight-rope walker carries a pole to maintain stability. By swaying from side to side, he/she ensures that the vertical line drawn from his/her centre of gravity falls within the feet on the rope in order to maintain stability. (Fig. 5.16).

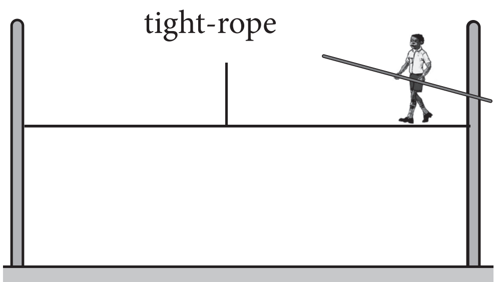


Fig. 5.16: A tight-rope walker carries a pole to maintain balance.

Unit summary and new words

- The centre of gravity, c.o. g, of a body is the point where the whole weight of the body appears to act from.
- Centre of mass of an objects is the point where all the mass of the object is concentrated.
- The centre of gravity of a regular lamina or object is at its geometric centre.
- The centre of gravity of a lamina can be found using a plumbline or by balancing it on a knife edge.
- A body is said to be in stable equilibrium if it returns to its original position after being displaced slightly.
- A body is in unstable equilibrium if on being slightly displaced, it does not return to its original position.
- A body is said to be in neutral equilibrium it moves to a new position but maintains the position of the c.o.g above its base support.
- Bodies can be made more stable if their centres of gravity are made as low as possible and the bases are made as broad as possible.

Unit Test 5

1. Define the term centre of gravity?
2. Differentiate between centre of mass and centre of gravity.
3. Redraw the figures shown in Fig 5.17 and indicate their centres of gravity.

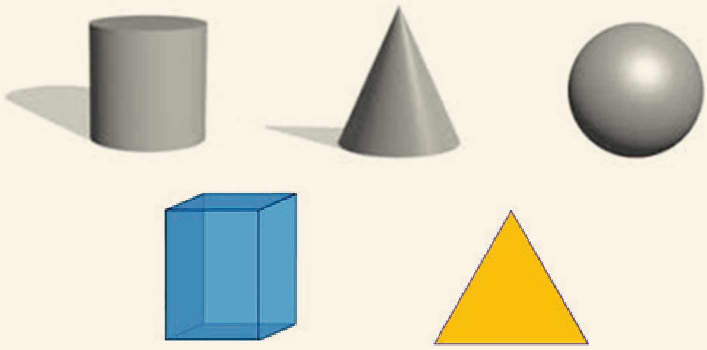


Fig. 5.17: Solids

4. Describe how you can determine the centre of gravity of the lamina shown in Fig 5.18.

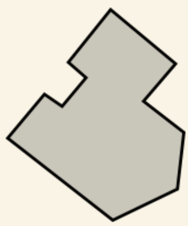


Fig. 5.18 Irregular shape

5. Fig. 5.19 shows a marble in three types of equilibrium. State and explain the type of equilibrium in each case.

Fig. 5.19: Marble in three state of equilibrium

6. What is stability?
7. One vehicle which was travelling from Kigali to Butare was seen carrying heavy goods on its roof top and some of its passengers in the vehicle were standing. Discuss why the vehicle is likely to topple if it negotiates a corner at high speed.

8. Explain why a three-legged stool design is less stable than a four legged one.
9. Explain the following:
   (a) The passenger of a double-decker bus are not allowed to stand on the upper deck.
   (b) A racing car is made of a heavy chasis in its lower parts.
   (c) When one is alighting from a moving vehicle, it is advisable to spread out his/her legs.

My safety

Do not stand in a moving vehicle. Let us observe traffic rules.

UNIT 6 Work, Energy and Power (I)

Key Unit Competence

By the end of the unit, I should be able to analyse the process of energy transformations and conservation.

Unit outline

- Forms of energy.
- Transformation of kinetic energy to potential energy and vice verse.
- Sources of energy.
- Different ways to conserve energy.
- Law of conservation of mechanical energy.

Introduction

Everyday, we do many types of work. We work in the offices, in the farms, in the factories etc. To make our work easier, we use machines ranging from simple tools to sophisticated machinery. Different machines or people do work at different rates (known as power). The ability and the rate of doing certain amount of work depends on how much energy is used. In this unit, we will seek to understand these three terms i.e work, energy and power from the science point of view.

6.1 Work

Activity 6.1 **Distinguish cases when work in science is done or not**

Materials: a chart showing people carrying out different activities, pieces of chalk, pen, chair, desk.

Steps

1. Conduct a research from books on the scientific definition of work.
2. Walk from your desk to the chalkboard and write the word 'work' on the chalkboard.
3. Collect any litter in your classroom.

Be responsible

Always keep where you live clean. It is good for your health.

4. Carry your chair to the front of you classroom and sit on it.
5. Push a rigid wall of your classroom.
6. Discuss with your colleagues whether scientifically speaking work, is done in steps 1, 2, 3 and 4. What do think is the meaning of 'work' ?
7. Now, look at the activities being performed by the people in Fig. 6.1.

(a)

(b)

(c)

(d)

Fig. 6.1: People performing different tasks

According to the scientific definition of work, in which of the diagrams is the person doing work? Explain.

From your research and discussion, you should have established in science, work is only said to have been done when an applied force moves the object through some distance in the direction of force. Therefore in Activity 6.1, work was done in steps 2, 3 and part of 4 (when carrying the desk). However, no work was done when you sat on you chair without moving in step 4 and pushing the wall without moving it in step 5.

Similary, in Fig 6.1, work is being done in (a) and (d) only. When the girl applies a force to a wall in (b) and even becomes exhausted, she is not doing any work because the wall is not displaced. When the woman carries the basket on the head, she is not doing any work. This is because she exerts an upward force on the basket which is balanced by the weight hence there is no motion of the basket in the direction of the applied force.

Definition of work

Work is defined as the product of force and distance moved in the direction of the force. i.e

Work = force × distance moved in the direction of the force

$$W = F \times d$$

The SI unit of work is joule.

Where 1 joule =1 newton × 1 metre

A joule is the work done when a force of 1 newton moves a body through a distance of 1 metre.

Bigger units used are kilojoules (1 kJ) = 1 000 J

Megajoule (1 MJ) = 1 000 000 J

Note: Whenever work is done, energy is transferred.

Example 6.1

Find the work done in lifting a mass of 2 kg vertically upwards through 10 m. ($g = 10\ m/s^2$)

Solution

To lift the mass upwards against gravity, a force equal to its own weight is exerted.

Applied force = weight = mg = 2kg × 10N/kg = 20 N

Work done = F × d = 20 N × 10 m

= 200 Nm

= 200 J

Work done in pulling an object along a horizontal surface

Activity 6.2 **To determine the work done in pulling an object along a horizontal surface**

Materials: a block of wood, a spring balance, and a tape measure/metre ruler.

1. Place the block of wood on a smooth horizontal surface.
2. Attach the spring balance on the block and pull it slowly. What do you observe?
3. Record the force needed to pull the block of wood.
4. Measure the distance through which the block of wood has moved from the beginning to the end (d) in metres using a tape measure/metre ruler.
5. Calculate the work done in pulling the block. What assumption did you make? Explain.

While doing the activity, you should have observed that when the block of wood was being pulled, the spring balance registered the force applied. Since the block was on a smooth surface, we assume that friction force is negligible hence the force applied is constant along the distance of motion, *d*.

Work done in moving the block is given by:

Work = force × distance

Example 6.2

A horizontal pulling force of 60 N is applied through a spring to a block on a frictionless table, causing the block to move by a distance of 3 m in the direction of the force. Find the work done by the force.

Solution

The work done = F × d = 60 N × 3 m

= 180 Nm

= 180 J

Example 6.3

A horizontal force of 75 N is applied on a body on a frictionless surface. The body moves a horizontal distance of 9.6 m. Calculate the work done on the body.

Work = force × distance

= 75 N × 9.6 m

= 75 × 9.6 Nm

= 720 J

Exercise 6.1

1. Explain why in trying to push a rigid wall, a person is said to be doing no work.
2. Define the term work and state its SI unit.
3. How much work is required to lift a 2 kilogram mass to a height of 10 metres (Take g=10 m/s^2).
4. A garden tractor drags a plow with a force 500 N a distance of 2 metres in 20 seconds. How much work is done?

6.2 Power

Activity 6.3 To compare the time taken to do a piece of work by a person and a machine

Materials: writing material, stopwatch and scientific calculator.

Steps

1. By timing yourself, start solving the following problems without using calculator:

   (a)376998 J × 276 J

   (b)35264 J × 469 J
2. Repeat step 1, but now with a scientific calculator and compare the time taken. Which one takes longer or shorter time to complete the task?
3. Now, think of a tractor and a man ploughing two square pieces of land that measure 100 m by 100 m each. Which one do you think takes longer or shorter time to complete the activity? Suggest a reason.
4. Discuss observations made in steps 2 and 3 with your colleagues. Tell your group members what power is.

In your discussion, you must have noted that sometimes work is done very quickly and sometimes very slowly. For instance, it takes a longer time to multiply the problems without a calculator in step 1 than with a calculator in step 2. Similarly, in step 3, a tractor will take few hours ploughing a piece of land while a man will take more hours ploughing the same piece of land. The person and the tractor are doing the same work but the tractor is doing it at a faster rate than the person does. This is because they have different power ratings.

Different machines and engines have different power ratings. Engines with bigger power ratings are said to be powerful and operate very fast.

Definition of power

Power is the rate of doing work. i.e.

$$\text{Power} = \frac{\text{work done}}{\text{time taken}} = \frac{\text{force} \times \text{distance}}{\text{time}}$$

SI units of power are Watts.

$$1\text{watt} = 1\ \frac{\text{joule}}{\text{second}}$$

Large units used are kilowatt and megawatt.

$$1\text{kilowatt} = 1\ 000\ \text{W}$$

$$1\text{megawatt} = 1\ 000\ 000\ \text{W}$$

Example 6.4

What power is expended by a boy who lifts a 300 N block through 10 m in 10 s ?

Given data;

Force = 300 N, Distance = 10 m, Time = 10 s

$$\text{Work done by the boy} = F \times d = 300 \times 10 = 3000\ \text{J}$$

$$\text{Power} = \frac{\text{work}}{\text{time}} = \frac{3000\ \text{J}}{10\ \text{s}}$$

$$= 300\ \text{W}$$

To estimating the power of an individual climbing a flight of stairs

Activity 6.4 **To estimate the power of an individual climbing a flight of stairs**

Materials: stopwatch, weighing machine, tape measure

Steps

1. Find a set of stairs that you can safely walk and run up.

2. Count their number, measure the vertical height of each stair and then find the total height of the stairs in metres.
3. Let one member weigh himself/herself on a weighing machine and record the weight down.
4. Let him/her walk then run up the stairs. Using a stopwatch, record the time taken in seconds to walk and run up the stairs (Fig 6.2).

Fig. 6.2: Measuring one's own power output

5. Calculate the work done in walking and running up the stairs. Let each group member do the activity. Is the work done by different members in walking and running up the stairs same? Discuss.
6. Calculate the power developed by each individual in walking and running up the stairs. Which one required more power, walking or running up the flight of stairs? Why?

Note:

(i) The disabled should be the ones to time others. Care must be taken on the stairs.

(ii) Incase of lack of stairs, learners can perform other activities like lifting measured weights.

From your discussion, you should have established that:

Height moved up (h) = Number of steps (n) × height of one step (x)

$$h = n \times x$$
$$= n\,x$$

Time taken to move height $(h) = t$

$$P = \frac{\text{Work done against gravity}}{\text{time}} = \frac{mgh}{t} = \frac{w \times h}{t}$$

$$= \frac{w \times n \times x}{t}$$

$$P = \frac{wnx}{t}$$

If x is in metres, w in newtons and t in seconds then power is in **watts**.

Example 6.5.

A girl whose mass is 60 kg can run up a flight of 35 steps each of 10 cm high in 4 seconds. Find the power of the girl. (Take $g = 10\ \text{m/s}^2$).

Force overcome (weight) = mg

= 60 × 10

= 600 N

Total distance = 10 × 35 = 350 cm = 3.5 m

Work done by the girl = F × d = 600 × 3.5

= 2100 J

$$\text{Power} = \frac{\text{work}}{\text{time}} = \frac{2100\ \text{J}}{4\ \text{s}}$$

The power of the girl is 525 W

My health

Do you know that regular exercises are good for your health.

Exercise 6.2

1. A machine is able to do 30 joules of work in 6.0 seconds. What is the power developed by the machine?
2. Mitaako is 42 kg. She takes 10 seconds to run up two flights of stairs to a landing, a total of 5.0 metres vertically above her starting point. What power does the girl develop during her run?
3. Student A lifts a 50 newton box from the floor to a height of 0.40 metres in 2.0 seconds. Student B lifts a 40 newton box from the floor to a height of 0.50 metres in 1.0 second. Which student has more power than the other?
4. Four machines do the amounts of work listed in Table 6.1 shown. The time they take to do the work is also listed. Which machine develops the most power?

Machine	Work	Time
A	1 000 joules	5 sec
B	1 000 joules	10 sec
C	2 000 joules	5 sec
D	2 000 joules	10 sec

Table 6.1

6.3 Energy

Activity 6.5 **To brainstorm about energy**

Steps

1. What enables your body to perform various functions besides keeping warm.
2. From your knowledge of science in primary school, define the term energy.
3. Discuss the importance of energy in our daily lives.

Energy is one of the most fundamental requirements of our universe. It moves motorcycles, cars along roads, airplanes through air, and boats over water. It warms and lights our homes, makes our bodies grow and allows our minds to think. A person is able to push a wheelbarrow, a stretched catapult when released is able to make a stone in it move, wind mills are turned by a strong wind and cooking using electricity in a cooker. All these are possible because of energy.

Therefore, for any work to be done, energy must be provided. But what is energy?

Definition of energy

Energy is the ability or capacity to do work.

Work done = energy transferred

SI unit of energy is joules (J).

Relationship between energy and work

Activity 6.6 **To investigate the relationship between energy and work**

Materials: A heavy bag with books, stairs

Steps

1. Runs up a flight of stairs with a heavy bag to the top most floor of a building. How do you feel?
2. What happens to a car that has been moving if it runs out of fuel (petrol or diesel)? Explain.

You should have noted that you got exhausted because you did a lot of work against gravity to carry your body and the heavy bag to the top of the building. The work you did led to the loss of energy (chemical energy from the food) from your body.

6.4 Forms of energy

Energy is not visible, it occupies no space and has neither mass nor any other physical property that can describe it. However, it exists in many forms, some of these forms include:

6.4.1 Solar energy

Activity 6.7 **To investigate the effect of solar energy**

Materials: plastic basin, water, convex lens, thin piece of paper

Steps

1. On a bright sunny day, fill a plastic basin with cold water and place it in the compound where there is no shade. Dip your hand into the water after 2 hours. What do you observe?
2. Get a convex lens on the same day and put it horizontally with one surface facing the sun and another surface facing down. Place a thin paper below the lens. What do you observe after 30 minutes or more?
3. Discuss your observations in steps 1 and 2.

From Activity 6.7, you should have observed that the water becomes hot in case 1 and in case 2, the paper is burnt because of the heat from the sun. These are some of the effects of solar energy. This energy from the sun is inform of *radiant heat* and *light*. In some countries where the sun shines throughout, large concave mirrors have been set to collect energy from the sun by focusing its rays on special boilers which provide power for running electric generators.

6.4.2 Sound energy

Activity. 6.8 **To investigate the production of sound energy**

Materials: Two pens, a stone

Steps

1. Get two pens and knock them against each other. What do you hear? Explain to your class partner.
2. Lift a stone a metre above the ground and release it. What do you hear? Explain.
3. In what form is the energy released by the pen and the stone. Discuss with your class partner.

From your discussion, you should have heard sound in steps 1 and 2. In each case, kinetic energy has been converted to sound and heat energy. Sound energy is the energy associated with the vibration or disturbance of bodies or matter.

6.4.3 Heat energy

Activity 6.9 **To demonstrate heat energy**

Materials: Bunsen burner/candle, matchbox, a retort stand, a nail/metallic rod

Steps

1. Light a Bunsen burner or a candle using a lighter (matchbox).
2 Clamp a nail (metallic rod) on a retort stand and bring it near the flame.
3. Carefully touch the other end of the nail after sometime. What do you feel? Explain.

From activity 6.9, you will notice that the other end of the nail is felt to be hot after sometime. The hotness is due to heat energy that has been transferred from the hot part to the cold part of the nail. Therefore, heat energy only travels from a hot object to a cooler one.

Heat energy is a form of energy that is transferred from one body to another due to the difference in temperature.

6.4.4 Electrical energy

Activity 6.10 **To demonstrate production of light by electrical energy**

Materials: bulb, electric wire, cells (battery), switch, bulb holder and cell holder

Steps

1. Fix the battery/cells in their holders and the bulb too.
2. Connect one wire from one end of the cell holder to the bulb holder. Then connect the same wire from the bulb holder to the switch holder and then connect another wire from the other part/side of cell holder to the switch. Make sure the switch is open and the cells are fixed into their holder.
3. What do you observe after the connection? Explain.
4. Complete the circuit then close the switch and observe what happens.

You should have noted that the bulb lights when the circuit is complete. Electrical energy is the energy produced by the flow of electric charges (electrons). Work is done when electrons move from one point to another in an electric circuit with electrical appliances such as bulbs.

6.4.5 Nuclear energy

Activity 6.11 **To find out what nuclear energy is**

1. Conduct a research from internet and reference books on the meaning of nuclear energy.
2. In your research, also find out advantages and disadvantages of nuclear energy.
3. Compare and discuss your findings with those of other groups in your class. You may consult your teacher for more guidance on your discussion.

In your discussion, you should have noted that nuclear energy is the energy that results from nuclear reactions in the nucleus of an atom. It is released when the nuclei are combined or split.

6.4.6 Chemical energy

Activity 6.12 **To investigate and demonstrate chemical energy**

Materials: glass beaker, a small bowl, steel wool, white vinegar, thermometer

Steps

1. Place the steel wool in the bowl and soak it in white vinegar for a couple of minutes.
2. Squeeze out excess vinegar and wrap the steel wool around the thermometer in a way that you are still able to read the temperature.
3. Put the steel wool in the beaker, then place a cover with a paper or small book on the top.
4. Record the temperature immediately, then again in a minute or so, and again every minute for about five minutes. What did you observe?

From Activity 6.12, you should have noted that the thermometer records a higher temperature reading. The chemical reaction of vinegar and steel wool generates energy in form of heat. This causes temperature to rise as shown by the thermometer.

Chemical energy is a type of energy stored in the bonds of the atoms and molecules that make up a substance. Once chemical energy is released by a substance, it is transferred into a new substance. Food and fuels like coal, oil, and gas are stores of chemical energy. Fuels release their chemical energy when they are burnt in the engine (e.g in a car engine).

6.4.7 Mechanical energy

Activity 6.13 **To describe mechanical energy**

Materials: pen, a piece of chalk

Steps

1. Raise a piece of chalk or pen from the ground to a position above your head and release it to fall to the ground. What do you observe with the change in height and the speed of the piece of chalk as it falls.
2. Throw two full pieces of chalk on the wall one at a time using different forces or at different speeds (one should move faster and another one slowly). Note the sound created by the piece of chalk after colliding with the wall. Which one makes more noise after collision?

Mechanical energy is the energy possessed by a body due to its motion or due to its position. It can either be kinetic energy or potential energy of both. When an object is falling down through the air, it posses both potential energy (PE) due to its position above the ground, and kinetic energy (KE) due to its speed as it falls. The sum of its PE and KE is its mechanical energy.

Mechanical energy = kinetic energy + potential energy.

(a) Potential energy

Activity 6.14 **To demonstrate the forms of potential energy**

Materials: a catapult or a spring , a small stone.

Steps

1. Raise a small stone from the ground or any other resting position upwards to a particular height above its resting surface. What kind of energy do you think it attains?
2. Now, release the stone and observe what happens. Explain your observations.
3. Compress a spring to a particular size. What kind of energy do you think it attains? Explain.
4. Release the spring and observe what happens.
5. Identify two types of potential energy from the activities.

From your discussion in activity 6.14, you should have observed that when the stone was released it moved down to the ground. This implies that the stone had stored energy due to its position that makes it to start moving down after it has been released.

The energy possessed by a body (e.g. a stone) due to its position above the ground is called gravitational potential energy.

Similarly, when the spring was released, it relaxed to a bigger size. This also implies that the spring had stored energy due to compression.

The energy possessed by a body due to compression (e.g. a spring) or stretch (e.g catapult) is called elastic potential energy.

Therefore, potential energy is in two forms; gravitational potential energy and elastic potential energy.

(i) Gravitational potential energy

From Activity 6.14, we show that bodies which are at a given height above the ground posses gravitational potential energy. This energy depends on the position of objects above the ground. The following activity will help us to understand how to calculate potential energy of a body at a particular position above the ground.

Activity 6.15 **To determine gravitational potential energy of a raised object**

Materials: three bricks, meter ruler, beam balance, soft board

Steps

1. Conduct research from the Internet and books on the mathematical expression of potential energy.
2. Support the soft board on two bricks.
3. Measure the mass of the third brick by using a beam balance then place it on the soft board.
4. Now lift the third brick to a height h_1. Let your partner measure the height h_1, in metres.
5. Allow the brick to drop gently onto the soft board. Observe what happens to the soft board.
6. Calculate the potential energy gained by the stone using the expression of potential energy you got from the research.
7. Repeat the activity with the other two different heights h_2 and h_3.
8. Compare and discuss your observations and values of PE in the three cases and deduce a general conclusion from your discussion.

In your discussion in activity 6.15, you should have noted that if a stone is lifted upwards through a height *h*; and placed on a table (Fig 6.3), work is done against gravity.

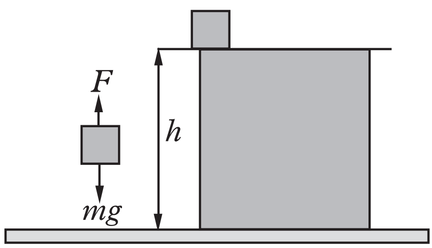


Fig. 6.3: Potential energy depends on height, h.

The work done to overcome gravity is equal to the gravitational potential energy gained by the stone.

But work done $= F \times h$; $F = mg$

$\therefore$ work done $= mg \times h$

But, potential energy = work done.

Therefore: P.E = mgh

Example 6.6

A crane is used to lift a body of mass 30 kg through a vertical distance of 6.0 m.

(a) How much work is done on the body?

(b) What is the P.E stored in the body?

(c) Comment on the two answers.

Solution

(a) Work done = F × d = mg × d = 30 × 10 × 6 = 300 × 6 = 1 800 J

(b) P.E = mgh = 300 × 6 = 1 800 J

(c) The work done against gravity is stored as P.E in the body.

Caution

A stone dropped from the roof of a building will cause more pain if it falls on someone's foot than when the same stone falls from a table. This is because the one on the roof has more gravitation potential energy because it is at a greater height (position) above the ground.

(ii) Elastic potential energy

In Activity 6.14, we saw that a stretched catapult or compressed (Fig. 6.4(a)) has energy stored inform of elastic potential energy. When the stretched spring catapult is released it releases the energy that can be used to do work e.g. to throw a stone.

Fig. 6.4: A compressed and a stretched spring

We will learn more about elastic potential energy and how to determine it in Senior 2.

(b) Kinetic energy

Activity 6.16 **To demonstrate kinetic energy**

Material: trolley, table

Steps

1. Place a trolley on the table and give it a slight push. Observe what happens to it. Explain your observations.
2. Now, observe any moving objects or things around you. Which energy do you think they possess when they are in motion?

From your discussion in activity 6.16, you should have observed that the trolley starts to move once given a slight push. It possess energy as it moves. The energy which is possessed by a moving object due to its speed is called kinetic energy (KE).

Examples of objects that posses KE include moving air, rotating windmills, falling water, rotating turbines and a moving stone. In general, any moving body possesses energy called kinetic energy.

The kinetic energy of a moving body is given by:

$$\text{Kinetic energy} = \frac{1}{2}mv^2$$, where m and v are the mass and velocity of the body respectively.

Excercise 6.3

1. Define the term energy.
2. State and explain briefly six forms of energy.
3. Differentiate between:
   (a) Potential energy and kinetic energy.
   (b) Gravitational potential energy and elastic potential energy.
4. A brick of mass 0.5 kg is lifted through a distance of 100 m to the top of a building. Calculate the potentials energy attained by the brick.

6.5 Sources of energy

Activity 6.17 **To identify and name sources of energy**

Materials: Internet, reference books, a stream of water or a water tap

Steps

1. Tell your group members the meaning of the terms 'source' and 'energy source'.
2. Now, think of plants, animals, vehicles and so on. Where do you think their energy comes from? What of electricity used in your school and at home, where does it come from?

From your discussion in activity 6.17, you should have learnt that the word 'source' means the beginning of something e.g. the stream begins from the mountain or hills around your school.

Hey!!

Are you aware that cutting down trees will lead to the loss of our forest in our country and consequently the loss of water sources? Let us protect our water sources by planting more trees.

You should have also established that the energy source is a system which produces energy in a certain way. For instance, a hydroelectric station uses the motion of the water of the river to turn the turbines and thus producing electricity.

There are two kinds of energy sources;

1. Primary sources.
2. Secondary sources.

Primary sources of energy

Activity 6.18 **To identify primary sources of energy**

Materials: reference books

Steps

1. Conduct a research from the Internet and reference books on primary sources of energy.
2. In your research find out:
   (a) The types of primary sources of energy.
   (b) The generation of energy from each source.

From your research and discussion in activity 6.18, you should have established the following that Primary Sources are from sources which can be used directly as they occur in the natural environment. They include.

1. Flowing water
2. Nuclear
3. Sun
4. Wind
5. Geothermal (interior of the earth)
6. Fuels
7. Minerals
8. Biomass (living thing and their waste materials

- **Water**

(a) Flowing water - the flowing water from dams rotate turbines at the bottom of the dam which turn the generator resulting in generation of electricity. This water is kept behind a dam (reservoir) and released at a controlled rate downwards where it meets the turbines and turns them. An example is Ntaruka dam on river Burera in Butaro Rwanda.

(b) Waves - energy from water waves (generated by winds) is also used in generating electricity using sea wave converters. An example is pelamis wave energy converter, a technology that uses the motion of ocean surface waves to create electricity.

• Nuclear energy

Nuclear energy is created through reactions that involve the splitting or merging of the atoms of nuclei together. The process of splitting of large atoms such as those of uranium into smaller atoms is called *fission*. *Fusion* on the other hand, is the combining of two smaller atoms such as hydrogen or helium to produce a heavier atom. All these reactions release heat which is turned into electricity in nuclear power plants (Fig 6.5). An atomic bomb derives its energy from these kinds of reactions.

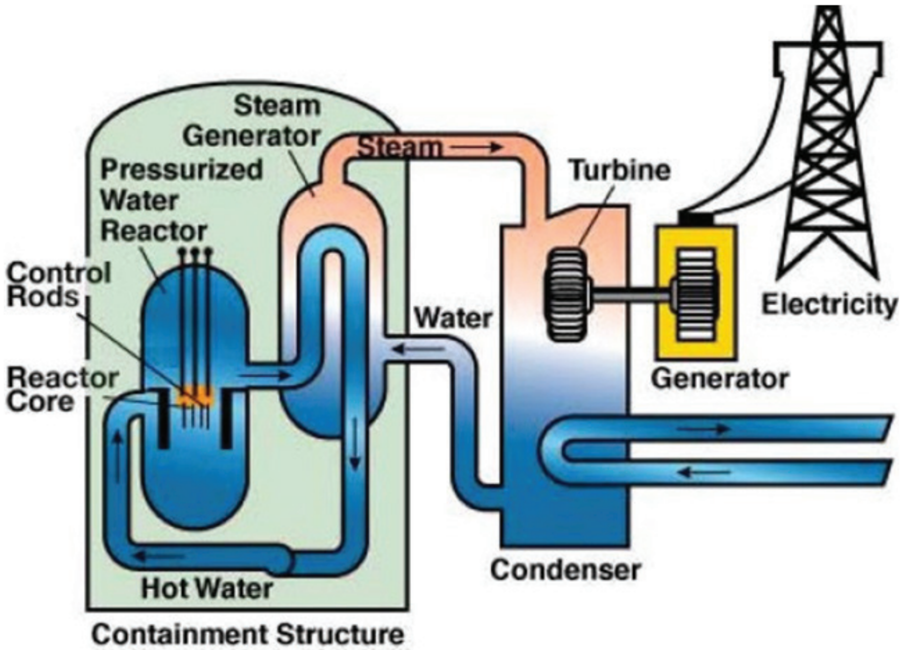


Fig 6.5: Nuclear plant

• The sun

The sun is the biggest source of energy and has played an important role in shaping our life on earth since the dawn of time.

The sun gives off radiant energy in form of *electromagnetic waves*. The light energy (visible spectrum) part of the spectrum can be converted directly into electricity in a single process using the *photovoltaic (PV)* cell otherwise known as the *solar cell.*

The solar thermal energy is used for heating swimming pools, heating water for domestic use (solar heater) and heating of building. Solar thermal electricity generation is where the sun's rays are used to heat a fluid for the production of high pressure and high temperature steam. The steam is in turn converted into mechanical energy in a turbine to generate electricity.

(a) Solar panel *(b) Solar heater*

Fig. 6.6: Solar panel and solar heater

- **Wind**

Wind is caused by the sun heating the earth unevenly. The air is heated differently causing hotter air to expand rise, and the colder one to condense and sink. This results to the movement of air and hence formation of wind.

Modern wind turbines placed on the top of steel tubular towers harness the natural wind in our atmosphere and convert it into mechanical energy and then to electricity.

Wind mills (Fig. 6.7) are also be used to pump water from the underground and do some other work.

Fig 6.7: Wind mills

- **Geothermal energy**

Geothermal gradient is the difference in temperature between the core (interior) of the earth (planet) and its surface brings about conduction of heat from the core to the surface. The earth's internal heat is generated from radioactive decay and continual heat loss from the earth's formation.

From hot springs, geothermal energy has been used for bathing to heal some diseases as in some cultures. Geothermal energy is also used to generate electricity at geothermal power stations where heat is used to heat water to get steam which in turn is used to turn the turbines to generate electricity.

Fig. 6.8: Geothermal power station

- **Thermal energy**

Thermal energy is the internal energy in a system by virtue of its temperature. It is defined as the average translational kinetic energy possessed by free particles in a system of free particles in a thermodynamic equilibrium. It can also include the potential energy of a system's particle which may be an electron or an atom. Thermal (heat) energy is transferred of heat across the system boundaries. Thermal energy is important in our daily life, for example in warming the house, cooking, heating the water and drying the washed clothes.

• Biogas

Activity 6.19 **To conduct research on how to produce biogas**

Materials: bio-digester

Make a trip to a farm with biogas plant and take turn to ask about working of biodigester

Biomass is the total mass of organic matter in plant or animal. It is used to generate energy e.g. through burning to give heat energy.

When bacteria acts on biomass, a gas called biogas is produced which is flammable hence is used as fuel to produce heat. It is a mixture of 65% methane and 35% carbondioxide.

A biogas plant or digester collects and directs the gas through pipes to the kitchen for cooking in a house or to a generator where electricity is produced.

Fig. 6.9 shows a biogas plant.

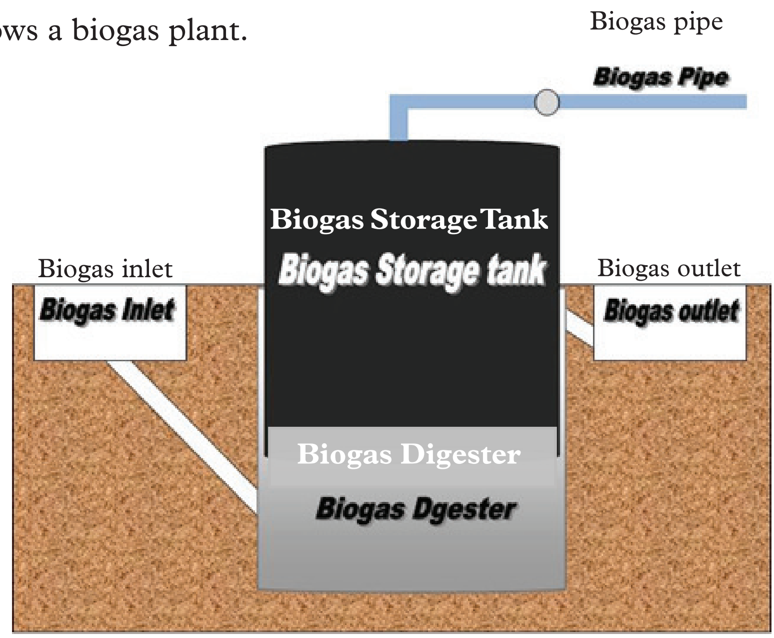


Fig. 6.9: Biogas plant

• Fuels

Fuels are substances which produce heat when burnt in the presence of oxygen. They include kerosene, diesel, biogas, are sources of energy in homes, industries. In the process of combustion, the chemical energy in the fuel is converted into heat energy that is converted to other forms as desired.

- ## Chemical energy

Chemical energy is stored in the chemical bonds of atoms and molecules. It can only be seen when it is released in a chemical reaction. When chemical energy is released, from a substance, the substance is entirely changed into an entirely different substance.

Some substances that store and release chemical energy are;

(i) Electrolytes – the chemical reactions in an electrolyte in the batteries produce electricity.

(ii) Petroleum – petroleum is made of molecules containing carbon and hydrogen. In vapor form, its natural gas and in liquid form, it is crude oil. Energy from petroleum is used to drive vehicles and to produce electricity. Examples include jet fuel, gasoline and electricity.

(iii) Wood – dry wood acts as a store of chemical energy. This chemical energy is released when wood burns and it's converted into heat and light energy.

(iv) Food – the chemical energy in food is released while the food is being digested. As the bonds between the atoms of the food break, new substances are created and chemical energy is given out.

Warning

Subjecting a battery to abuse or conditions for which it was never designed can result in uncontrolled and dangerous failure of the battery. This may include explosion, fire and the emission of toxic fumes. Keep batteries well out of reach of children.

Button batteries are small and can be found in toys, calculators, remote controls, watches.

- ## Light energy

The potential of light to perform work is called light energy. It is formed through chemical radiation and mechanical means. It is a form of energy produced by hot bodies and travels in a straight line. It's the only form of energy that we can see directly (visible light). It can be converted like sunlight energy is used during photosynthesis by planets to create chemical energy. UV lights are often used by forensic scientists to see details that are not seen by unaided eyes.

Secondary sources of energy

Activity 6.20 **To identify secondary sources of energy**

Materials: reference books, Internet

Steps

1. Conduct a research from the internet and reference books on secondary sources of energy.
2. In your research, find out what secondary sources of energy are and the types.

In your discussion in activity 6.20, you should have established that secondary sources are energy sources that are generated from primary sources. For instance, electricity is a secondary source because it is generated for example from solar energy using solar panels or from flowing water using the turbines to generate hydroelectricity.

Other secondary sources of energy include; petroleum products, manufactured solid fuels, gases, heat and bio fuel.

6.6 Renewable and non renewable sources of energy

Activity 6.21 **To distinguish between renewable and non-renewable sources of energy**

Materials: matchbox, reference books

Steps

1. Take one matchstick from the matchbox and light it.
2. Leave it to burn for few second and then put it off.
3. Use the same matchstick and try to lit it again. Observe and explain what happens.
4. From the knowledge of sources of energy, what do you think renewable and non-renewable sources are?
5. Discuss your observation in steps 2 and 3 with your class partner.
6. Now, conduct a research from internet and reference book on renewable and non renewable energy source.
7. Compare and discuss your findings with other groups in your class.

Hey!!! Be safe

Always be careful with fire. It can cause massive damage which can results to loss of properties and lives.

From your discussion in Activity 6.21, you should have noted that the burnt matchstick cannot be used again for the same purpose. Similarly, there are energy sources that cannot be used again once used to generate energy. They are called non renewable sources while those that can be used again without exhausting them are called renewable resources.

Renewable energy sources

A renewable energy source is an energy source which can't be depleted/exhausted. They exist infinitely i.e. never run out. They are renewed by natural processes. Examples include;

(i) Sun
(ii) Wind
(iii) Geothermal
(iv) Trees

However, some like trees they can also be depleted, like trees and animals if used too much more than the natural process can renew them. So it's advisable to take precaution while using them, that is, they should be conserved.

Non-renewable energy sources

These are sources which can be depleted because they exists in fixed quantities. So they will run out one day. Examples are coal, crude oil, natural gas, and uranium.

Fossil fuels like coal, crude oil, natural gas are mainly made up of carbon. They are usually found in one location because they are made through the same process and material. Millions of years ago dead sea organisms, plants, and animals settled on the ocean floor and in porous rocks. With time, sand, sediments and impermeable rock settle on the dead organic matter, as the matter continue to decay forming coal, oil and natural gas. Earth movements and rock shifts creates spaces that force these energy sources to collect at well-defined areas. With the help of technology, engineers are able to drill down into the sea bed to mine these sources and harness the energy stored in them.

6.7 Environmental effects of the use of energy sources

Activity 6.22 **To investigate the environmental effects of the use of energy sources**

Matereials: reference books, Internet

Steps

1. Conduct a research from the Internet and reference books on environmental effects of the use of energy sources.
2. In your research, identify the effects and suggest the measure to be taken to ensure safe use of those resources.
3. Record down your findings from your discussion and report to the whole class through your secretary.

In Activity 6.22, you should have learnt that, there is no such thing as a completely "clean" energy source. All energy sources have atleast an effect to the environment. Some energy sources have a greater impact than others. Energy is mostly lost into the environment in form of *heat* and *sound*.

The following are some of the effects of use of the energy sources to the environment:

- air and water pollution
- climate change and global warming.
- deforestation
- land degradation

(a) Air and water pollution

Fossil fuels e.g petroleum, diesel are used in factories. Very harmful by-products may be released to the atmosphere or water bodies. Carbon monoxides, sulphur dioxide and carbon dioxide may be released to the atmosphere causing air pollution that may harm living things that depend on air. When human beings inhale some of the polluted air, they can develop respiratory diseases. The wastes disposed to the water bodies can cause death of living things in the water. It also make the water unsafe for human consumption.

Factories and industries operators are encouraged to use bio-fuels which are less harmful to the environment. Most factories are trying to clean up the waste so as to reduce the environmental pollution.

(b) Climate change and global warming

Most energy sources e.g fossil fuels, coal etc, when used as sources of energy, produce wastes such as carbon dioxide, sulphur dioxide and mercury which are *the greenhouse gases*. The accumulation of these gases in the atmosphere make the temperatures to be higher than the normal. This is referred to as *global warming*.

Sometimes, these gases interfere with the climate causing very high temperature in the atmosphere, acidified rains, frequent droughts, floods etc. This results to *climate change*.

The greenhouse gases e.g. excess carbon dioxide, sulphur dioxide etc destroy the ozone layer exposing living things to dangerous emissions from the sun e.g. UV rays.

Release of these harmful gases into the atmosphere is a global problem and very many environmental agencies are encouraging on the proper disposal of these wastes.

United Nations Conference on Environment and Development (UNICED) lead Nations to sign a joint treaties to pursuire of economic development in ways that would protect the earth's environment and non renewable resources but it is still a problem up to now.

(c) Deforestation

Using firewood and charcoal in most African countries lead to loss of biodiversity and erosion due to loss of forest cover. These may lead to deforestation i.e. *the reduction of forest cover*. Of great concern is that Africa is losing forest twice as fast as the rest of the world.

Human beings are encouraged to use green energy that is renewable and have less effect to the environment.

With your help we can support projects that help to train and educate forest communities so that they can use forests in a sustinable manner and protect their livelihoods for years.

(d) Land degradation

Land degradation is the process in which the value of bio-physical environment is affected by human – induced activity on the land. It is caused by over-cutting of vegetation e.g. forest, and woodland, for firewood and disposing factory wastes to the soil that may contaminate the soil. Use of non-biodegradable sources of energy is encouraged.

Let's adopt the use of biogas in cooking, energy saving stoves and reduce the use of firewood to the possible level and amount of smoke generated reducing the impact of indoor air pollution. This will reduce environmental impacts.

Exercise 6.4

1. Differentiate between energy and power.
2. In groups of two, identify any three primary sources of energy and hold a discussion on their:

   (a) definition and origin.

   (b) importance to us and our country.

3. Choose any renewable energy resource. Brainstorm on two to three jobs opportunities available in that field.
4. Distinguish between the terms renewable resource and non-renewable resources.
5. Give one example of a body with potential energy due to its state.

6.8 Energy transformations

Activity 6.23 **To investigate energy transformation**

Materials: an electric heater, radio, water in a basin.

Steps

1. Place the electric heater in the basin with water and connect it to the socket.
2. Put on the switch. Observe and explain what happens after a couple of minutes. Suggest the types of energy involved in this case.
3. Now, disconnect the heater and connect the radio to the socket.
4. Turn the radio on and suggest the types of energy involved.
5. Repeat the activity by connecting wires, battery, switch and bulb. Observe and explain what happens when you make simple circuit and the switch is closed.
6. Discuss the meaning of energy transformation and give five examples of energy transformation.
7. What the name given to devices such as the radio, heater, battery, bulb etc. that converts energy from one form to another.
8. Discuss other forms of energy transformation and show with diagrams how energy is transformed from one form to another on the chalkboard.

Hey!!! Be safe

Don't touch water while an electrical heater is on, you may get an electrical shock.

From your discussion, you should have observed that the water in the basin boils. Electrical energy has been converted to heat energy which boils the water. When the radio was connect to the socket and turned on, electrical energy is converted to sound energy.

In step 5, when the wires are connected, the bulb is seen to give off light when you close the switch. This is because chemical energy in the battery has been converted to electrical energy which is then changed to light energy in the bulb and some part to heat energy.

Therefore, energy in many of its forms may be used in its natural process or to provide some services to society such as heating, refrigeration, or performing mechanical work to operate machines. This is possible because energy can be changed from one form to another. This process of changing of energy from one form to another is called energy transformation. A device that converts energy from one form to another is known as a transducer.

Fig 6.10 is a chart that shows some examples of energy transformation in our day to day activities.

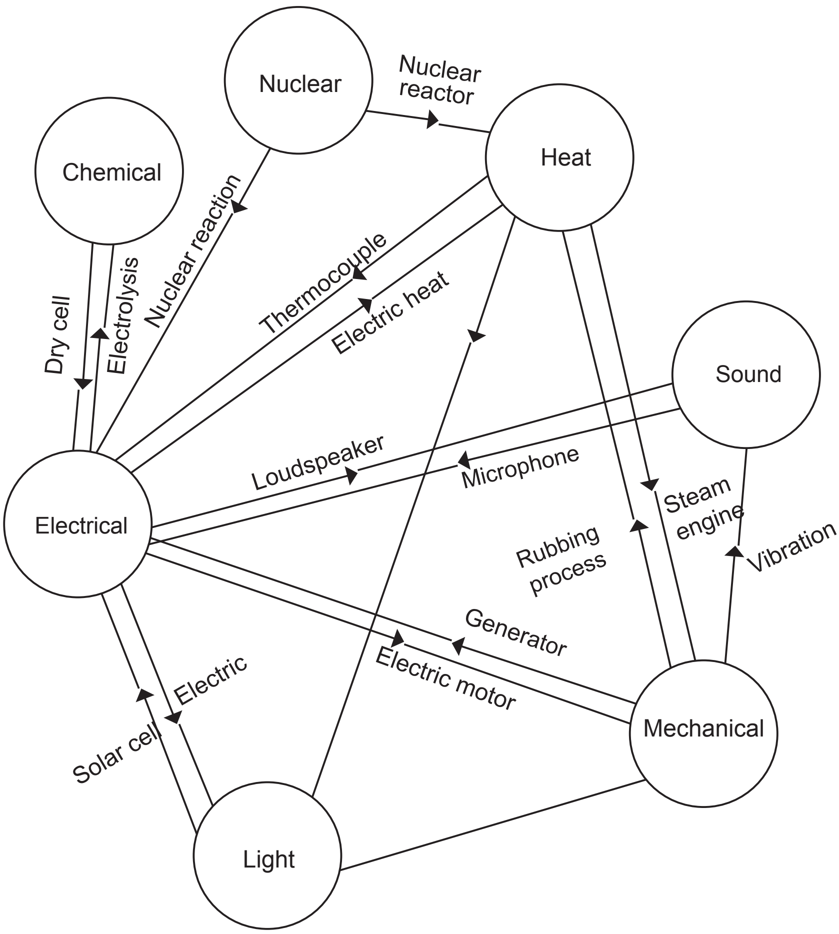


Fig. 6.10: A flow chart of energy transformation

Let us consider a few examples of energy transformation:

1. Hammering a nail

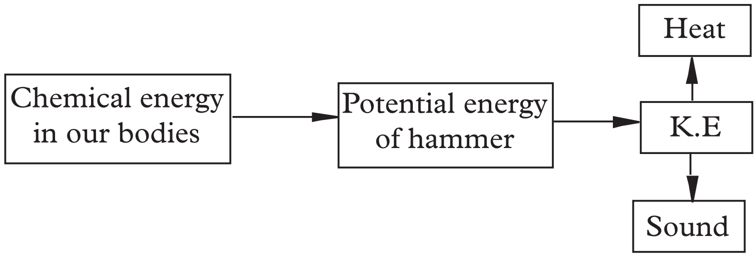


Fig. 6.11: Energy transportation

2. Lighting a bulb using a battery

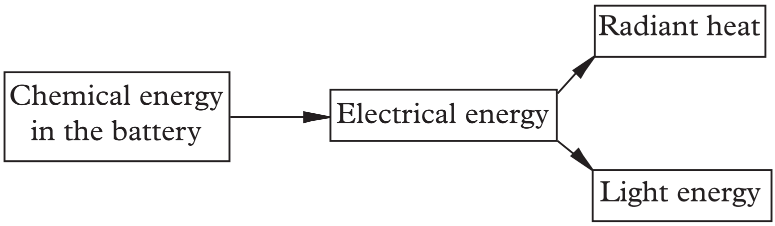


Fig. 6.12: Energy transformation

3. Hydroelectric power

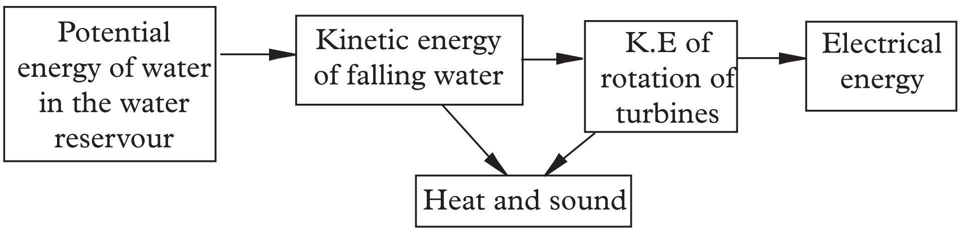


Fig. 6.13: Potential energy and its transformation

Other examples of energy transfomers.

Wind turbines use wind energy to transform it into electricity.

Energy from **food** (chemical energy) can be transformed in energy to play and run.

A **solar cell/ panel** convert radiant energy of sunlight to electrical energy that can be used to give off lightning a bulb or to power a computer

The **sun** gives the grass thermal energy which helps it to grow by transforming the energy into chemical energy using photosynthesis. Animals eat grass and help them to grow and have power to run.

A **microphone** changes electric energy to sound energy and so on.

One other example of energy transformations occurs when **lightning strike**. If it hits a tree, it's electrical energy will be changed to heat and thermal energy. The tree will become hot and can even burn as a result of electric discharge, it can split and the leaves dry.

Exercise 6.5

1. Table 6.2 shows how energy is converted from form A to form B and the devices concerned. Complete the table.

Form A	Form B	Device
Electrical	Sound	Loudspeakers
Electrical	Kinetic	_
_	Electrical	Photocell
Sound	Electrical	_
_	Electrical	Thermocouple
_	_	Heater

Table 6.2: Forms of energy

2. Describe the energy changes that occurs in the following processes.
   - **(a)** When you lift a brick to a certain height.
   - (b) When you lift a brick and let it slide down a rough slope until it reaches the surface of the slope.
3. Describe the forms of energy shown in Fig 6.14.

Fig. 6.14: Forms of energy

4. Name the changes in energy that take place when a torch is switched on.
5. Name the energy changes that take place when lighting a match box.

6.9 Law of conservation of energy

Activity 6.24 **To demonstrate the law of conservation of energy**

Materials: a ball

Steps

1. Hold a football at a height of 1 m above the ground. What type of energy does the ball posses at that position?
2. Release the ball to start falling freely to the ground. What type of energies does the ball posses while falling?
3. What type of energy does the ball posses while just about to touch the ground.
4. Ignoring air resistance, compare the amount of energy possesed by the ball in step 1 and 3. What can you conclude?

When the ball was stationary at a point 1 m above the ground in Activity 6.24, it possed P.E only. When released the P.E starts being converted to K.E hence the ball dropped. When it was just about to touch the ground, all the P.E had been converted to K.E hence by ignoring air resistance,

Initial P.E = final K.E

We say that energy has been conserved.

This is summarised in the law of conservation of energy.

The law of conservation of energy states that energy cannot be created or destroyed but is simply converted from one form into another.

Energy can be inter-converted among many forms, mechanical, chemical, nuclear, electric, and others but the total amount of it remains constant.

For instance, in boiling water using a kettle, electrical energy drawn from the power source flows into the heating element of the kettle. As the current flows through the element, the element rapidly heats up, so the electrical energy is converted to heat energy that is passed to the cold water surrounding it. After a couple of minutes, the water boils and (if the power source remains in the water) it starts to turn into steam. Most of the electrical energy supplied into the kettle is converted to heat energy in the water though some is used to provide latent heat of evaporation (the heat needed to turn a liquid into a gas without a change in temperature).

If you add up the total energy supplied by the power source and the total energy gained by the water, you should find they are almost the same. The minor difference would be due to energy loss in other forms.

Why aren't they exactly equal?

It's simply because we don't have a closed system. Some of the energy from the power source is converted to sound and wasted (kettles can be quit noisy). The kettles also give off some heat to their surrounding so that's also wasted energy.

Another example is a flying ball, that hits a window plane in a house, shattering the glass. The energy from the ball was transferred to the glass making it shatter into pieces and fly in various directions.

6.10 The law of conservation of mechanical energy

Activity 6.25 **To verify the law of conservation of mechanical energy**

Materials: A smooth metallic hemispherical bowl, a ball bearing

Steps

1. Place the hemispherical bowl on the bench in a stable position. Mark at point A on the inside surface of the bowl at point A on the inside surface of the bowl
2. Place the ball bearing at point A and release it to slide downwards freely along the inside surface of the bowl as shown in Fig. 6.15.

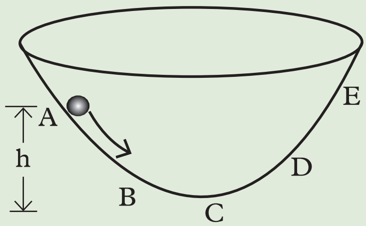


Fig. 6.15: A ball bearing sliding oscillating in a bowl

3. Mark point B where the ball rises to on the opposite side in the bowl.
4. Compare the vertical height of points A and E. What do you notice?
5. Repeat the activity with point A at a lower vertical height.
6. What type of energy does the ball bearing posses at points A, B, C, D and E.
7. Compare and comment on the total amount of energy possessed by the ball bearing points A, B, C, D and E.
8. Make a conclusion based on your observation in step 7.

From your research and discussion in activity 6.25, you should have learnt that the law of conservation of mechanical energy states that

The total mechanical energy (sum of potential energy and kinetic energy) in a closed system will remain constant/same.

A closed system is one where there are no external dissipative forces (like friction, air resistance) which would bring about loss of energy.

The sum of potential energy and kinetic energy anywhere during the motion must be equal to the sum of potential energy and kinetic energy anywhere else in the motion.

To demonstrate the law of conservation of mechanical energy

(a) A swinging pendulum

Activity 6.26 **To demonstrate the law of conservation of M.E using a swinging pendulum**

Materials: a bob, string

Steps

1. Tie a string to the bob and fix it to a rigid object.(See Fig. 6.16).
2. Pull the bob to the right or left side at an angle and then release it. Observe the movement of the bob.
3. Draw a diagram for the motion of the pendulum and discuss with your class the energy changes at various points e.g. A, B, C, D and E shown in Fig. 6.16.

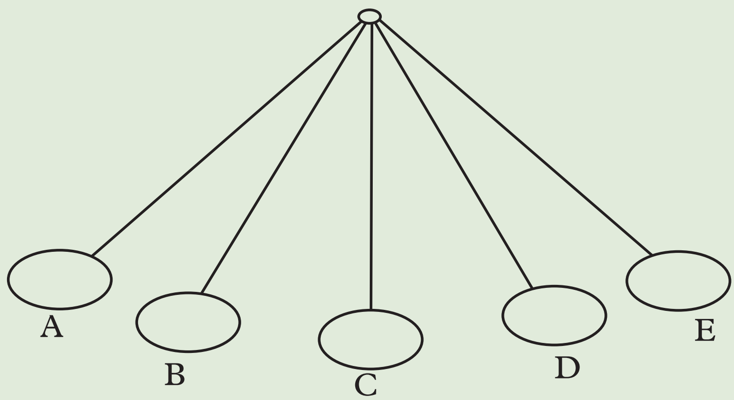


Fig. 6.16: A swinging pendulum

From the above activity 6.26, you should have noticed that the bob will attain a maximum potential energy due to its height above the ground at point A she have minimum kinetic energy because it is at rest.

When it swings after letting it go, it will start loosing potential energy as it gain kinetic energy at point B because of its motion. As it passes through the lowest point point C, its potential energy is minimum kinetic energy will be maximum. Because of its kinetic energy, it swings up to the other side and now its kinetic energy starts decreases as, potential energy increases at point D until when it reaches the maximum point E where it stops moving momentarily. At that point, it has maximum potential energy but minimum kinetic energy.

At all positions, the total mechanical energy is constant (conserved). That is kinetic energy + potential energy = constant. Therefore, mechanical energy has been conserved.

(b) A body thrown upwards

Activity 6.27 **To demonstrate the law of conservation of M.E using a ball thrown upwards**

Materials: tennis ball

Steps

1. Throw a tennis ball upwards. Observe the movement up to the maximum (highest) point.
2. Now, drop the ball from a high point e.g from top of the building or a cliff (see Fig 6.16).
3. Sketch its motion on a paper at three different intervals, starting from the lowest when thrown upwards or from highest when dropped from a cliff.
4. Indicate the forms of energy at each stage.

In your discussion, you should have learnt that when a body (e.g. a ball) is thrown up vertically, it has maximum speed, (maximum kinetic energy) at the starting point.

The ball moves up with a reducing speed because of the force of gravity acting on it downwards until it reaches the maximum point/ height where it stops moving momentarily and it falls back.

At maximum height, it has a maximum potential energy and minimum kinetic energy because the body is not moving. So the kinetic energy at the bottom is all turned into potential energy at the maximum point (Fig 6.17).

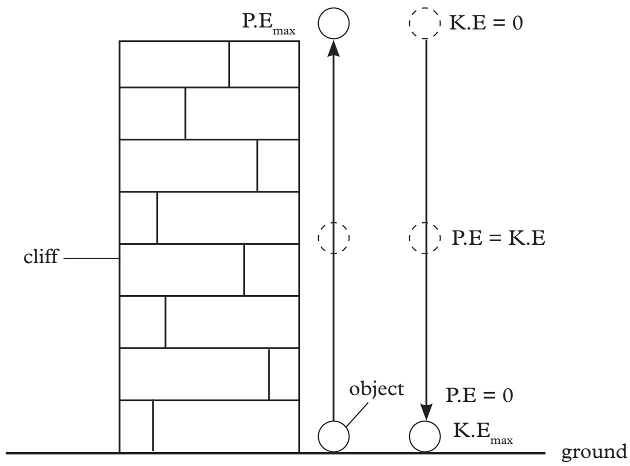


Fig. 6.17: Sketch of a ball thrown upwards

The ball is under free fall because it is only being acted upon by the force of gravity. Initially the ball has maximum potential energy and no kinetic energy. As it falls down, its potential energy keeps on reducing as its position above the ground reduces but its kinetic energy is increasing because it speeds up as it falls downwards.

The kinetic energy at the ground level is equal to the potential energy at the top of the wall. Hence mechanical energy is conserved.

Exercise 6.6

1. A pendulum bob swings as shown in the diagram. Fig 6.18

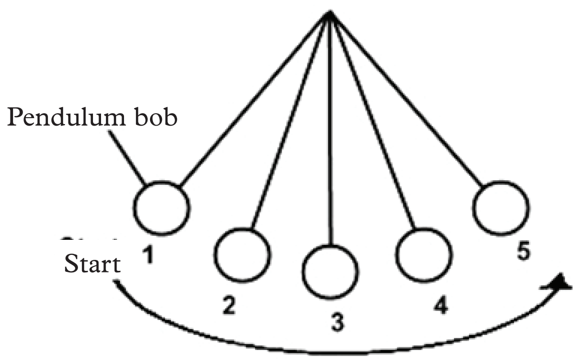


Fig 6.18: A pendulum swinging

At which position (s) is:

(a) the kinetic energy of the pendulum bob least.

(b) the potential energy of the pendulum bob most.

(c) the kinetic energy of the pendulum bob the most.

(d) the potential energy of the pendulum bob the least.

2. State the following laws:
   (a) law of conservation of energy
   (b) law of conservation of mechanical energy.
3. Describe how mechanical energy is conserved.

6.11 Ways of conserving energy

Activity 6.28 **To do research about conservation of energy and identify ways of conserving energy**

Materials: internet, reference book

1. Conduct a research from Internet and reference books on ways of conserving energy.
2. In your research, identify different ways of conserving energy and find out what energy efficiency is.

From your research and discussion in activity 6.28, you should have established that energy conservation is the act of saving energy by reducing the length of use. In other words, to conserve energy, you need to cut back on your usage.

For example, driving your car fewer miles per week, turning your thermostat down a degree or two in the winter time and unplugging your computer or home appliance when they are not in use. All these ways reduce the amount of energy you use by doing without or using less fuel or electricity. It can help reduce the monthly heating and electricity bills and save money at the gas pump. You also reduce the demand of fuels like coal, oil, and natural gas. Less burning of fuels means lower emissions of carbon dioxide, the primary contributor of to global warming and other pollutants.

Other examples include:

(i) Clean or replace air filters of cars as recommended. Energy is lost when air conditioners and hot air furnaces have to work harder to draw air through dirty filters. So save money by replacing old air filters with new (standard) ones which will take less electricity.

(ii) Select the most energy efficient models when you replace the old appliances. Look for the energy star label because the product saves energy and prevents pollution.

(iii) Turn your refrigerator down. Refrigerators accounts for about 20% of the house hold electricity costs. You can use a thermometer to set it at a temperature close to 37°C and your freezer as close as 3.

(iv) Buy energy-efficient compact fluorescent bulbs for the lights you use most. Although they cost more, they save money in the long run because they only use a quarter the energy used by ordinary incandescent lamps and lasting 8-12 times longer.

(v) Reduce the amount of waste you produce by buying minimally packaged goods, choosing reusable products over disposable ones, and recycling. Use 30% to 50% less paper products, 33% less glass and 90% less aluminum.

(vi) People who live in colder areas should super insulate your walls and ceiling. It can save your the electricity of heating or fire wood costs.

(vii) Plant shade trees and paint your house a light colour if you live in a hot country or dark colour if it is a cold country.

If we do not conserve energy, it will be exhausted and we will have nothing to use. Energy conservation is also important when in managing climate change. Currently erratic climates and climatic changes are the greatest threats that we are facing today. Hence it is important to conserve energy.

6.12 Energy efficiency

Energy efficiency is the act of saving energy but keeping the same level of service.

For example, if you turn off the lights when you are leaving a room, that's energy conservation, if you replace an efficient incandescent light bulb with a more efficient compact fluorescent bulb, you are practicing energy efficiency.

Energy efficiency uses advances in sciences and technology to provide services and products that require the use of less energy.

Exercise 6.7

1. **(a)** Demonstrate how mechanical energy is conserved.

   (b) What is energy efficiency?

2. By identifying practical activities in our daily lives, discuss how you can conserve energy.

Project work 1

Energy saving charcoal burner

In most developing countries, wood is the most important source of energy mainly for cooking. The amount of wood consumed depends on the climate, culture and availability. Most people use open, three stone fireplaces for cooking. The fireplaces are often dirty, dangerous and inefficient. The smoke and soot settles on utensils, walls, ceiling and people. The smoke produced in fireplaces irritates people posing danger to health. The fireplaces have been found to be about 10-15% efficient.

In view of the above, energy saving stoves have been designed. Most of these stoves use charcoal. Charcoal is preferred to wood in urban areas because of its portability, convenience and cleanliness. In designing energy saving stoves, one should try to minimise energy losses to the surrounding. One of the many advantages of a charcoal stove, is that the rate of charcoal burning can be controlled.

Materials

Metal sheets and clay

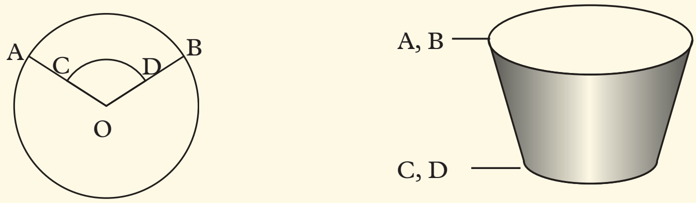
Construction

Cut the metal sheet into a circular sheet (Fig. 6.19(a)). The radius AO will depend on the size of the stove required. Mark arc AB which represents the circumference of the *mouth* of the charcoal burner. Draw AO and OB. Draw arc CD. The radius OD will depend on the area of the base on which the charcoal is to rest. Cut the section ACDB.

Assembly

Fold the plate ACDB in a shape of a cone as shown in Fig. 6.19(b). Rivet the sides AC and BD together.

Repeat the procedure to construct the lower compartment. But this time make AC and DB shorter.



(a) Circular metal sheet

(b) Upper compartment

Fig. 6.19: Making the upper compartment of an energy saving charcoal burner

Bring the two compartment together and join them by riveting Fig. 6.20(a). Cut off a small section of the lower compartment and construct a gate. Mould clay in such a shape that it fits into the upper compartment. Make the air holes while the clay is still wet.

Allow the clay to dry. Construct the stands for holding the cooking pot. A complete stove should look like the one shown in Fig. 6.19(b).

(a) Upper and lower compartment joined (b) Complete charcoal burner

Fig. 6.20(a): Upper and lower compartments joined to make a complete charcoal burner

Larger stove can be made by cutting the sheet as shown in Fig. 6.21.

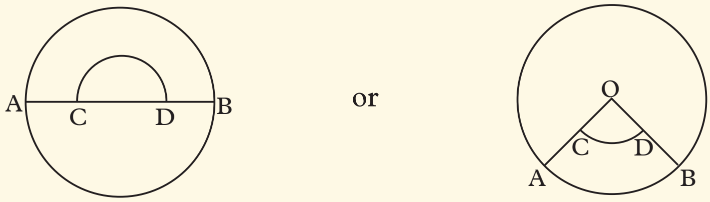


Fig. 6.21: Larger jikos

Project work 2

Solar heater

Solar energy can be trapped with the help of solar heater and utilized to heat water. The most common type of solar water heater incorporates a flat-plate solar collector and a storage tank. The tank is positioned above the collector. Water from the tank is circulated through the collector and back to the tank by means of convectional currents caused by the heated water.

Construction of a solar heater

Suggested materials

A 20 litre jerry can container, plastic pipes, cellophane paper, half open 20 litre jerry can, black paint or smoke soot and a wire mesh.

Assembly

Heat collector

Paint the plastic pipes black. Use a wire mesh and curve the plastic pipes as shown in Fig. 6.22. The size of the wire mesh should be able to fit into an open 20 litre jerry can container.

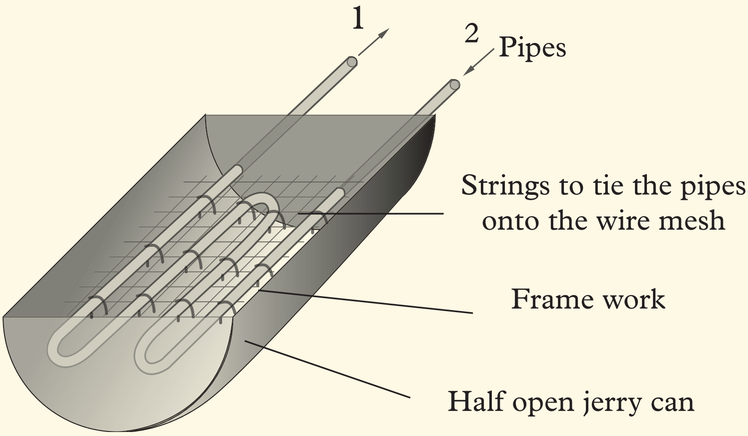


Fig. 6.22: Heat collector

Heat exchanger

Use another 20 litre jerry can (Fig. 6.23) and open at the top to allow the pipes to enter and then seal it using the same material and a hot object. The hot object will make the materials to fuse together. Make provisions for water to enter and leave the heat exchanger when required.

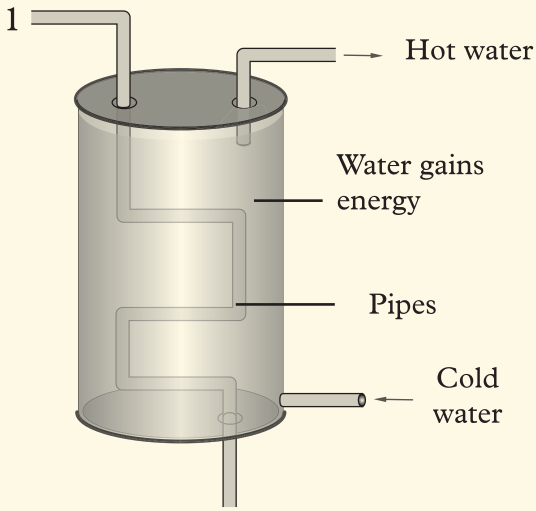


Fig. 6.23: Heat exchanger

Join pipe 1 of the heater collector to pipe 1 of the heat exchanger. Do the same with pipe 2. Make sure the collector is inclined at a certain angle to allow water from the heat exchanger to flow freely. (Fig. 6.24).

Cover the heat collector with a cellophane paper.

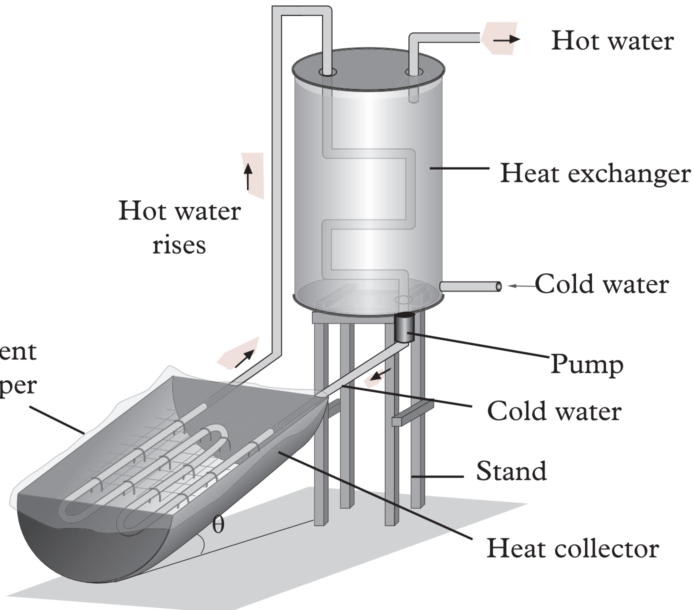


Fig 6.24: Solar heater

How to use

Fill the pipes of the heat collector with water and expose them to the sun. Allow water from a reservoir to fill the heat exchanger.

Unit summary and new words

- Work is the product of force and distance moved in the direction of the force.
- A joule is the work done when a force of one newton acts on a body and makes it to move a distance of one metre in the direction of the force.
- When work is done on an object, energy is transferred. Work is said to be done if a force acts on a body and makes it move (get displaced) in the direction of the force
- Energy is the ability to do work.
- Moving objects have kinetic energy that depends on the mass of the body and the velocity.
- Potential energy is the energy possessed by a body due to its position. It depends on the objects height above the ground.
- The total amount of kinetic energy and potential energy in a system is the mechanical energy of the system. Mechanical energy = KE + PE.
- Falling, swinging, and projectile motion all involve transformations between kinetic and potential energy.

- According to the law of conservation of energy, energy cannot be created or destroyed but can only be converted from one form to another.
- Energy is converted changes from one form to another by transducers such as light bulbs, hair driers. For example, a hair drier converts electrical energy into thermal energy, kinetic energy and sound energy.
- Fuel is a substance which when burnt produces heat.

Unit Test 6

1. Define the term power and give its SI unit.
2. A motor raised a block of mass 72 kg through a vertical height of 2.5 m in 28 s. Calculate the:
   (a) work done on the block.
   (b) useful power supplied by the motor.
3. A person of mass 40 kg runs up a flight of 50 stairs each of height 20 cm in 5 s. Calculate:
   (a) the work done.
   (b) the average power of the person.
   (c) explain why the energy the person uses to climb up is greater than the calculated work done.
4. A runner of mass 65 kg runs up a steep slope rising through a vertical height of 40 m in 65 s. Find the power that his muscles must develop in order to do so.
5. A fork-lift truck raises a 400 kg box through a height of 2.3 m. The case is then moved horizontally by the truck at 3.0 m/s onto the loading platform of a lorry.
   (a) What minimum upward force should the truck exert on the box?
   (b) How much P.E. is gained by the box?
   (c) Calculate the K.E of the box while being moved horizontally.
   (d) What happens to the K.E once the truck stops?
6. A stone falls vertically through a distance of 20 m. If the mass of the stone is 3.0 kg,
   (a) Sketch a graph of work done by the gravity against distance.
   (b) Find the power of the gravitational pull.

7. Mugisha climps 16 m rope in 20 s. If his mass is 60 kg, find the average power he developed.
8. A car is doing work at a rate of 8.0×10^4 W. Calculate the thrust of the wheels on the ground if the car moves with a constant velocity of 30 m/s.
9. Uwimbabazi took 55.0 s to climb a staircase to a height of 14.0 m. If her mass is 40 kg, find:
   (a) How much force did she exert in getting to the that level?
   (b) Her power?
10. In Fig. 6.25 three positions of a monkey swinging from a branch of a tree are shown.

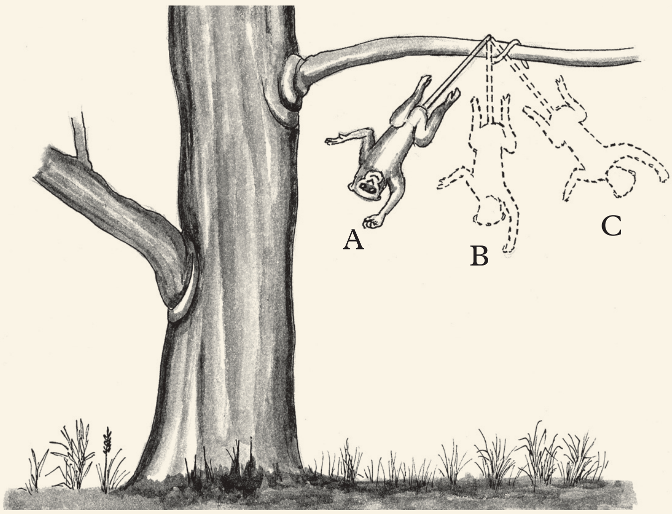


Fig. 6.25: A monkey swinging

   (a) What kind of energy does the monkey have at each position?
   (b) What happens to the energy when the monkey is midway between A and C?
   (c) In which positions does the monkey have the least energy? What name is given to this type of energy?
11. A device which converts one form of energy to another is called a *transducer*. Name one transducer in each of the cases energy transformation given below.
   (a) Heat to kinetic energy
   (b) Electrical to light
   (c) Sound to electrical
   (d) Potential energy to kinetic energy
   (e) Chemical to electrical

12. Discuss the energy transformations in Fig. 6.26.

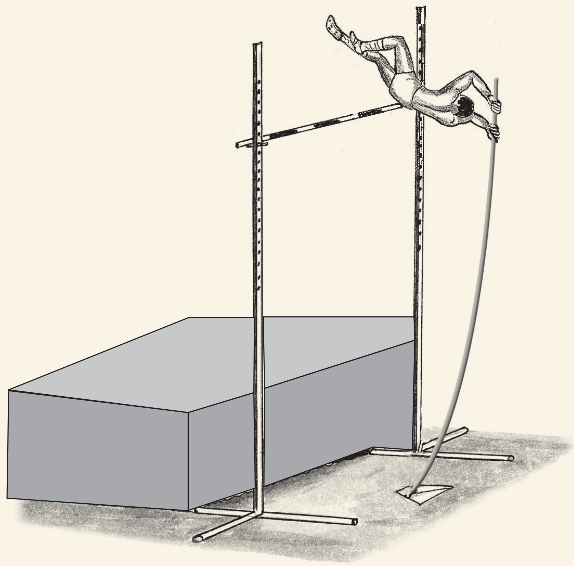


Fig. 6.26: A boy jumping

13. **(a)** State the law of conservation of energy.

(b) Differentiate between renewable and non-renewable sources of energy. Give two examples of each.

(c) Explain the energy transformation in a hydroelectric power station.

UNIT 7 Simple machines (I)

Key Unit Competence

By the end of this unit, I should be able to analyse relationship between energy, work and power for simple machines.

Unit outline

- Definition of simple machine.
- Examples of simple machine (lever, pulley, wedge and axle, inclined plane, screw).
- Working principal of simple machines.
- Machine work out and friction in the machine.
- Mechanical advantage and velocity ratio of a machine.
- Determination of output of simple machine (efficiency).
- Experiment to determine efficiency of simple machines.

Introduction

In everyday life, people perform various tasks in order to improve their standard of life, environment, quality of health, and understanding of natural phenomena in order to exploit and be in terms with them. Some of the tasks people do include; drawing of water from a well using a windless, construction of houses using timber, nail and harmer, loading and unloading of good into the ships for export, joining of timber and metal using screws, splitting of firewood using a wedge, digging a garden in preparation for planting, lifting heavy objects into tracks. The devices that help us to perform work easily are called machines.

Machines can either be simple or compound. In this unit we are going to learn, understand and apply the principles behind simple machines.

7.1 Definition of simple machines

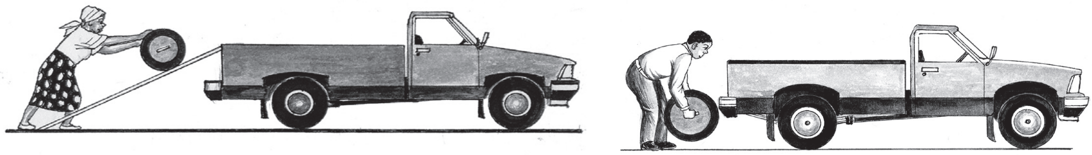
Activity 7.1 **To appreciate the definition and importance of a machine**

Materials: closed soda bottle, a bottle opener

Steps

1. Try to open a soda bottle with your hand. What do you notice?
2. Now try opening the same bottle using an opener. Which of the two tasks is easier and why.
3. Based on your observation in steps 1 and 2, define a simple machine.

A machine is a mechanical device or a system of devices that is used to make work easier. For example in loading an oil drum onto a truck, it is easier to roll it up an inclined plane (Fig. 7.1(a)) than lifting it up onto the truck (Fig. 7.1(b)).



(a) Rolling up a drum into a truck (b) Lifting up a drum into a truck

Fig. 7.1: Machines make our work easier

A machine may be defined as *any mechanical device that facilitates a force applied at one point to overcome another force at a different point in the system*. Examples of simple machines include lever, pulley, wedge, wheel and axle, inclined plane, and screws.

A simple machine is a machine that is made up of only one type of machine. Examples of simple machines are the screw, lever, inclined plane, pulley, wheel and axel and gears.

A compound machine is made up of more than one simple machines working together to perform a particular task with ease. An example of a compound machine is the car engine. The car engine consist of pulley, belts, gears, wheel and axel, pistons and other simple machines working together to bring about the movement of the car.

In mechanical machines, the force that is applied is called the effort (E) and the force the machine must overcome is called the load (L). Notice that both the load and effort are forces which act on the machine.

7.2 Terms used in machines

Activity 7.2 **To explain terms used in machines**

Materials: Internet, reference books

Steps

1. Conduct a research from the Internet or reference books on the terms used to describe the ability of machines to do work.

2. In your research, find out what mechanical advantage, velocity ratio and efficiency of machine are and their equations.
3. Present your findings to the whole class on the chalkboard.

From Activity 7.2, you should have established the following:

Mechanical advantage (M.A) of machines

Machines helps to overcome a large load by applying a small effort i.e. the machines magnify the force applied. The number of times a machine magnifies the effort is called the mechanical advantage (MA) of a machine. In other words, the mechanical advantage of any machine is the number of times the load is greater than the effort.

The mechanical advantage is therefore defined as the ratio of load to the effort. It describes how the applied force compares with the load to be moved. A machine with a mechanical advantage (M.A) of 1 does not change the force applied on it. A machine with a M.A of 2 can double your force, so you have to apply only half the force needed.

$$\text{Mechanical advantage} = \frac{\text{force applied by the machine to do the work (Load)}}{\text{force applied to the machine by the operator (Effort)}}$$

$$\therefore \text{ Mechanical advantage (M.A)} = \frac{\text{load (N)}}{\text{effort (N)}}$$

Since mechanical advantage is a ratio, it has no units.

Velocity ratio (V.R) of a machine

Velocity ratio of a machine is the *ratio of the velocity of the effort to the velocity of the load.*

$$\text{Velocity ratio (V.R)} = \frac{\text{velocity of the effort}}{\text{velocity of the load}}$$

$$= \frac{\frac{\text{displacement of efforts}}{\text{time}}}{\frac{\text{displacement of load}}{\text{time}}}$$

Since the effort and the load move for the same time,

$$\text{Velocity ratio (V.R)} = \frac{\text{displacement of effort}}{\text{displacement of load}} \text{ or } \frac{\text{effort distance}}{\text{load distance}}$$

Velocity ratio has no units

Efficiency of machines

For a perfect machine, the work done on the machine by the effort is equal to the work done by the machine on the load. However, there is no such a machine because some energy is wasted in overcoming friction and in moving the moveable parts of the machine. Hence, more energy is put into the machine than what is output by it. Thus,

Work input = Useful work done + Wasted work done

To describe the actual performance of a machine we use the term efficiency. Efficiency tells us what percentage of the work put into a machine is returned as useful work.

The efficiency of a machine is defined as the ratio of its energy output to its energy input.

$$\text{Efficiency} = \frac{\text{useful energy output}}{\text{energy input}} \times 100\%$$

or

$$\text{efficiency} = \frac{\text{useful work output}}{\text{work input}} \times 100\% = \frac{\text{load} \times \text{distance moved by load}}{\text{effort} \times \text{distance moved by effort}} \times 100\%$$

$$= \frac{\text{load}}{\text{effort}} \times \frac{\text{distance load is moved}}{\text{distance moved by effort}} \times 100\%$$

$$= \text{M.A} \times \frac{1}{\text{V.R}} \times 100\%$$

$$\text{Efficiency} = \frac{\text{M.A}}{\text{V.R}} \times 100\%$$

Example 7.1

A machine whose velocity ratio is 8 is used to lift a load of 300 N. The effort required is 60 N.

(a) What is the mechanical advantage of the machine

(b) Calculate the efficiency of the machine

Solution

(a) Mechanical advantage $= \frac{\text{load}}{\text{effort}} = \frac{300\text{ N}}{60\text{ N}} = 5$

(b) Efficiency $\frac{\text{M.A}}{\text{V.R}} = \frac{5}{8} \times 100\%$

$= 62.5\%$

Example 7.2

An effort of 250 N raises a load of 900 N through 5 m in a machine. If the effort moves through 25 m, find

(a) the useful work done in raising the load

(b) the work done by the effort

(c) the efficiency of the machine

Solution

(a) Useful work done in raising the load

$$= \text{load} \times \text{distance moved by load}$$

$$= (900 \times 5) = 4\ 500 \text{ J}$$

(b) Work done by the effort

$$= \text{effort} \times \text{distance moved by effort}$$

$$= 250 \times 25 = 6\ 250 \text{ J}$$

(c) Efficiency $= \dfrac{\text{work output}}{\text{work input}} \times 100\%$

$$= \frac{4\ 500 \text{ J}}{6\ 250 \text{ J}} \times 100\ \%$$

$$= 72\%$$

Example 7.3

Calculate the efficiency of a machine if 8 000 J of work is done on the machine to lift a mass of 120 kg through a vertical height of 5 m.

Solution

Work done in lifting the load $= 1\ 200 \times 5 = 6\ 000$ J

Work input $= 8\ 000$ J

Efficiency $= \dfrac{\text{work output}}{\text{work input}} \times 100\%$

$$= \frac{6\ 000 \text{ J}}{8\ 000 \text{ J}} \times 100\%$$

$$= 75\%$$

7.3 Types of simple machines

Activity 7.3 **To identify types of simple machines**

Steps

1. Brainstorm with your partner how simple machines are classified.
2. Now, access the internet and reference books and do a research on classification of simple machines.
3. Discuss your findings with others in your class.

Simple machines may be classified into two groups i.e. force multiplier and distance or speed multipliers. Force multipliers are those that allow a small effort to move a large load e.g. levers. Distance or speed multipliers are those that allow a small movement of the effort to produce a large movement of the load e.g. fishing rod, bicycle gear etc. Let us consider some simple machines and show how they operate.

7.3.1 Levers

Activity 7.4 **To demonstrate the working of levels**

Materials: a nail, claw hammer, piece of cloth, a pair of scissors, groundnut, pliers.

Part 1

Steps

1. Drive a long iron nail into a piece of timber.
2. Try to remove the nail from the timber using your fingers. What do you notice? Explain.
3. Repeat step 2 but use a claw hammer instead of your fingers. What happens?

Part 2

Steps

1. Take a piece of cloth and try to cut it into two pieces using your hand. What happens? Explain.
2. Repeat step 1 but use a pair of scissors instead of hands. What happens? Explain.

Part 3

Steps

1. Take a groundnut and try to crash it between your finger. Explain what happens.
2. Repeat the above but use a nut cracker. What do you observe? Explain.

In activity 7.4, you must have observed that it is difficult to perform the tasks using your fingers. However, using the simple machine, the work becomes easier. These types of machines are called levers.

Levers *are simple machines that apply the principle of moments*. A lever consists of a rigid bar capable of rotating about a fixed point called the pivot. The effort arm is the perpendicular distance from pivot to the line of action of effort (See Fig. 7.5).

There are classes of levers. The difference between these types depends on the position of the pivot (fulcrum) with respect to the load and the effort.

Class 1. The pivot in between the load and the effort. Examples (Fig. 7.2).

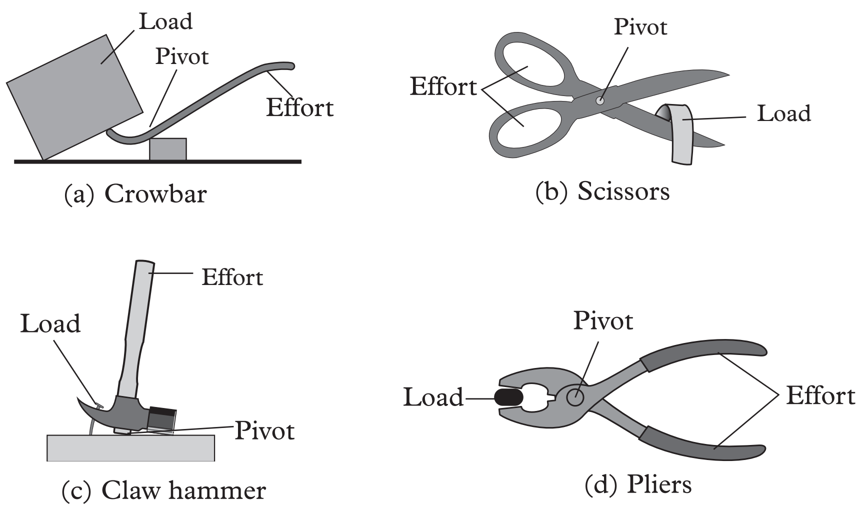


Fig. 7.2: Pivot between the load and the effort

Class 2. Load between effort and pivot. Examples (Fig. 7.3).

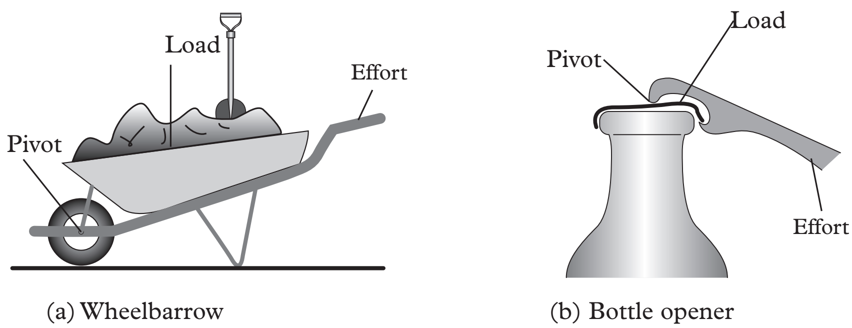


Fig. 7.3: Load between efforts and pivots

Class 3. Effort between load and pivot. Examples (Fig. 7.4).

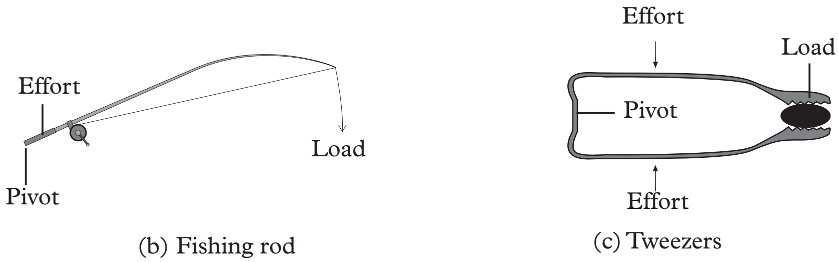


Fig. 7.4: Efforts between load and pivots

Mechanical advantage of levers

Consider a lever with the pivot between the load and the effort (Fig. 7.5).

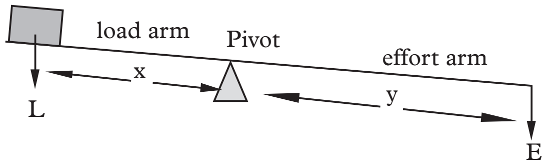


Fig. 7.5: Mechanical advantage for levers.

Taking moment about the pivot

load × load arm = effort × effort arm

$$\frac{\text{load}}{\text{effort}} = \frac{\text{effort arm}}{\text{load arm}}, \text{ But } \frac{\text{load}}{\text{effort}} = \text{mechanical advantage}$$

$$\text{Mechanical Advantage} = \frac{\text{effort arm}}{\text{load arm}} = \frac{y}{x}$$

This also applies to the other types of levers

Since effort arm is usually greater than load arms, levers have mechanical advantage greater than 1.

Velocity ratio for levers

Consider three types of levers in which the load and the effort have moved a distance d_L and d_E respectively (Fig. 7.6).

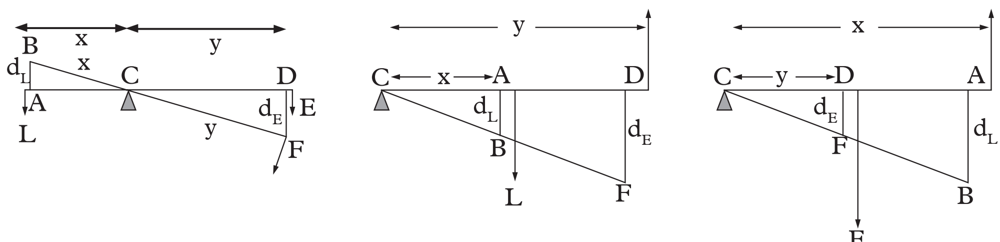


Fig. 7.6: Determination of velocity ratio of levers

Triangles ABC and DFC are similar triangles.

$$V.R = \frac{d_E}{d_L} = \frac{y}{x}$$

In Fig. 7.6(a) and (b), y is greater than x. The velocity ratio is therefore greater than 1. However in (c), y is less than x, and therefore the velocity ratio is less than 1. Cases (a) and (b) are examples of force multipliers. All force multipliers have M.A and V.R greater than 1. Case (c) is an example of distance multiplier in which both the velocity ratio and mechanical advantage are less than 1.

Example 7.4

A lever has a velocity ratio of 4. When an effort of 150 N is applied, a force of 450 N is lifted. Find (a) mechanical advantage (b) efficiency of the lever.

Solution

(a) Mechanical advantage $= \frac{\text{load}}{\text{effort}} = \frac{450\text{ N}}{150\text{ N}} = 3.0$

(b) Efficiency $= \frac{\text{M.A}}{\text{V.R}} \times 100\% = \frac{3}{4} \times 100\%$

$= 75\%$

Example 7.5

A worker uses a crow bar 2.0 m long to lift a rock weighing 750 N (Fig. 7.7).

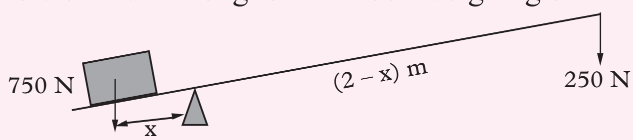


Fig. 7.7: Crow bar

(a) Calculate the position of the pivot in order to apply an effort of 250 N.

(b) Find the **(i)** velocity ratio **(ii)** mechanical advantage and **(iii)** efficiency of the lever.

(c) What assumptions have you made?

Solution

(a) Applying the principle of moments

$750x = 250(2 - x)$

$750x = 500 - 250x$

$1\,000x = 500$

$x = 0.5$ m from the end with 750 N.

(b) (i) velocity ratio $= \frac{\text{effort distance}}{\text{load distance}}$

$= \frac{1.5}{0.5}$

$= 3$

(ii) mechanical advantage $= \frac{750}{250} = 3$

(iii) efficiency $= \frac{\text{M.A}}{\text{V.R}} \times 100\% = \frac{3}{3} \times 100\% = 100\%$

(c) We have assumed that there is no friction and that the crowbar is weightless

Exercise 7.1

1. A machine requires 6 000 J of energy to lift a mass of 55 kg through a vertical distance of 8 m. Calculate its efficiency.
2. A machine of efficiency 75% lifts a mass of 90 kg through a vertical distance of 3 m. Find the work required to operate the machine.
3. A machine used to lift a load to the top of a building under construction has a velocity ratio of 6. Calculate its efficiency if an effort of 1 200 N is required to raise a load of 6 000 N. Find the energy wasted when a load of 700 N is lifted through a distance of 3 m.
4. Define the following terms as applied to levers:

   (a) mechanical advantage **(b)** velocity ratio
5. Find the velocity ratio of the levers shown in Fig. 7.8.

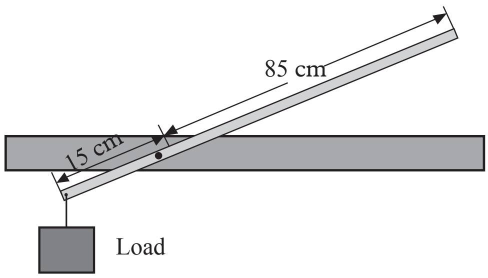


Fig. 7.8: Levers

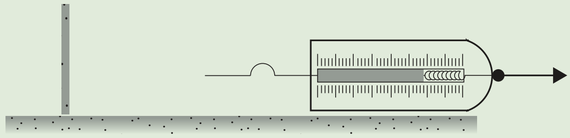
7.3.2 Inclined plane

Activity 7.5 **To determine the work done on trolley when pulled on a flat surface and on an inclined plane**

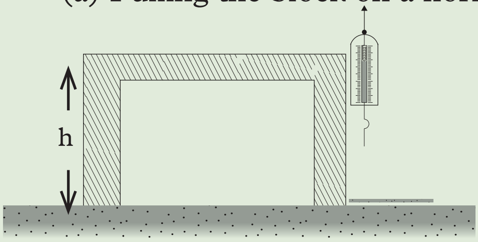
Materials: a wooden trolley, a spring balance, tape measure, a trolley, a cardboard, reference books, Internet.

Steps

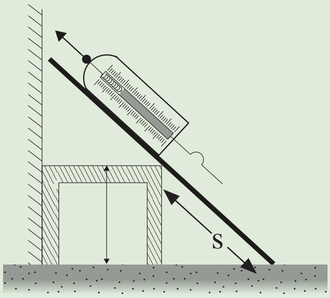
1. Attach screw e.g. onto a wooden block. Place a the block on a smooth horizontal surface.
2. Pull the wooden block with a spring balance to make the block move with constant speed (Fig. 7.9). Record the force reading on the spring balance (Fig. 7.9(a)).



(a) Pulling the block on a horizontal surface



(b) Lifting the block vertically upwards through (h)



(c) Moving the block along the slope through s

Fig 7.9: Determination of work done

3. Measure the height (h) of a table above the floor using a tape measure. Calculate the amount of work done when the trolley is lifted from the floor to the top of table (Fig. 7.9(b)).

4. Incline a wooden plank against the edge of the table.

5. Measure the force needed to pull the trolley up along inclined plane at a constant speed up to the top of the table (Fig. 7.9(c)).

6. Measure the distance (s) moved by the trolley along the inclined plane.

7. Determine the work done on the trolley when it is pulled up the inclined plane.

8. Which of the three ways it was easier to lift the trolley?

9. Analyse what force balanced the force applied as the block was being pulled across the table.

An inclined plane is a ramp or sloping surface that enables a load to be raised more easily using a smaller effort than when it is raised vertically upwards. It usually consists of a long plank inclined at an angle θ to the horizontal (Fig. 7.10). It is thus easier to take a heavy load from A to C by dragging along the plank than lifting it upwards from B to C.

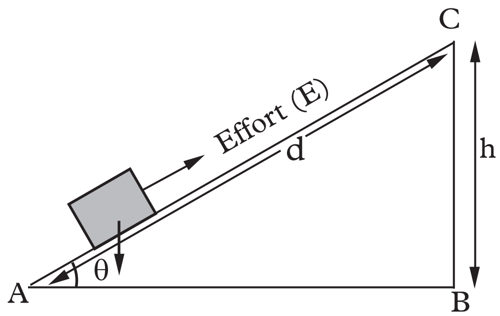


Fig. 7.10: Inclined plane

Velocity ratio of an inclined plane

$$\text{Velocity ratio (V.R)} = \frac{\text{distance moved by effort (d)}}{\text{distance moved by load (h)}}$$

Mechanical advantage (M.A) of an inclined plane

If the inclined plane is perfectly smooth (no friction), then the work done on load is equal to the work done by effort

$$\text{Work on load} = \text{Work done by effort}$$

$$\text{load} \times \text{h} = \text{effort} \times \text{d}$$

$$\frac{\text{load}}{\text{effort}} = \frac{\text{d}}{\text{h}}$$

$$\text{Hence mechanical advantage} = \frac{\text{d}}{\text{h}}$$

The ratio $\frac{d}{h}$ for an inclined plane is always greater than 1, hence its mechanical advantage is greater than 1. In practice, mechanical advantage is usually less than the calculated values due to frictional force.

To show how the length of an inclined plane affects mechanical advantage

Activity 7.6 **To investigate how the length of an inclined plane affects mechanical advantage**

Materials: A trolley, inclined plane, masses

Steps

1. Measure the mass of a trolley. Place it on an inclined plane of length *l*, (Fig. 7.11). Add slotted masses until the trolley just begins to move up the plane.

2. Record the values of the load, effort and the length l of the inclined plane.
3. Repeat the activity with inclined planes of different lengths. Make sure the height, h, and the load are kept constant.

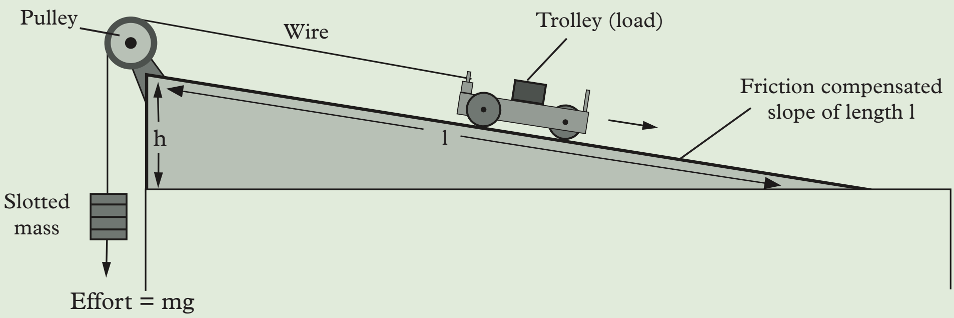


Fig. 7.11: How the length of inclined plane affects the mechanical advantage.

4. Record your results in Table 7.1. What happens to the applied effort when the length of the inclined plane is increased?

Effort E (N)	Length, l	Mechanical advantage = $\frac{L}{E}$

Table 7.1: Effort, length and ME values

We observe from the activity that as the length, l is increased, the effort applied is decreased.

Work done on the load = load × distance moved by the load

$= L \times h$

Work done on the effort = effort × distance moved by the effort

$= E \times l$

But the work done on the load is equal to the work done by the effort i.e.

$$El = L\,h$$

$$\therefore \quad E = \frac{Lh}{l} = \frac{mgh}{l} \text{ since } L = mg$$

But mgh is a constant: $\therefore \quad E \propto \frac{1}{l}$.

Therefore a small effort travels a long distance to overcome a large load.

7.3.3 Screws and bolts

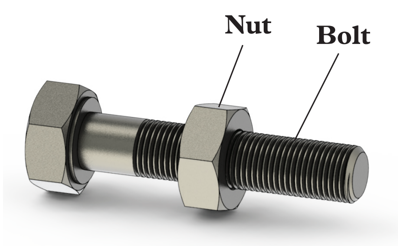
Activity 7.7 **To investigate the work of screw and bolt**

Materials: a screw, bolt, soft wood, a screw driver

Steps

1. Take a taping screw and count the number of threads it has.
2. Use a screw driver to drive the screw into a soft wood. Once it reaches the end, remove it from the wood.
3. Feel the threads with your fingers.
4. Measure the depth of the hole made by the screw.
5. Measure the total length of all the threads.
6. Compare the length of the threads with the depth of the hole.
7. Count the number of threads.
8. Determine the distance between two consecutive threads (Suggest the name given to this distance).
9. How many revolution of the screw head makes when the threads disappears completely into the wood?
10. Repeat the above steps using a bolt and a nut Fig 7.12.

Fig 7.12(a) shows a screw, bolt and nut.



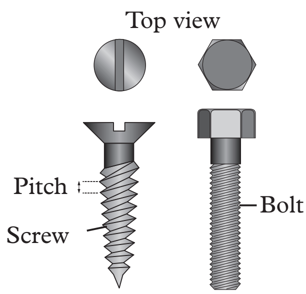


Fig. 7.12 (a): Screws, bolts and nut

The distance between the two successive threads is called pitch. When the screw is turned through one revolution by a force applied at the screw head, the lower end moves up or down through a distance equal to its pitch. The working of screws and bolts is based on the principle of an inclined plane.

Velocity ratio for a bolt

As the bolt is turned through one revolution, the screw moves one pitch up or down. The effort turns through a circle of radius R as the load is raised or lowered through a distance equivalent to one pitch (Fig. 7.13).

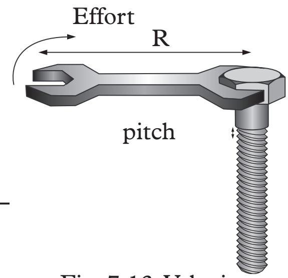


Fig. 7.13: Velocity ratio for a bolt

$$\text{velocity ratio} = \frac{\text{distance moved by effort}}{\text{distance moved by load}}$$

$$= \frac{\text{circumference of a circle, R}}{\text{pitch (p)}} = \frac{2\pi R}{p}$$

$$\text{V.R} = \frac{2\pi R}{p}$$

The effect of friction on mechanical advantage, velocity ratio and efficiency

From activity 7.7 you noticed that the threads felt warm after being driven into the wood. This means some of the work done was wasted as heat due to friction.

The mechanical advantage of a machine depends on the frictional forces present, since part of the effort has to be used to overcome friction. However, the velocity ratio does not depend on friction but rather on the geometry of the moving parts of the machine. Consequently a reduction of mechanical advantage by friction reduces the efficiency of a machine.

7.3.4 The wheel and axle

Activity 7.8 **To demonstrate action of wheel and axle**

Materials: cylindrical rod, y-shaped branches, a stone with string tied to it.

Steps

1. Construct a wheel and axle using locally available materials as shown in Fig. 7.14

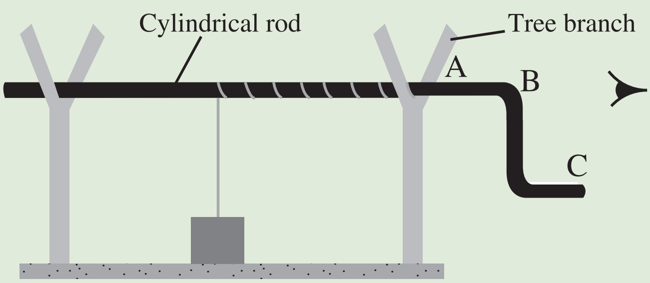


Fig 7.14: A wheel and axle

2. Turn the cylindrical rod at A to raise the stone. What do you realise?
3. Repeat turning the cylindrical rod but this time by turning at C. What do you realise? Explain.
4. Compare the energy needed to turn the cylindrical rod in the two cases.
5. Which feature of the setup represent the wheel and axle?
6. View the setup from B and draw the wheel, axle, load and effort.
7. Using various loads, find the force which in each case will just raise the load. Record your results in tabular form as shown in Table 7.2.

Load	Effort	M.A

Table 7.2: Values of load, efforts and N.A

Fig 7.15 shows simplified examples of wheel and axle.

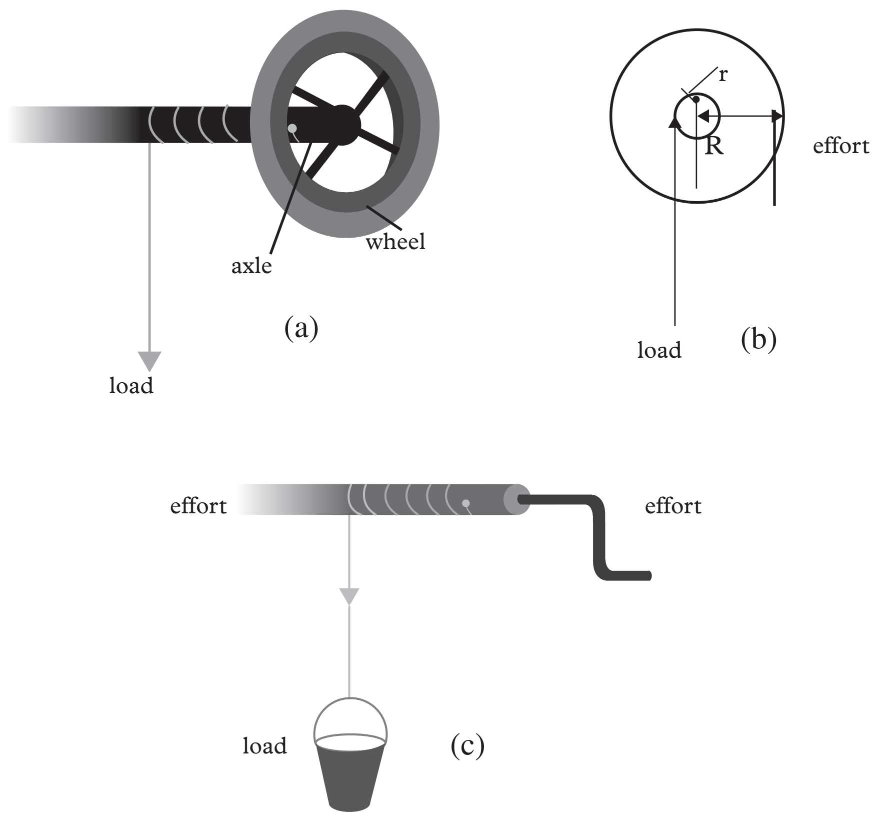


Fig 7.15: Simple wheel and axle

The wheel has a large diameter while the axle has a small diameter. The wheel and axle are firmly joined together and turn together on same axis. The effort is applied to the handle in the wheel. When the effort is applied, the axle turns, winding the load rope on the axle and consequently raising the load.

$$\text{Velocity ratio} = \frac{\text{distance moved by effort}}{\text{distance moved by load}} = \frac{2\pi \times \text{radius of wheel(R)}}{2\pi \times \text{radius of axle (r)}}$$

M.A may be obtained by taking moment

Load × radius of axle = effort × radius of wheel

$$\text{M.A} = \frac{\text{Load}}{\text{Effort}} = \frac{\text{radius of wheel}}{\text{radius of axle}} = \frac{R}{r}$$

Exercise 7.2

1. Give an example of a lever with a mechanical advantage less than 1. What is the real advantage of using such a machine?
2. Describe an experiment to determine the velocity ratio of a lever whose pivot is between the load and the effort.
3. An effort of 50 N is applied to drive a screw whose handle moves through a circle of radius 14 cm. The pitch of the screw thread is 2 mm. Calculate the:
   (a) velocity ratio of the screw.
   (b) load raised if the efficiency is 30%.

7.3.5 Pulleys

Activity 7.9 **To demonstrate the action of a pulley**

Materials: Reference books, Internet, a flag post

Steps

1. Conduct a research from the Internet and reference books on the working of pulleys and their application.
2. In your research, find out the types of pulleys and how to determine their velocity ratio.
3. Now, identify a flag post in the school compound. Suggest the kind of pulley it is.
4. Compare and discuss your findings with other groups in your class.
5. Let one of the group members present your findings to the whole class.

A pulley is usually a grooved wheel or rim. Pulleys are used to change the direction of a force and make work easy. Let us consider three types of pulleys i.e. single fixed, single movable and block and tackle.

(a) Single fixed pulley

Fig. 7.16 shows a single fixed pulley being used to lift a load. This type of pulley has a fixed support which does not move with either the load or the effort. The tension in the rope is the same throughout. Therefore the load is equal to the effort if there is no loss of energy. The mechanical advantage is therefore 1. The only advantage we get using such a machine is convenience and ease of raising the load.

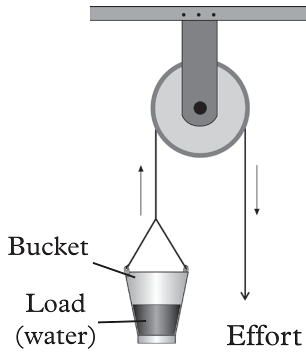


Fig. 7.16: Single fixed pulley

Since some energy is wasted due to friction and in lifting the weight of the rope, the mechanical advantage is slightly less than 1. The load moves the same distance as the effort and therefore the velocity ratio of a single fixed pulley is 1. Examples of real life applications of a single fixed pulley are as shown in Fig. 7.17.

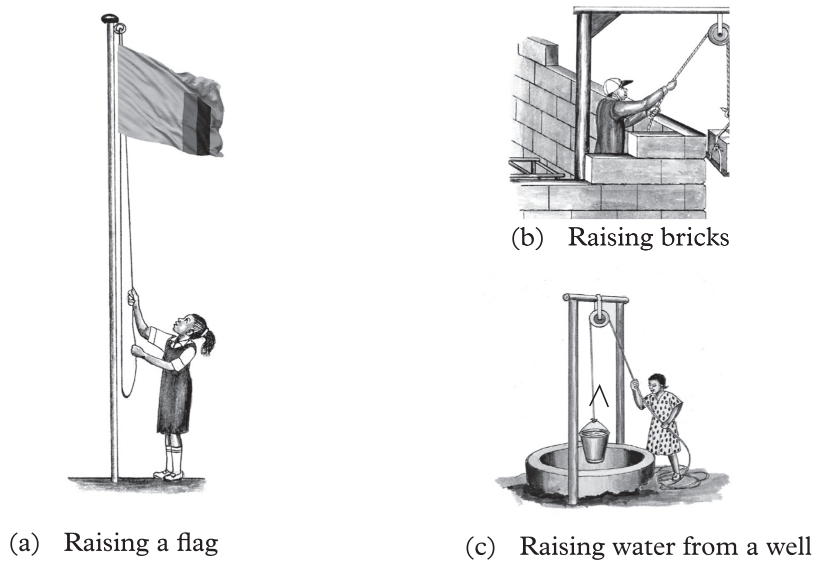


Fig. 7.17: Examples of single fixed pulley

My health

Ensure you have covered the well/borehole in our homes after use. Its water may be polluted or even cause death due to accidents.

The single moving pulley

Fig.7.18 shows a single movable pulley. A movable pulley is a pulley-wheel which hangs in a loop of a rope. A simple movable pulley may be used alone or combined with a single fixed pull. The total force supporting the load is given by the tension, T, plus effort, E, but since the pulley is moving up, the tension is equal to the effort.

Therefore, the upwards force is equal to twice the effort (2E). Hence the load is equal to twice the effort (2E).

$$\text{Mechanical advantage} = \frac{\text{load}}{\text{effort}} = \frac{2E}{E} = 2$$

However, since we also have to lift the pulley, the mechanical advantage will be slightly less than 2. Experiments show that the effort moves twice the distance moved by the load. Therefore,

$$\text{velocity ratio} = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}} = 2$$

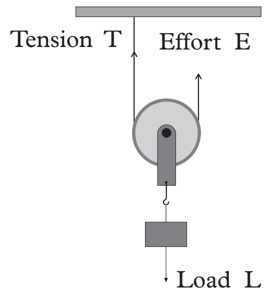
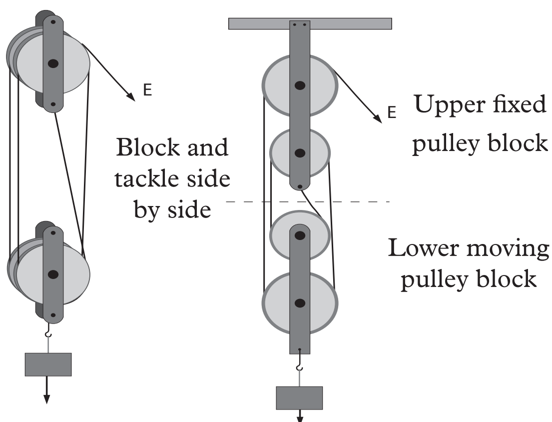


Fig. 7. 18: A single movable pulley

A block and tackle

A block and tackle consists of two pulley sets. One set is fixed and the other is allowed to move. The pulleys are usually assembled side by side in *a block* or frame on the same axle as shown in Fig. 7.19 (a). The pulleys and the ropes are called the *tackle*. To be able to see clearly how the ropes are wound, the pulleys are usually drawn below each other as shown in Fig. 7.19 (b).



(a) Pulley put side by side (b) Pulley drawn below each other

Fig. 7.19: Block and tackle systems.

To determine the velocity ratio of a block and tackle

Activity 7.10 **To determine velocity ratio of a block and tackle**

Materials: A block and tackle pulley system, a load, a metre rule

Steps

1. Set up a block and tackle system with two pulleys in the lower block and two pulleys in the upper block as shown in Fig. 7.19 (b).
2. Count the number of sections of string supporting the lower block. Raise the load by any given length, *l*, by pulling the effort downwards. Measure the distance, e, moved by the effort. Record the result in a table. (Table 7.3).
3. Repeat the activity by increasing the distance moved by the effort.
4. Plot a graph of *e*, against, *l* (Fig. 7.20). Determine the gradient of the graph.

Distance moved by effort (e) cm	Distance moved by load *l* cm
10	
20	
30	
40	

Table 7.3: Distance by effort and distane by land

5. Compare the value of the gradient obtained with the number of sections of supporting strings. What do you notice? Explain.

From Activity 7.10, it should have observed that the distance moved by the effort is $\frac{1}{4}$ distance moved by the load.

The graph of effort against the load is as shown in Fig 7.20

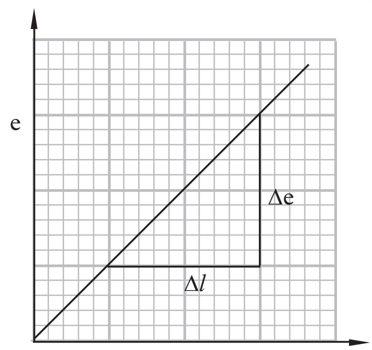


Fig. 7.20: Graph of the effort against the load.

The gradient $\frac{\Delta e}{\Delta l}$ which is the velocity ratio is found to be 4. When the value of the gradient is compared with the number of sections of string supporting the lower block, we note that they are the same i.e also 4.

Tip: *The velocity ratio of a pulley system is equal to the number of strings sections supporting the load.*

Precaution: The weight of the block in the lower section of the system has to be considered as this increases the load to be lifted.

Activity 7.11 To determine the mechanical advantage of a block and tackle

(Work in groups)

Materials: A block and tackle pulley, a load

Steps

1. Assemble the apparatus as in Fig. 7.19 shown in Activity 7.10 and connect a spring balance on the effort string. For a given load, pull the string on the effort string until the load just begins to rise steadily.
2. Repeat the activity with other values of load.
3. Record the values of the effort in a table (Table 7.4).

L	E	$\frac{L}{E}$

Table 7.4: Values of load (L), effort (E) and $\frac{L}{E}$

4. For each set of load and effort, calculate the mechanical advantage. Plot a graph of mechanical advantage against the load (Fig. 7.21). Comment on the shape of the graph.

Fig 7.21 shows a graph of mechanical advantage against the load.

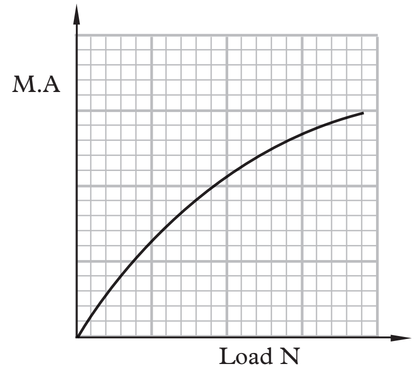


Fig. 7.21: Graph of mechanical advantage against the load

As the load increases, the mechanical advantage also increases. When the load is less than the weight of the lower pulley block, most of the effort is used to overcome the frictional forces at the axle and the weight of the lower pulley block. That is, the effort does useless work.

However, when the load is larger than the weight of the lower block, the effort is used to lift the load. This shows that the machine is more efficient when lifting a load that is greater than the weight of the lower block. Using the value of the velocity ratio obtained in Activity 7.11, calculate the efficiency of the pulley system. Plot a graph of efficiency against load (Fig. 7.22).

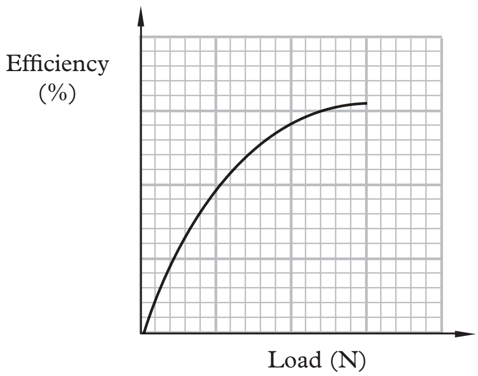


Fig. 7.22: The graph of efficiency against load

The efficiency of the system improves with larger loads.

Example 7.6

For each of the pulley systems shown in Fig. 7.23, calculate:

(i) velocity ratio

(ii) mechanical advantage

(iii) efficiency

Solution

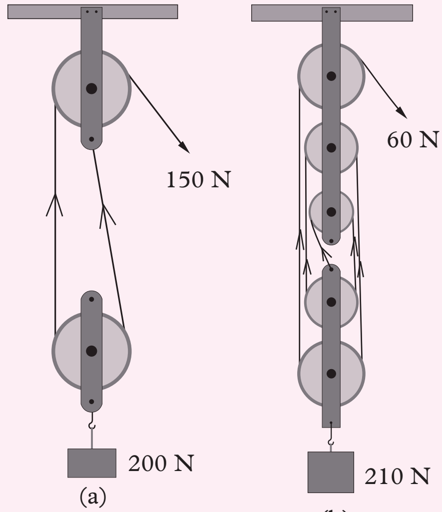


Fig. 7.23: Pulley system

(a) (i) velocity ratio = 2 (number of sections of string supporting the lower pulley)

(ii) mechanical advantage

$$= \frac{200\text{ N}}{150\text{ N}}$$

$$= \frac{4}{3} = 1.33$$

(iii) efficiency $= \left(\frac{4}{3} \times \frac{1}{2}\right) \times 100\%$

$$= 66.6\%$$

(b) (i) velocity ratio = 5

(ii) mechanical advantage

$$= \frac{\text{load}}{\text{effort}}$$

$$= \frac{210\text{ N}}{60\text{ N}} = 3.5$$

(iii) efficiency $= \frac{3.5}{5} \times 100\%$

$$= \frac{3.5}{5} \times 100\%$$

$$= 70\%$$

Example 7.7

Draw a diagram of a single string block and tackle system with a velocity ratio of 6. Calculate its efficiency if an effort of 1 500 N is required to raise a load of 5 000 N.

Solution

See Fig. 7.24

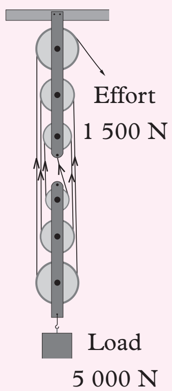


Fig. 7.24: Block Tackle pulley system

velocity ratio = 6

mechanical advantage $= \frac{5\ 000\text{ N}}{1\ 500\text{ N}} = \frac{10}{3}$

efficiency $= \frac{\text{M.A}}{\text{V.R}} \times 100\% = \frac{10}{3} \times \frac{1}{6} \times 100\%$

$$= 55.5\%$$

Example 7.8

A block and tackle pulley system has a velocity ratio of 4. If its efficiency is 75%. Find the

(a) mechanical advantage.

(b) load that can be lifted with an effort of 500 N.

(c) work done if the load is lifted through a vertical distance of 4.0 m.

(d) average rate of working if the work is done in 2 minutes.

Solution

(a) efficiency $= \dfrac{\text{M.A}}{\text{V.R}} \times 100\%$

$$75 = \frac{\text{M.A}}{4} \times 100\%$$

mechanical advantage = 3

(b) $\text{MA} = \dfrac{\text{load}}{\text{effort}}$

$$3 = \frac{\text{load}}{500}$$

Load = 1 500 N

(c) work = force × distance in the direction of force

= 1 500 × 4

= 6 000 J

(d) Rate of doing work = Power

$$\text{Power} = \frac{\text{work done}}{\text{time}}$$

$$= \frac{6\,000}{120} = 50 \text{ W}$$

Exercise 7.3

1. **(a)** Draw a system of pulleys with two pulleys in the lower and upper block.
   (b) Describe how you would find experimentally its mechanical advantage.

2. Fig. 7.25 shows a pulley system.

   Find;

   (a) the velocity ratio of the pulley system.

   (b) the mechanical advantage, if the system is 80% efficient.

   (c) the effort.

   (d) the work done by the effort in lifting the load through a distance of 0.7 m.

   (e) how much energy is wasted.

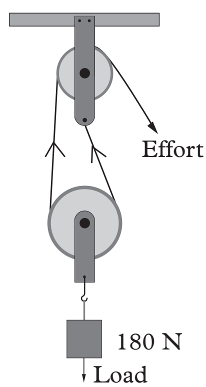


Fig. 7.25: Pulleys system

3. A pulley system has a velocity ratio of 3. Calculate the effort required to lift a load of 600 N, if the system is 75% efficient.

4. A pulley system has a velocity ratio of 4. In this system, an effort of 68 N would just raise a load of 217 N. Find the efficiency of this system.

Unit summary and new words

- A machine is a device that makes work easier.
- Mechanical advantage (M.A) is defined as the ratio of load to effort.
- Mechanical advantage = $\frac{\text{load}}{\text{effort}}$.

  The mechanical advantage of a machine depends on loss of energy of the moving parts of a machine. Mechanical advantage is a ratio of similar quantities hence it has no units.
- Velocity ratio (V.R) is defined as the ratio of distance the effort moves to that moved by the load.

$$\text{Velocity ratio} = \frac{\text{Distance moved by the effort}}{\text{Distance moved by the load}}.$$

  Velocity ratio is a ratio of similar quantities hence it has no units.

- Theoretical value of velocity ratio may be obtained from the dimensions of the machine e.g. in pulleys–number of the sections of string supporting the load.

Machine	VR
Inclined plane	$\frac{1}{\sin \theta}$
Screw	$\frac{2\varpi r}{\text{pitch, P,}}$
Wheel and axle	$\frac{\text{Radius of wheel, R}}{\text{Radius of axle, r}} = \frac{R}{r}$

Table 7.5: Expressions for velocity ratio of various machinery

- Efficiency $= \frac{\text{work output}}{\text{work input}} \times 100\% = \frac{\text{mechanical advantage}}{\text{velocity ratio}} \times 100\%$

Unit Test 7

1. Define the following terms:
   - (a) Power of a machine
   - (b) Efficiency
   - (c) Mechanical advantage (M.A)
   - (d) Velocity ratio (V.R)

2. A farmer draws water from a well using the machine shown in Fig. 7.26. The weight of the bucket and water is 150 N. The force, F exerted by the farmer is 170 N. The bucket and its content is raised through a height of 15 m.
   - (a) What is the name given to such a machine?
   - (b) Why is the force, F, larger than the weight of the bucket and water?
   - (c) What distance does the farmer pull the rope?
   - (d) How much work is done on the bucket and water?
   - (e) What kind of energy is gained by the bucket?

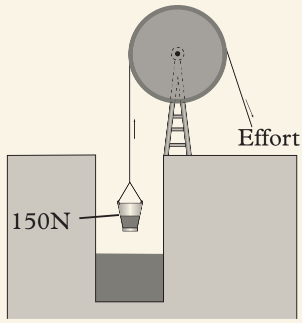


Fig. 7.26: A simple pulley system

   - (f) How much work is done by the farmer?
   - (g) Where does the energy used by the farmer come from?
   - (h) Show with a flow diagram the energy conversion in lifting the water from the well.

3. A factory worker lifts up a bag of cement of mass 50 kg, carries it horizontally then up a ramp of length 6.0 m onto a pick-up and finally drops the bag of cement on the pick-up (Fig. 7.27).

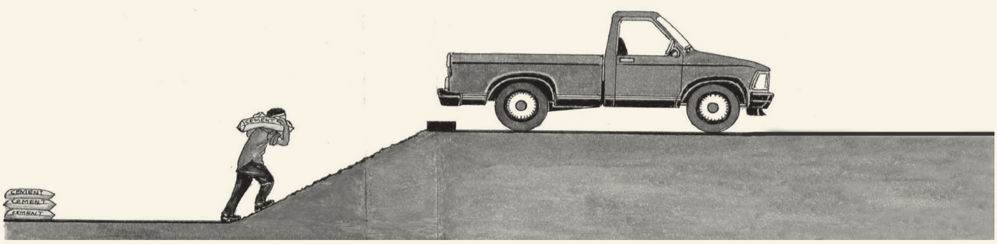


Fig. 7.27: Worker lifting cement on the pick-up

   - (a) Explain the energy changes in the various stages of the movement of the worker.
   - (b) During which stages is the worker doing work on the bag of cement.

(c) If the worker has a mass of 60 kg and the ramp is 1.5 m high, find the

(i) velocity ratio.

(ii) efficiency of the inclined plane if the mechanical advantage is 3.

4. Fig. 7.28 shows the cross-section of a wheel and axle of radius 6.5 cm and 1.5 cm respectively used to lift a load. Calculate the efficiency of the machine.

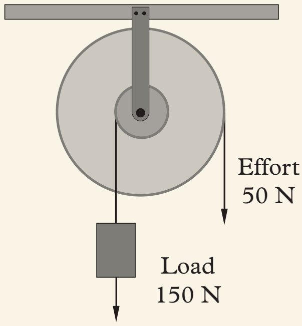


Fig. 7.28: Wheel and axle

5. A student wanted to put 10 boxes of salt at the top of the platform using an inclined plane (Fig. 7.29).

If the resistance due to friction is 10 N, calculate

(a) the work done in moving the 10 boxes.

(b) the efficiency of this arrangement.

(c) the effort required to raise one box to the platform.

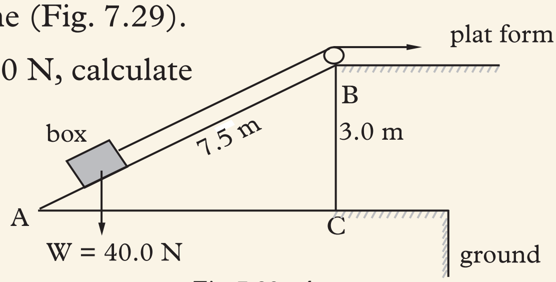


Fig. 7.29: A crane

6. A crane just lifts 9 940 N when an effort of 116 N is applied. The efficiency of the crane is 75%. Find its:

(a) mechanical advantage

(b) velocity ratio

7. Fig. 7.30 shows a pulley system. An effort of 113 N is required to lift a load of 180 N.

(a) What distance does the effort move when the load moves 1 m?

(b) Find the work done by the effort.

(c) Find the work done on the load.

(d) Calculate the efficiency of the system.

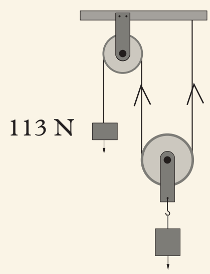


Fig 7.30 A pulley system

8. The Fig. 7.31 shows a single fixed pulley.

Calculate its:

(a) V.R

(b) Efficiency

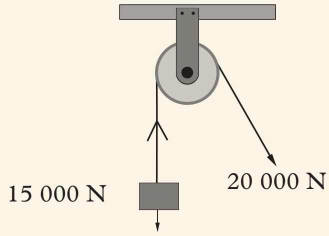


Fig 7.31: Single fixed pulley

9. In the system shown in Fig. 7.32, the winding machine exerts a force of 2.0×10^4 N in order to lift a load of 3.2×10^4 N.

(a) What is the velocity ratio?

(b) Calculate the M.A.

(c) Find the efficiency.

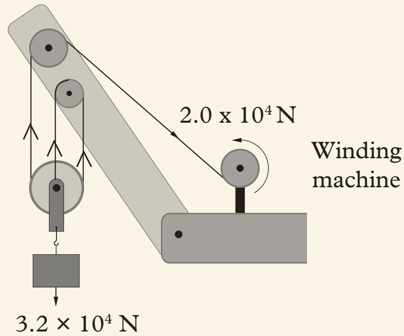


Fig. 7.32: A winding crane

10. Fig. 7.33 shows a pulley system.

(a) What is the velocity ratio of the system?

(b) Calculate the efficiency of the system.

(c) Show the direction of the force on the string.

11. A block and tackle pulley system has five pulleys. It is used to raise a load through a height of 20 m with an effort of 100 N. It is 80% efficient.

(a) Is the end of the string attached to the upper or lower block of pulleys if the upper block has three pulleys? Show it in a diagram.

(b) State the velocity ratio of the system.

(c) Calculate the load raised.

(d) Find the work done by the effort.

(e) Find the energy wasted.

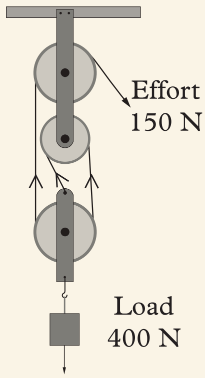


Fig. 7.33: A block and tackle pulley

12. A man pulls a hand cart with a force of 1 000 N through a distance of 100 m in 100 s. Determine the power developed.

UNIT 8 Kinetic Theory and States of Matter

Key Unit Competence

By the end of this unit, I should be able to relate physical properties of solids, liquids and gases to temperature.

Unit outline

- Simple kinetic theory.
- Physical properties of solids.
- Physical properties of liquids.
- Physical properties of gases.
- Applications of physical properties.
- Recognision of physical properties of matter.

Introduction

In our daily life we interact with solids, liquids and gases. We see them behaving in certain ways under particular conditions. But what are they exactly made of and what makes them behave in such ways? In this unit we will study the particulate nature of solids, liquids and gases and their behaviour when heated. This is usually referred to as the kinetic theory of matter.

8.1 Matter and its composition

Activity 8.1 **To describe matter**

From your knowledge of science at the primary level:

1. Discuss with your class partner 10 things that surround you.
2. Verify whether these objects have a specific mass and occupy space.
3. What common scientific name should be given to those objects since both have mass and occupy space?

As you learnt in your primary science, matter is anything that has mass and occupies space. Anything around us is matter, e.g. cup, a plate, a wall, milk, air, banana and so on. But what is matter made up of? Activity 8.2 will help us to understand this.

Activity 8.2 **To investigate composition of matter**

Materials: a piece of chalk

Steps

1. Get a piece of chalk. Break it into two halves.
2. Continue breaking until when the breaking can't continue any further. What do you notice about the initial piece of chalk and the final particle in terms of size?
3. Discuss your observations in step 2 with your colleagues.
4. Discuss with your colleague what you think an element, compound and mixture are.

From Activity 8.2, we observe that matter is made of tiny particles. The smallest particle of mater that can't be broken down further is called an atom. An atom is the smallest particle of matter that can take part in a chemical reaction.

Warning

Talking of tiny particles/things that have a great impact, the HIV/AIDS virus for instance, is a very **tiny** infectious virus that has killed over 25 million people since the beginning of the epidemic in the early 1980s. Currently, over 33.4 million people in the world are infected with HIV or have AIDS, meaning they are in the final stage of the HIV disease. There is NO CURE for HIV or AIDS. That means prevention is the most important step in protecting your health. **SAY NO TO SEX BEFORE MARRIAGE.**

Matter can be made of particles (atoms) of the same kind or a mixture of particles of different kind. Matter made of same kind of particles is called an **element**, while that made up of different kinds of particles can be a **mixture or a compound.**

An element is a substance which cannot be split into a simpler substance. In other words, all the atoms in a substance have the same identity that substance is called an element e.g. copper, graphite in pencil (carbon).

A compound is a substance made of two or more elements combined together in a fixed proportion. E.g. water is made up of oxygen and hydrogen, table salt is made of sodium chloride, chalk is made up of calcium carbonate, that is, calcium, oxygen, and carbon.

Mixtures is a material made up of two or more substances that can easily be separated by physical means. e.g. pizza.

8.2 Physical properties of matter

Matter can be in the form of solids, liquids and gasses and can be classified based on its chemical property and physical properties that have been tested and have been observed.

Some physical properties are only known through experimentation, while others are visible to the unaided eyes.

Activity 8.3 **To differentiate between physical and chemical properties of matter**

Materials: piece of dry wood, bunsen burner, match box, magnet and a rail, piece of paper

Steps

1. Bring a magnet near a piece of wood then to the nail. What do you observe? Take it away. Do the wood and nail change in any way?
2. Light a match stick or a bunsen burner and burn either the paper or a piece of dry wood to ashes. After that, check if the ash still the same as wood (If they have the same composition). What can be done to the ash to turn it back into wood or piece of paper?

You observed that the composition of the piece of wood and nail does not change after being brought near the magnet. Such a property that is observed on matter and it does not change its composition is called a physical property.

A physical property is a characteristic that can be observed or measured without changing the composition of the sample.

For example copper is a solid metal at room temperature, with a high melting point of about 1083°C. It is shiny, bendable, and orange-brownish in colour. It can be stretched into a wire or flattened into a very thin sheet of metal. All these are physical properties because they do not change into anything else when these properties are observed. Similarly, passing electricity through copper will not change it into another substance.

A chemical property is a characteristic of a substance that is only altered through a chemical reaction and results into a substance of different composition and internal structure. In the same activity, you observed that when the piece of wood was burned, the chemical composition change hence it become ash. This is an example of a chemical property.

In Activity 8.4, we noticed that the spheres of different sizes have different masses. i.e mass depend on the size (quantity) of the substance. Such a quantity like mass is called an intensive property. We also noted that density of water is the same irrespective of the magnitude of volume or mass. Such a quantity like density is called an extensive quantity.

(i) Intensive property; it is a characteristic of matter that does not depend on the amount of matter being measured. They are the same even if it is for one gram or a 1000 kg of the substance. e.g. colour, odour, density, conductivity, hardness etc.

(ii) Extensive property; is any characteristic of matter that depends on the amount of matter being measured e.g. mass, weight, volume and length.

In activity 8.5, you should have observed that the magnet attracts iron filings to itself thus separating them from the sand. This is possible because of the attraction property between a magnet and magnetic material.

Applications of properties of materials

Some of the applications of properties of materials include:

1. Ductile materials like copper can be drawn into wires which conduct heat and electricity quickly. That's why it is used in power cords.
2. Gold can be recast into sheets as thin as 0.1 μm. This property of gold makes it useful for decorating picture frames and other objects. Gold that has been recast in this way is called a gold leaf.
3. The element with the highest melting point is tungsten metal which melts at 3695 K (3422°C, 6192°F) making it excellent for use as a filament in light bulbs.
4. The property of elasticity gives objects the ability to 'bounce back' hence withstand impact without breaking. Examples are netball, and football, and car tyres.
5. Magnets easily separates iron filings from sand and can be explained by Activity 8.5.

Eercise 8.1

1. What is matter?
2. Senior 1 students, Akaliza and Gasimba, were discussing the difference between physical and chemical properties of matter after carrying out activities on each of them. How does a physical property of matter differ from a chemical one?
3. Define the following terms:
   (i) an element **(ii)** a compound
4. Differentiate between intensive and extensive properties of matter and give two examples of each.

8.3 Introduction to kinetic theory

Activity 8.4 **To demonstrate motion of matter using purple crystals of potassium permanganate, water and a bunsen burner**

Materials: two beakers, purple crystals of potassium permanganate, water a bunsen burner and a perfume.

Steps

1. Get a beaker and pour in water up to more than half its height and leave it to settle.
2. Get the crystals of potassium permanganate and drop them into the water in the beaker. What do you observe? Explain your observation.
3. Repeat step 2 but this time heat the beaker gently. Compare your observations with that in step 2.
4. Stand in one corner of the classroom with a perfume and spray (release the spray). What is observed by other pupils in the opposite corner after a few seconds? Explain.
5. Discuss your observations in steps 2, 4 and 5 and state the kinetic theory of matter.

In Activity 8.4 step 2, the purple colour is seen to spread throughout the water and when heat is supplied, the colour spreads very first. In step 5, the scent of the perfume is smelt because the particles of the perfume have moved from one point to the other. This shows us that matter is made of particles that are constantly moving. If matter were not moving, then we would only see a clump of colour as there would be nothing that could move about and mix with the water. The movement of these tiny particles is summed up in a model called the kinetic theory of matter.

The kinetic theory of matter

The word kinetic is derived from the Greek word "*kineo*" which means "I move". Particles in substance are in constant motion; they posses kinetic energy, which is the energy due to movement. Therefore, kinetic theory of matter states that matter is made up of tiny discrete individual particles that are continuously in random motion. It says that the materials particles have greater kinetic energy and are moving faster at higher temperatures.

When a fast moving particle collides with a slower moving particle, it transfers some of its energy to the latter, increasing the speed of that particle. If that particle collides with another particle that is moving faster, its speed will be increased even more. But if it hits by a slow moving particle, then it will speed up the third particle.

The theory explains how particles are packed in solids, liquids or gasses; the attractive forces between them; and the effect of temperature on them. The arrangement of particles of matter and the way they move determines the state of a substance, i.e. whether to be in solid, liquid or gaseous state.

Note!

One important fact explained by the kinetic theory is that the average molecular kinetic energy is proportional to the absolute temperature of the material. A such, temperature is a measure of the average internal kinetic energy of an object.

8.4 Physical properties of solids

Arrangement of particles in a solid

Activity 8.5 **To investigate physical properties of solids**

Materials: Internet, reference books, marbles and a transparent square bowl

Steps

1. Access the Internet or reference books and do a research on the physical properties of solids and their application.
2. Now, put as many marbles into a transparent square bowl as you can. Incline the bowl a bit.
3. Continue adding more marbles into the bowl as many as possible.

4. Cover the bowl with a lid and note the pattern (arrangement) of marbles inside it.
5. Draw the arrangement of the particles.
6. Fill the bow fully with the marble and cover it tightly with a lid. Try to shake the bowl while pressing the lid firmly. Explain the effect on their pattern and the movement to your partner.

The pattern of marbles in Activity 8.5 illustrates the arrangement of particles in a solid. This is shown by the diagram in Fig. 8.1.

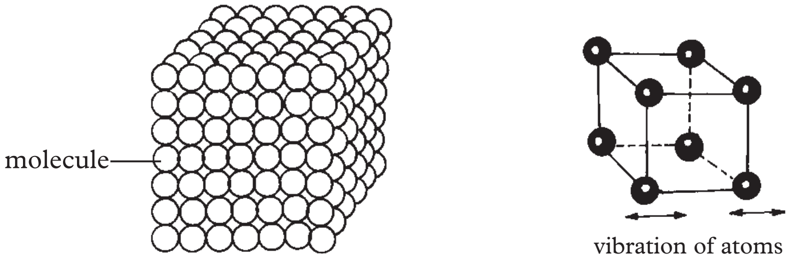


Fig 8.1 Arrangement of particles in solids

The particles in a solid are so tightly packed making them difficult to move. Solids have strong intermolecular forces in between the particles making them particles to be closely packed in fixed positions (rigidity).

Therefore, solids have a definite shape and volume. They are rigid and incompressible. They have the highest density compared to liquids and gases.

A large force is needed to change the size and shape of a solid. Also, for a solid to melt into a liquid, it requires a lot of heat energy since the cohesive forces between the particles are strong.

Kinetic theory of solids

Particles or molecules in a solid are continuously vibrating in a fixed or mean position. When a solid is heated, the heat energy absorbed by the particles increases the kinetic energy; this makes the particles to vibrate more vigorously but in their fixed positions.

Increase in heat energy increases the kinetic energy in the particles and weakens the cohesive forces between the molecules up to a point when the intermolecular forces are weak to allow the matter to flow. This point is referred to as melting. The process of a solid changing into a liquid is called melting.

Some physical properties of solids include

- **Malleability:** is a measure of solid's ability to be reshaped into other shapes else like thin sheets. Aluminum is a highly malleable metal. Aluminum foil and cans are two good examples of how manufacturers take advantage of the malleability of aluminum.
- **Tensile strength:** is the measure of how much pulling, or tension a material can withstand before breaking. It is an important property of fibers, as it determines the strength of ropes and fabrics. It is also crucial to the manufacture of cables and girders used to support bridges.
- **Conductivity:** solids have wide range of electrical conductivities (the easiness with which heat and electricity to go through it).

On the basis of conductivity the solid can be classified as:

(i) Conductors are good conductor of electricity. Examples are metals.

(ii) Insulators- have very low conductivity. Examples are wood, plastics, sulphur, rubber.

(iii) Semiconductors- their conductivity is in between conductors and insulators.

- **Elasticity:** this is the ability of a material to regain its original size and shape when the stretching force has been removed. If you pull a rubber band, its shape changes. If you let it go, the rubber band returns to its original shape. This property also gives objects the ability to bounce and withstand impact without breaking.
- **Hardness:** is a measure of a solid's resistance to breakage. Diamond is the hardest natural substance found on earth. Geologists sometimes classify rocks based on hardness.
- **Density:** is the mass per unit volume of the substance. The density of a homogeneous material is the same no matter how large or small the samples of material.

The density gives an indication of how tightly packed the atoms or molecules are. For instance, lead has many atoms very tightly packed together. This gives it a very high density of 11300 kg/m^3.

Samples of heterogeneous mixtures may not necessarily have the same density.

8.5 Physical properties of liquids

Activity 8.6 **To investigate physical properties of liquids**

Materials: Water in a beaker, bunsen burner, chalk dust

Steps

1. Put the chalk dust on the surface of the water in the beaker. Observe and explain the motion of the chalk particles.
2. Now, start heating the water to boil. Observe and explain the motion of the chalk particles.
3. Draw the arrangement of particles in liquids.

In Activity 8.6 the chalk dust particles are seen moving in random manner. Tiny invisible water molecules, moving in different directions with different speeds, collide with the chalk dust particles and force them to move. This activity suggests that the invisible, tiny molecules of water are in a constant random motion.

As seen in activity, the liquid molecules move freely, unlike the molecules in a solid. The distance between the molecules is slightly greater than the distance between molecules of a solid. The molecules of a liquid are loosely packed unlike those of the solid (Fig. 8.2).

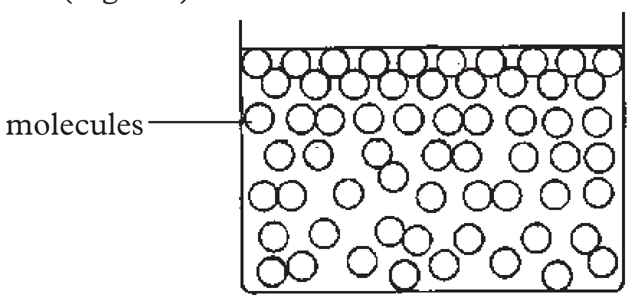


Fig 8.2: Arrangement of particles in liquids

Though solids have a definite volume, they have no definite shape. The force of attraction between the molecules is lower than the force of attraction between the molecules of a solid.

Though liquids have definate size (volume), they have no particular shape. They take the shape of the container.

When the temperature increases, liquid molecules acquire more kinetic energy and hence move faster. This increase in kinetic energy of liquid molecules weakens the intermolecular forces between the particles. A further increase in kinetic energy makes the molecules to escape through the surface of the liquid. i.e., change into steam or gaseous state. The process of a liquid changing into the gaseous state is called **evaporation/boiling**.

The following are some physical properties of liquids:

(a) Viscosity

Activity 8.7 **To demonstrate viscosity in liquids**

Materials: house hold liquids (water, honey, oil, milk, paraffin), a sphere such as a steel ball, 100 ml graduated cylinders, ruler, stopwatch.

Steps

1. Measure equal amounts of water, honey, oil, milk and paraffin and pour them into different the graduated cylinders.
2. Measure and record the depth of the liquids in the cylinders.
3. Place the sphere on the surface of water. Using a stopwatch, measure and record how long it takes for it to travel to the bottom of the liquid.
4. Remove the sphere and repeat step 3, two times for the same liquid. What do you observe?
5. Rinse and dry the sphere.
6. Repeat steps 3,4 and 5 for the rest of the liquids. What do you observe? Explain your observation.
7. Tabulate your result in a table form as one shown in Table 8.1.

Substance	Trial	Depth of liquid (cm)	Time (s)	Speed (s)

Table 8.1: Table of results

From Activity 8.7, you should have noted that the sphere travelled at different speeds in different liquids. The sphere moved fastest in water and lowest in honey. This shows that, water has the lowest viscosity than other liquids since it offers minimum resistance to the movement of the sphere through it. Honey has the highest viscosity than the other liquids.

(a) Solubility

Activity 8.8 **To dissolve some salt in water**

Materials: A beaker, table salt, water, stirrer

Steps

1. Put some crystals of table salt in a beaker
2. Pour some water in the beaker
3. Stir the mixture for sometime.
   (a)What happens to the salt crystals?
   (b)What name is used to describe this process.

The solubility of a substance is the amount of that substance that will dissolve in a given amount of solvent. Some substances are soluble while others are not. Examples of soluble substances are sugar, salt while insoluble substances are stones, metals, and sand.

(b) Evaporation

Activity 8.9 **To observe evaporation of liquids**

Materials: Methylated spirit

Steps

Pour some drops of methylated spirit onto the back of your palm.

(a) What do you feel? Suggest reason.

(b) What happens to the drops of the liquid after some time?

(c) What name is given to this process?

Evaporation is the process of changing from liquid to gas. Evaporation at a liquid's surface can take place at a wide range of temperatures.

(c) Boiling point

Activity 8.10 **To investigate boiling of water**

Materials: Beaker, water, source of heat, tripod stand, wire guaze, stirrer, thermometer

Steps

1. Put some water into the beaker. Dip the stirrer and thermometer into the beaker. Record the temperature.
2. Place the beaker and its content onto the stand and place the source of heat below it as shown in Fig. 8.3.
3. Continue heating the water as you observe the change in temperature.
4. The temperature reaches a point when the water will start boiling violently. Record the temperature. What is the name of this process?

   During this process is there a change in the temperature of the water? Try explaining what is happening to the molecules of water during this process

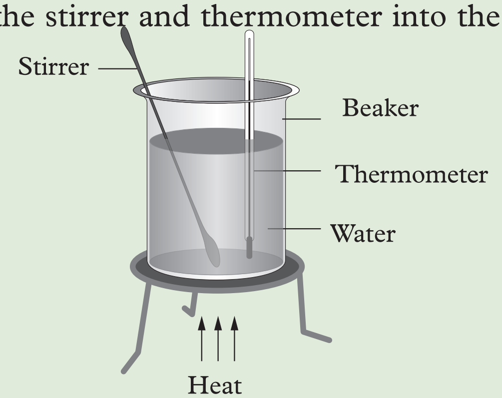


Fig 8.3: Boiling water

Boiling point is the temperature at which a liquid changes into a gas when the saturated vapor pressure of the liquid is equal to the external atmospheric pressure under one atmosphere. At this point, the liquid changes to gases state at constant temperature.

Application of some physical properties of a liquid

Activity 8.11 **To separate a mixture of sand and salt**

Materials: sand, salt, water, source of heat, a beaker made of hard glass

Steps

1. Mix the sand and salt together.
2. Add water to the mixture and stir. Allow the sand to settle at the bottom of the beaker.
3. Filter out the sand (sand is removed by by filtration because it doesn't dissolve in water).

3. Boil the solution in the beaker to allow the water evaporate away leaving saturated solution.
4. Allow the saturated solution to cool. This will make crystals start to grow which can be collected and allowed to dry.

In Activity 8.11, we have applied the solubility property of salt to separate it from sand.

1. In general, to separate a liquid from an insoluble solids, filtration is done. The solid remains in the filter paper and the liquid goes through the paper into the beaker. There are two basic purposes of filtration: either to obtain the solid material suspended in the liquid, or to purify the liquid in which the solid is suspended. One of the common application is in sewage treatment. In this process the solid waste is filtered out and liquid water is treated before it is released to the rivers.

2. To separate and collect a liquid from a solution, the solution is heated in a flask until it boils. The vapour produced is passed through a condenser where it is cooled and condenses to a liquid. The pure liquid (distillate) is collected in a beaker. Distilled water, purchased for drinking and other purposes, is just one of the most common applications of the distillation process.

Warning

Always drink boiled or treated water to avoid being infected by diseases like typhoid.

8.6 Physical properties of gases

Activity 8.12 **To investigate the physical properties of gases**

Materials: three marbles, transparent dish, a lid, reference books, Internet

Steps

1. Access the internet and reference books and do a research on the physical properties of gases. Discuss your findings with other groups in your class.
2. Now, put three marbles in a transparent dish. Try as much as you can to move them further away from one another.
3. Cover the dish with a lid. Shake the dish. What do you observe in the movement of the marbles? Explain.

In Activity 8.12, you observed that marbles moved very freely in all directions about in the dish. This is similar to the behaviour of particles in a gas.

In gases, the intermolecular forces are so weak to be considered. Weak intermolecular forces only exist upon collision. A gas has no definite shape and volume, so they fill the container of any size and shape completely.

Activity 8.16 To demonstrate that gases occupies space

Materials: polythene bag (plastic bag), a straw, cello tape, heavy book.

Steps

1. In groups of five, pick one plastic bag (polythene bag) and insert a straw into it. Leave part of the straw to protrude from the bag and then seal it with cello tape.
2. Place it on the table and then place a heavy book on it.
3. In turns, blow into the bag. What do you observe? Explain your observation.
4. Discuss the arrangement of gas particles and sketch the diagram to show them.

CAUTION

The material making up, plastic bags (polythene bags) determine, how easily it can be recycled. Some plastics can take years to decompose. But some companies and stores have begun using different types of biodegradable bags to avoid environmental pollution. If poorly disposed plastic pollutes the environment and can easily to ingested by livestock and wild animals.

From Activity 8.13, you observed that the polythene paper bulged when you blew air into it. This is because the number of gas molecules increased in the bag as one blew into it. This demonstrate that gases occupy space. Fig 8.4 shows the arrangement of gas particles.

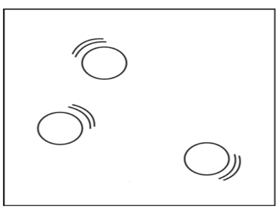


Fig. 8.4 Arrangement of gas particles

The distance between the molecules is large (see Fig 8.4) and the force of attraction between the molecules is very small (almost negligible). These molecules move about freely in all directions colliding with each other and with the walls of the container. The movement of molecules from a region of higher concentration to a region of lower concentration is called diffusion.

Gases can diffuse into each other rapidly, this is because gases are light (less dense) compared to solid and liquid and that gas particles are smaller.

Gases are compressible (they can be squeezed) into a small volume, like in a car tyres and bicycle tyres when pumped. This is because they have spaces in between them (Fig 8.4).

8.2 Exercises

1. Copy and complete the table below by writing Yes or No in the empty spaces.

Physical property	**Solids**	**Liquids**	**Gases**
Can flow			
Definite Volume			
Can expand to fill available space			
Definite shape			
Can be compressed easily			

2. Name these changes of state:
   a. From liquid to a solid
   b. From gas to solid
   c. From solid to liquid
   d. From a liquid to a gas

3. For each of the following, state whether they are true or false when a liquid is heated:
   a) its molecule move at the same speed
   b) evaporation takes place throughout the liquid
   c) boiling occurs at all temperatures

4. Explain why it is easier to compress a gas than a liquid

5. Draw diagram showing the arrangement of particles in solids, in liquids and in gases

Unit summary and new words

- Matter is anything that has mass and occupies space.
- Kinetic theory of matter states that matter is made up of of tiny particles that are in constant motion.
- Matter can be classified into three states: solids, liquids and gases.
- A gas has neither size nor shape. Its molecules are free to move randomly.
- Solids have definite size and shape. The molecules of solids are closely packed hence they just vibrate to and fro about their fixed positions.
- Liquids molecules move freely inside the liquid. Liquids take the shape of the container vessels and the.
- Melting is the process by which a solid is converted to a liquid at a constant temperature.
- Viscosity is a measure of how much a fluid resists movement of objects through it.
- Malleability is the measure of solid's ability to be reshaped into something else like thin sheets.
- Brittleness is the tendency of a material to break under stress.
- Ductile materials like copper can be drawn out into wires which are used in transmitting electricity.
- Gases are compressible because they have spaces in between them.

Unit Test 8

1. Explain why the density of a gas is much less than that of a solid or a liquid.
2. Draw a diagram to show how one air molecule moves in a closed container.
3. Explain why it is easier to compress a gas than a liquid or a solid?
4. State one similarity between particles of a liquid and those of a gas.
5. Describe the difference between solids, liquids, and gases in terms of the arrangement of the molecules throughout the bulk of the material.
6. Explain why tyres burst when left outside during hot weather?
7. According to the kinetic theory, what is temperature?
8. State and explain two applications of physical properties of solids, liquids and gases and show how they have improved our lives.
9. Define the following terms:
   a) Malleability
   b) Viscosity
   c) Mixture
   d) Ductility
10. Explain how ductility of some solid materials is important to a wire making company.

UNIT 9 Heat and Temperature

Key Unit Competence

By the end of this unit, I should be able to explain principle of thermometry and compare different temperature scales.

Unit outline

- Heat as a form of energy.
- Different between heat and temperature.
- Temperature scales.
- Types of thermometers.
- Measurement of temperature of substances.
- Thermal equilibrium.
- Functioning of thermometers.
- Liquid for thermometers.
- Temperature conversion.
- Effect of solutes on boiling points of liquids.

Introduction

Heat and temperature pervade our lives. Just think about it. We give attention to hotness and coldness in deciding what to eat or drinking and what to wear during the day or at night.

Our bodies are highly sensitive to hot and cold environments. We learn very early in life through the school of pain that we shouldn't touch a hot pot on the stove or a hot lamp. In the same school, we learnt that we should be careful about mouthing or tasting hot foods. We also learnt how to use our hands to feel the heat that emanates from such foods and how to blow gently on them to help cool the food down.

In this unit, we are going to learn more about temperature and how to measure it using different instruments.

9.1 Heat as a form of energy

Activity 9.1 **To demonstrate effect of hot water on ice**

Materials: ice, a bowl, hot water

Steps

1. Put some ice in a bowl.
2. Feel the bowl with the palm of your hand.
3. Pour hot water into the bowl containing ice.
4. Wait for sometime and again feel the container. What can you conclude?
5. Suggest what temperature and heat energy are and suggest an instrument used to measure temperature .
6. Present your findings to the whole class.

Heat is a form of energy which passes from a body at high temperature to a body at low temperature. The SI unit of heat is the joule (J). Temperature is the *degree of hotness or coldness of a body or a place.* In Activity 9.1, the fact that the bowl feels warmer, means that temperature has increased. This suggests that ice and bowl have gained heat energy. Temperature is measured using a device called thermometer while heat is measured using thermol imaging (infra-red) instrument.

9.2 Heat and temperature

To investigate the difference between heat and temperature

Activity 9.2 **To investigate the difference between heat and temperature**

Materials: Cooking oil, two identical test tubes, two identical thermometers, a beaker, a stirrer

Steps

1. Take equivalent masses of water and cooking oil in two identical test tubes fitted with two identical thermometers.
2. Place these test tubes in a large beaker containing water (See Fig. 9.1).

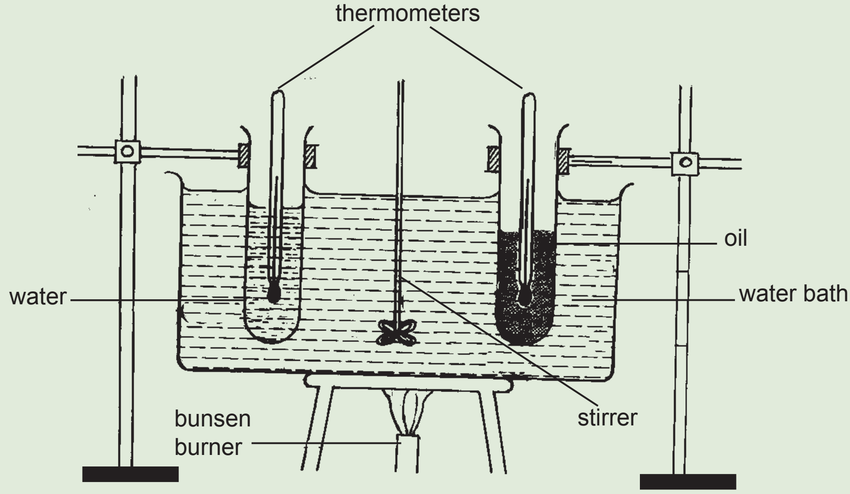


Fig. 9.1: A set up to investigate the difference between heat and temperature

3. Note the initial temperature of both water and oil in the tubes. Heat the water in the beaker and make sure that the heat is distributed uniformly by stirring the water.
4. After sometime, note the temperature of water and oil in the tubes. Are the two temperatures the same? Explain.

From Activity 9.2, you should have observed that the temperature of water is lower than that of oil.

When the tubes are heated for the same time, i.e. the same heat energy passes from the burner to the tubes, both oil and water gain equal amount of heat energy but are at different temperatures.

Therefore, two substances can have equal heat energy supplied but be at different temperatures.

9.3 Temperature scales

Activity 9.3 **To observe temperature scales**

Materials: Internet, reference books

Steps

1. Conduct a research from the Internet, books and any other relevant reading materials on:
   (a) The different types of temperature scales.
   (b) How the scales are graduated.

(c) Maximum and minimum temperature values on the scale and how they are called.

A temperature scale is a range of values for measuring the degree of hotness or coldness referred to as temperature. Temperature is commonly expressed in *degrees celsius* (also called *degrees centigrade*) using the celsius scale. However, the SI unit for temperature is the *kelvin(K)* which is measured using the *kelvin scale*. This is the unit that is used in scientific work. Other temperature scales include, *Fahrenheit* and *Reaumur*. Let us discuss each of these scales in details.

(a) The celsius scale

This scale uses the *degree celsius* (°C) as the unit of measuring temperature. Two values in this scale are fixed such that the temperature at which pure ice melts is 0°C and boiling point of pure water is 100°C (under standard atmospheric pressure of 101 325 Pa).

These two fixed points are called the *lower* and *upper fixed points* of the celsius scale respectively. The region between these two points on the scale(called fundamental interval) is graduated into 100 equally spaced temperature marks (Fig 9.2). Temperatures below 0°C have negative (–) values.

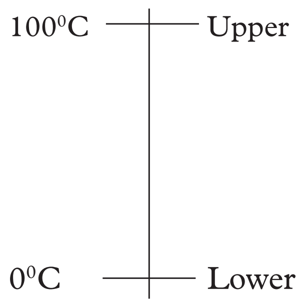


Fig 9.2: Celsius scale

(b) The kelvin scale

This scale uses *kelvin (K)* as the unit of measuring temperature. The scale uses the absolute zero (-273°C) as its reference point. Thus, 0 K on kelvin scale is equivalent to –273°C on the celsius scale. It is worth noting that a temperature change of 1 K is equal in size to a change of 1°C.

(c) Fahrenheit

This scale uses *degree Fahrenheit (°F)* as the unit of measuring temperature. Two values in this scale are fixed such that the temperature at which water freezes into ice is defined as 32°F and the boiling point of water is defined to be 212°F.

The two have a 180°F separation (under standard atmospheric process) Fig. 9.3 shows a Fahrenheit scale.

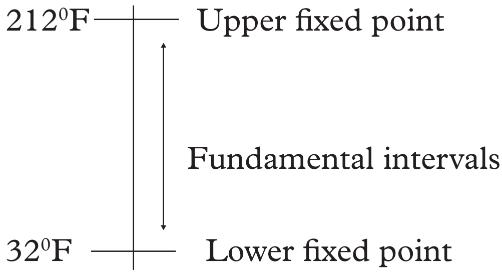
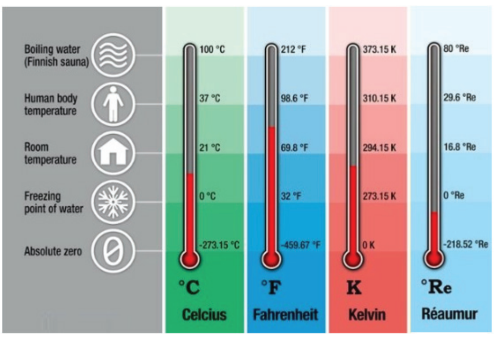


Fig. 9.3: Fahrenheit scale

(d) Reaumur Scale

This scale uses the degree Rankine (0°Re). In this scale, lower fixed point is the freezing of water (0°Re) and upper fixed point in the boiling of water 80°Re.

Comparative table of temperature scales



From the table we should conclude that

Note

- The Fahrenheit and Celsius scales coincide at -40
- The relationship above will help us in conversion of temperature scales from one another.

Conversion of temperature from one scale to another

Activity 9.4 **To convert from one temperature scale to another**

Materials: internet, reference books

Steps

1. Conduct a research from internet, reference books and any other relevant reading materials on the following.
   (a) How temperature is converted from:
      (i) Celsius to Kelvin scale.
      (ii) Celsius to Fahrenheit scale.
      (iii) Fahrenheit to Kelvin.
      (iv) Reaumur to Fahrenheit.
      (v) Fahrenheit to Reaumur.
   (b) Note down the formula of converting temperature from one scale to the other in each case in 1 (a).
2. By use of examples, present to the class on how to convert temperature from one scale to the other.

In your discussion in activity 9.4, you should have established the following:

(i) Relationship between Celsius and Kelvin scale

To convert temperature from degree Celsius (°c) to Kelvin temperature (K), we add 273 to degrees temperature i.e.

Temperature in K = temperature in °C + 273

$$T_{(K)} = (\theta + 273)K$$

To convert kelvin (K) temperature to degrees celsius (°C) temperature, we subtract 273 from kelvin temperature i.e.

Temperature in °C = temperature in K – 273

$$T_{(°C)} = (T_{(K)} - 273)°C$$

Fig. 9.4 shows a summary of the relationship between Kelvin scale and Celsius scales.

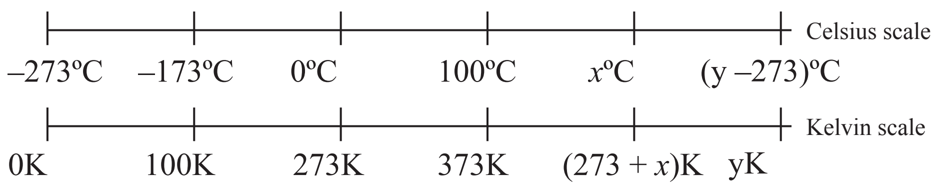


Fig. 9.4: Relationship between Kelvin and Celcius scale

In this case; x is any value of temperature in degrees celcius and y is any value of temperature in Kelvin.

N.B: The lower fixed point (ice point) is the temperature of pure melting ice at normal atmosphere measure. The upper fixed point (steam point) is the temperature of pure boiling water at normal atmosphere pressure.

Example 9.1

What is the lower fixed point (L.F.P) in Kelvin?

Solution

Lower fixed point is 0°C. To convert °C to kelvin, add 273.

Therefore, L.F.P = (0°C + 273)K = 273 K.

Example 9.2

Express the room temperature of 27°C in Kelvin.

Solution

To convert °C to kelvin, add 273.

Therefore, room temperature is (27 + 273)K = 300 K.

Example 9.3

Convert 327 K to degrees celsius.

Solution

To convert kelvin to degrees celsius, subtract 273.

Therefore, 327 K = (327 – 273) °C = 54°C.

(b) Relationship between Celsius and Fahrenheit

To convert Fahrenheit into Celsius, we subtract 32 and then multiply by $\frac{5}{9}$ i.e

$T_{(°C)} = [T_{(°F)} - 32] \times \frac{5}{9}$

Example 9.4

Convert 42 Fahrenheit to Celsius scale.

solution

$$T_{(^oC)} = [T_{(^oF)} - 32] \times \frac{5}{9} = (42\text{-}32) \times \frac{5}{9}$$

$$= \frac{50}{9}$$

$$= 5.56^oC$$

To convert Celsius to Fahrenheit, we multiply by $\frac{9}{5}$ then add 32 i.e.

$$\boxed{T_{(^oF)} = T_{(^oC)} \times \frac{9}{5} + 32}$$

Example 9.5

Convert 37 degree Celsius to degree Fahrenheit.

Solution

$$T_{(^oF)} = T_{(^oC)} \times \frac{9}{5} + 32 = [37 \times \frac{9}{5}] + 32$$

$$= 98.6\ ^oF$$

(c) Relationship between Fahrenheit and Kelvin

To convert Fahrenheit to Kelvin, we add 459.67 then multiply by $\frac{5}{9}$ i.e.

$$\boxed{T_{(K)} = (T_{(^oF)} + 459.67) \times \frac{5}{9}}$$

Example 9.6

Convert 22 degree Fahrenheit to Kelvin.

Solution

$$T_{(K)} = (T_{(^oF)} + 459.67) \times \frac{5}{9}$$

$$= (22 + 459.67) \times \frac{5}{9}$$

$$= 481.67 \times \frac{5}{9}$$

$$= 267.59\ K$$

(d) Kelvin to Fahrenheit

To convert Kelvin to Farhrenheit, we multiply by $\frac{9}{5}$ then subtract 459.67. i.e

$$T_{(F)} = \left(T_{(K)} \times \frac{9}{5}\right) - 459.67$$

$$T_{(K)} = \frac{5}{9}\left(T_{(F)} + 459.67\right)$$

Example 9.7

Convert 302 Kelvin to Fahrenheit scale.

Solution

$$T_{(^{o}F)} = T_{(K)} \times \frac{9}{5} - 459.67$$

$$= 302 \times \frac{9}{5} - 459.67$$

$$= 543.6 - 459.67$$

$$= 83.93\ ^{o}F$$

(e) Relationship between Fahrenheit and Reaumur

To convert Fahrenheit to Reaumur, we add 459.67 i.e

$$T_{(R)} = \frac{4}{9}\left(T_{(F)} - 32\right)$$

Example 9.8

Convert 35-degree Fahrenheit to degree Reaumur

Solution

$$T_{(Re)} = \frac{4}{9}\left(T_{(F)} - 32\right)$$

$$= \frac{4}{9}\left(35 - 32\right)$$

$$= \frac{4}{9} \times 3$$

$$= 1.33^{0}\,R$$

(f) Reaumur to Fahrenheit

Reaumur to Fahrenheit, we use the formula below:

$$T_{(^{0}F)} = \frac{9}{4}\left(^{0}\mathrm{Re}\right) + 32$$

Example 9.9

Convert 503 degree Reaumur to degree Fahrenheit

Solution

$$T_{(^{0}F)} = \frac{9}{4}\left(^{0}\mathrm{Re}\right) + 32$$

$$= \left(\frac{9}{4} \times 503\right) + 32$$

$$= 1131.75 + 32$$

$$= 1163.75^{0}F$$

(g) Convert from Celsius to Reaumur and vice versa

$$T_{(\mathrm{Re})} = \left(T_{(C)} \times \frac{4}{5}\right)$$

Example 9.10

Convert $100^{0}C$ to degree Reaumur

Solution

$$T_{(\mathrm{Re})} = \left(T_{(C)} \times \frac{4}{5}\right) = 100 \times \frac{4}{5} = 80^{0}\ \mathrm{Re}$$

(h) Convert Reaumur to Celsius

$$T_{(C)} = \left(T_{(\mathrm{Re})} \times \frac{5}{4}\right)$$

Example 9.11

convert 105^0 Re to Celsius

Solution

$$T_{(C)} = \left(T_{(Re)} \times \frac{5}{4}\right) = 105 \times \frac{5}{4} = 131.25^0\ C$$

$$T_{(Re)} = \left(T_{(K)} - 273\right) \times \frac{4}{5}$$

(j) To convert Kelvin to Reaumur

Example 9.12

Convert 35 K to degree Reaumur

Solution

$$T_{(Re)} = \left(T_{(K)} - 273\right) \times \frac{4}{5}$$

$$= \frac{4}{5}\left(35 - 273\right) = 183.4^0\ \mathrm{Re}$$

(k) Convert Reaumur to Kelvin

$$T_{(K)} = \frac{5}{4}\left(T_{(Re)}\right) + 273$$

Example 9.13

Convert $45^0\ R$ to degree Kelvin

Solution

$$T_{(K)} = \frac{5}{4}\left(45\right) + 273 = 329.25\ K$$

Note:

°F = 1°R = $\frac{5}{9}$ °C = $\frac{5}{9}$ K

The Fahrenheit and Celsius scales coincide at -40.

Exercise 9.1

1. Differentiate between heat and temperature. State their SI units.
2. Describe an experiment to differentiate between heat and temperature.
3. Name two fundamental intervals in a temperature scale.
4. Convert each of the following into kelvin scale.
   (a) 34 °C **(b)** -371 °C **(c)** 17 °C
5. Convert each of the following into degrees celsius.
   (a) 314 K **(b)** -6 K **(c)** 273 K **(d)** 45 K
6. Convert each quantities in question 4 and 5 into:
   (a) Degree Fahrenheit.
   (b) Degree Reaumur.

9.4 Thermal equilibrium

Activity 9.5 To investigate thermal equilibrium

Materials: source of heat, cold water, two beakers, thermometer

Steps

1. Pour cold water into a beaker and place it on a source of heat for 30 min then measure the temperature T_1.
2. Put some cold water in another beaker and measure its temperature T_2.
3. Mix the warm water and cold water into one of the beaker and stir well.
4. After stirring, measure the temperature T_3 of the mixture. In what state is the mixture after stirring?
5. What is the final value of temperature?

Thermal equilibrium is the state achieved when two regions or substances that are in thermal contact no longer transfer heat between them. Therefore, two substances in thermal equilibrium are at the same temperature. For example, when measuring the human body temperature, heat energy is transferred from the human body to the liquid inside the thermometer until the two (i.e. human body and thermometer) have the same temperature e.g. 37^0C in thermal equilibrium.

9.5 Measurement of temperature

We learnt that temperature is the degree of hotness or coldness of an object. It is measured using an instrument called thermometer.

In the construction of a thermometer, a thermometric substance is choosen first. Then, a temperature scale is defined by means of two fixed points; lower and upper.

Thermometric substances

Activity 9.6 **To define and discuss thermometric substances**

Materials: Reference books, Internet

Steps

1. Conduct a research from Internet and reference books on thermometric substances.
2. In your research find out:
   (a) Some of the common thermometric substances used in thermometers.
   (b) Advantages and disadvantage of using each of the thermometric substances identified in (a) above.

From Activity 9.6, you should have established that there are different thermometric substances used in different thermometers. Their properties changes uniformly with temperature.

Thermometric properties

Some important characteristics of thermometric substances are:

1. The property should remain constant, if temperature is constant.
2. The property should change uniformly with change in temperature.
3. The property should change uniformly for every 1°C change in temperature.
4. The property should acquire thermal equilibrium as quickly as possible, when temperature measurements are needed.
5. The property should cover a wide range of temperatures (should not freeze or boil at normal temperatures).
6. The property should be able to register the rapid changing temperature.
7. The property should have a large change even if the change in temperature is small.

8. The property should be such that the temperature can be taken easily without waiting for a long time.

Some of the common thermometric substances used in thermometers include mercury and alcohol..

Mercy as a thermometric liquid

Advantages of using mercury as a thermometric substance

1. Mercury is a shiny and opaque liquid. The position of the mercury meniscus is seen easily and readings taken without strain.
2. Mercury does not wet glass. Hence it does not stick to the sides of the capillary tube.
3. Mercury has a large increase in volume for 1°C rise in temperature.
4. Mercury expands uniformly. Its volume changes by equal amounts for equal change in temperature.
5. Mercury has a high boiling point of 357°C.
6. Mercury has the ability to transfer heat energy easily. The whole mass of mercury in the bulb attains the temperature of the substance in which the bulb is placed easily.

Disadvantages of mercury as a thermometric substance

1. Usually, it is only the bulb which is in contact with the body when taking the temperature. A large portion of the stem is not in contact with the body.
2. There is a change in internal pressure due to the different positions of the thermometer. The reading of the mercury level is low when the tube is vertical as compared to the reading in the horizontal position.
3. Mercury takes sometime to contract to the original volume. The same thermometer cannot be used to measure a low temperature soon after a high temperature.
4. There may be non-uniformity in the capillary bore of the tube.
5. This thermometer is not suitable to measure temperatures below –39°C.

Alcohol as a thermometric liquid

Advantages of using alcohol as a thermometric substance

1. Alcohol has a very low freezing point of –114°C hence its suitable in thermometers to record very low temperatures.

2. Alcohol can be coloured brightly (by adding a dye, generally red dye). This makes it clearly visible through glass.
3. Alcohol has a uniform expansion and contraction than mercury.
4. Alcohol is a good thermal conductor; it is also cheap and easily available.

Disadvantages of using alcohol as a thermometric substance

1. Alcohol sticks to the walls of the glass thus wetting it. This makes it difficult to read the temperature accurately.
2. Alcohol has a low boiling point of 78°C, therefore it cannot be used to measure high temperature.

9.6 Types of thermometers

Activity 9.7 **To identify different types of thermometers**

Materials: Reference books, Internet

Steps

1. Conduct a research from internet or reference books on types of thermometers.
2. In your research, identify the main features of each thermometer, how it is calibrated and how it is used to measure temperature of a body or a place.

There are various types of thermometers in use. The liquid-in-glass thermometer is the most common one. Others include electrical, digital and gas thermometers. The main difference between them is in the property of the thermometric substance. In this level we shall discuss liquid-in-glass thermometers only.

Liquid-in-glass thermometers

Activity 9.8 **To observe the working of mercury and alcohol in glass thermometers**

Materials: Mercury and alcohol - in- glass thermometers, hot water in a beaker

Steps

1. Hold the thermometers provided to you and note down the following:
   (a) The range of their scales.
   (b) Minimum and maximum values on the scales.
   (c) Some features of the thermometers and suggest some precautions to be taken when constructing it.
   (d) Note the kind of the liquids used.
2. Now, place it in hot water and measure the temperature of the water. Record down your result.
3. Suggest how the thermometer is used.

In your discussion, you should have noted that a liquid-in-glass thermometer uses either mercury or coloured alcohol as the thermometric substance. They include laboratory (i.e mercury-in-glass and alcohol-in-glass) thermometers, clinic thermometer and six's maximum and minimum thermometer.

Mercury-in-glass thermometer

This thermometer consists of *a thin walled bulb*, containing mercury and a thin *capillary tube (bore)* of uniform cross-sectional area. There is a space above mercury thread which is usually evacuated to avoid excess of pressure being developed when mercury expands (Fig. 9.5).

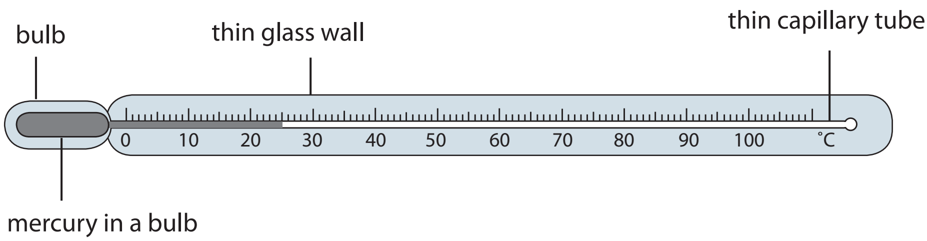


Fig. 9.5: Mercury-in-glass thermometer

Some important precautions are taken in the construction of this type of thermometer include:

(a) The walls of the bulb should be thin. This is to ensure that the mercury can be heated easily.

(b) The quantity of mercury in the bulb should be small so that the mercury takes little time to warm up.

(c) The thin capillary tube should be of uniform cross-section so that the mercury level changes uniformly along its length.

The example of mercury in glass thermometer is a laboratory thermometer. When using it, check its initial reading (room temperature) and ensure that its bulb is in contact with the substance whose temperature is to be measured.

Alcohol-in-glass thermometer

The alcohol-in-glass thermometer uses coloured alcohol instead of mercury.

Volume of alcohol changes uniformly and easily when heated. The change in volume of alcohol is about six times more than that of mercury for the same change in temperature.

The range of temperatures that can be measured with this thermometer is limited, as alcohol boils at 78°C. However this thermometer is ideal for measuring low temperatures since alcohol freezes at –114°C .

Using a laboratory thermometer

Before using a laboratory thermometer, you should note its initial reading (i.e room temperature reading) and while measuring temperature, ensure that its bulb is always in contact with the substance whose temperature is to be measured. Avoid direct heating of the bulb.

Clinical thermometer

Activity 9.9 **To observe the working of a clinical thermometer**

Material: Clinical thermometer

Steps

1. Hold the thermometer provided to you and note the following:
   (a) the range of the scale.
   (b) minimum and maximum values on the scale.
   (c) features of the thermometer.
2. Now, note the reading of the thermometer and place it in your armpit for a couple of minutes.
3. While still in the armpit, note the reading where the liquid becomes steady. What is the value? Record it down.

A clinical thermometer is designed for measuring the human body temperature. It consists of a thin walled bulb containing mercury. The capillary bore is very narrow and of uniform diameter.

This thermometer has a narrow *constriction* in the tube just above the bulb. The thermometer has a limited range from about 35°C to about 43°C (Fig. 9.6).

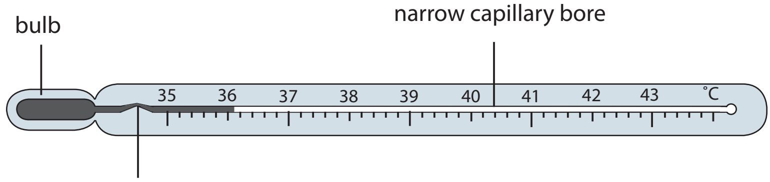


Fig. 9.6: Clinical thermometer

Working of a clinical thermometer

When the thermometer is in contact with a human body, mercury in the bulb expands. It forces its way through the constriction to the narrow bore. When the thermometer is removed from the body, the mercury in the bulb cools down and contracts. The mercury thread is broken at the constriction (Fig. 9.7). Hence the mercury in the tube stays back. The reading of the thermometer on the stem can be taken without any hurry. After use, the mercury in the tube can be forced through the constriction back to the bulb by flicking the thermometer vigorously.

The normal human body temperature is 36.9°C.

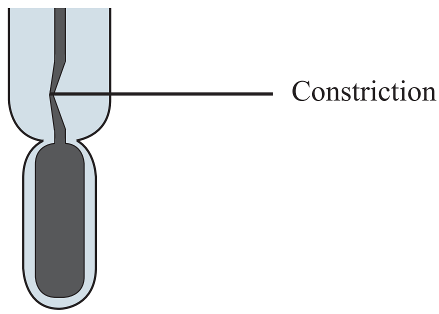


Fig. 9.7: Constriction of a clinical thermometer

The Six's minimum and maximum thermometer

Activity 9.10 **To demonstrate the working of the six's thermometer**

Materials: reference books, internet

Steps

1. Conduct a research on six's minimum and maximum thermometer.
2. In your research found out:
   (a) how it is calibrated.
   (b) the range of scales.
   (c) the minimum and maximum values on each scale.
   (d) the liquids used in the six's thermometer.

Six's maximum and minimum thermometer is used to measure the maximum and minimum temperature of a place during a day. It was invented by a physicist called *John Six*. The thermometer consists of a U-shaped tube connected to two bulbs. The U-tube contains mercury. The two bulbs contain alcohol, which occupies the full volume of one of the bulbs. The other bulb has a space above alcohol. There are two indices fitted with light fine springs (Fig. 9.8).

When temperature rises, alcohol occupying the full volume of bulb A, expands and forces mercury in the U-tube to rise on the right hand side. Mercury, in turn, pushes the index I_2 upwards. The maximum temperature can be noted from the lower end of index I_2.

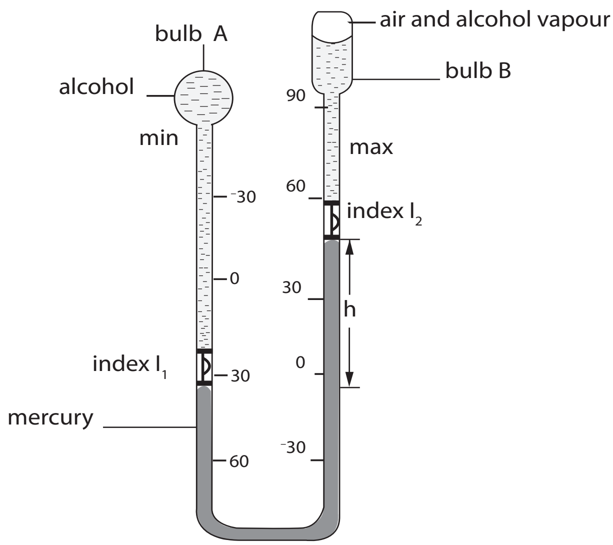


Fig. 9.8: Six's maximum and minimum thermometer

When the temperature falls, alcohol in bulb A contracts. Due to the pressure difference in the two arms of the U-tube, mercury level will rise on the left hand side of the U-tube pushing the index I_1 upwards. The index I_2 on the right hand side is left behind (held by the fine spring) to register the maximum temperature. The lower end of index I_1, touching the mercury meniscus gives the minimum temperature.

The two steel indices can be reset with the help of a magnet.

Exercises

1. What are the advantages of alcohol thermometer over mercury thermometer?
2. Compare a clinical thermometer and a laboratory thermometer.

9.7 Calibration of thermometers

To calibrate a mercury thermometer

Activity 9.11 **To demonstrate how to calibrate a mercury thermometer**

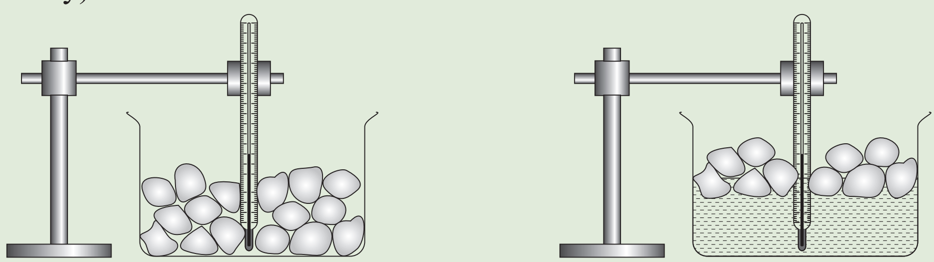
(a) Lower fixed point

Materials: Thermometer, ice, stand and clamp, bunsen burner, beaker

Steps

1. Immerse the bulb completely inside a beaker containing pure melting ice as shown in Fig. 9.9 (a). What do you observe? Explain.
2. Wait for sufficient time for the mercury to attain the temperature of the melting ice (Fig. 9.9 (b).
3. When there is no more change in the level of mercury, mark its position on the stem. Suggest the name given to the marked position.

The point marked is the lower fixed point. Mark it as 0ºC. Note that the melting point of ice is exactly 0ºC (mm Hg) at standard atmospheric pressure (760 millimetres of mercury).



(a) Pure ice at 0°C (b) Pure melting ice at 0°C

Fig. 9.9: Calibrating the lower fixed point

(b) Upper fixed point

Steps

1. Expose the bulb to steam just above the boiling water as shown in Fig. 9.10.

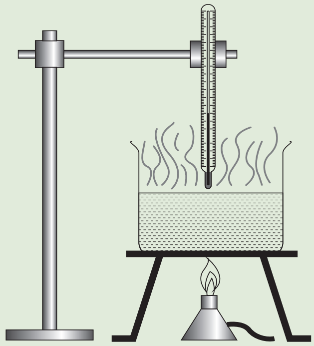


Fig. 9.10: Calibrating the upper fixed point

2. Give it time for the mercury to attain the temperature of the steam.
3. When there is no more change in the level of mercury, mark its position on the stem.

The point marked is the upper fixed point. Mark it as 100ºC. The temperature of steam is exactly 100ºC at standard atmospheric pressure (760 mmHg).

Thermometers are calibrated by identifying the fixed points. The fixed points will help in determining the highest and the lowest values a thermometer can measure.

Fixed point is a single temperature at which a particular physical event always takes place.

There are two types of fixed points namely: *upper fixed point* and *lower fixed point*.

The upper fixed point (steam point) is the temperature of steam above pure boiling water at normal atmospheric pressure. It takes place at 100°C at sea level.

The lower fixed point (ice point) is the temperature of a pure melting ice at normal atmospheric pressure. It takes place at 0°C. The different between the lower fixed point and upper fixed point is called the fundamental interval.

The distance between the two fixed points is divided into 100 equal parts. The scale obtained is called the *centigrade scale*, and the thermometer is known as the *centigrade thermometer*. Each division on the scale is one degree centigrade (1ºC).

Thermometers may be used to measure unknown temperature as shown below.

The stem of thermometer is y cm long between the upper and lower fixed points. The mercury thread is x cm above the lower fixed point at the unknown temperature θ.

Therefore, $\theta = \frac{x}{y} \times 100°C$

Where θ is the temperature in °C.

Example 9.10

Fig. 9.11, not drawn to scale, shows a mercury-in-glass thermometer where the mercury level stands at 1 cm mark in the tube at 0°C.

(a) Calculate the temperature when the mercury level stands at 7.5 cm mark.

(b) Find the mercury level in the thermometer when the temperature is 61°C

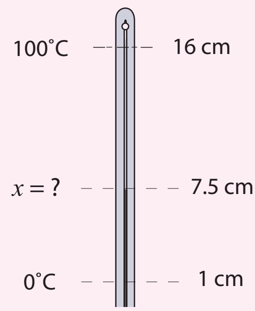


Fig. 9.11: Thermometer

Solution

(a) The distance between the two fixed points is 16.0 – 1.0 = 15.0 cm.

This distance represents a temperature change of (100 – 0) = 100°C.

Let (7.5 – 1.0) cm represent a temperature x °C

15 cm represents 100°C or $\theta = \frac{x}{y} \times 100°C$

1 cm represents $\frac{100}{15}$°C $= \frac{6.5}{15} \times 100°C$

$\therefore$ 6.5 cm represents $x = \frac{100}{15} \times 6.5$ $= 43.3°C$

$= 43.3$ °C

$\therefore$ The temperature reading is 43.3 °C

(a) 100°C is represented by 15 cm

1°C represents $\frac{15}{100}$ cm

61°C is represented by $\frac{15 \times 61}{100}$ cm = 9.15

Level of mercury = 9.15 cm + 1.0 cm

= 10.15 cm

Exercise 9.2

1. Describe how a clinical thermometer works.
2. Briefly explain the meaning of:
   (a) Lower fixed point.
   (b) Upper fixed point.
3. State two properties of thermometric liquids.
4. A thread of mercury in the bore of a thermometer has a length of 9 cm when the temperature is 15°C. When the temperature rises to 101°C, the length increases to 20 cm. Find:
   (a) The length when the temperature is 75°C.
   (b) The temperature when the length is 12 cm.

9.8 Melting and Boiling point of substances

To determine the melting point of substances

Activity 9.12 To determine the melting point of ice

Materials: A 500 g of pure ice, a copper calorimeter, source of electric power

Steps

1. Take 500g of pure crushed ice at about –10ºC.
2. Put the ice in a well insulated copper container as shown in Figure 9.12.
3. Record the initial temperature of the ice. Close the switch S and start the stopwatch at the same time.

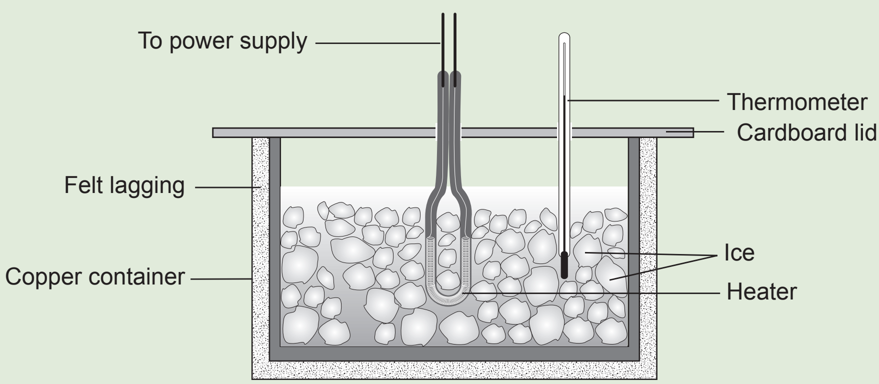


Fig. 9.12: Heating ice – melting process.

4. Record the temperature of ice at 30 seconds intervals until the temperature of the container is about 10 °C. Record your result as shown in Table 6.1.

Time(s)	0	30	60	90	120	140	160	180	200
Temp. (^{0}c)									

Table 9.1: Relationship between temperature and time

What happens to the amount of ice as heating continues?

5. Plot a graph of temperature against time. Explain the shape of the graph.
6. From the graph determine the melting point of ice.

From Activity 9.12, you should have observed the following:

- The temperature rises steadily during the first few seconds.
- The temperature remain constant for sometime.
- Then the temperature starts rising again.

Fig. 9.13 shows the graph of temperature against time.

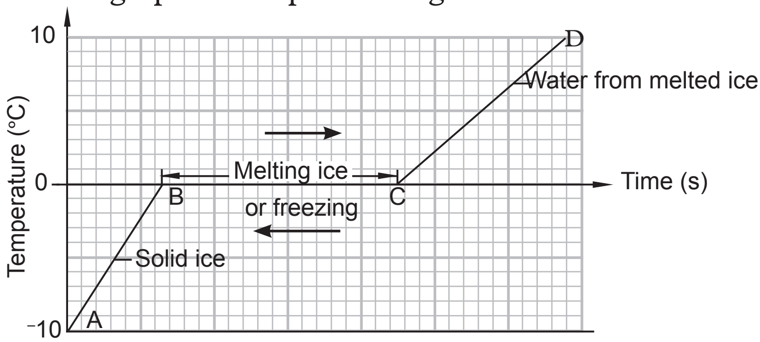


Fig. 9.13: A graph of temperature against time for melting ice

The graph shows that:

1. The temperature of ice rises steadily from ⁻10 °C to 0 °C. During this time, along AB, the ice remains as solid.
2. At 0 °C, along the line BC, the temperature remains constant for a period of time. During this period, the ice is observed to be melting. At C all the ice has melted and it becomes water.
3. After all the ice has melted, the temperature of water starts rising again as seen along the line CD of the graph.
4. From 0^0 C, the temperature of ice at 0^0 C starts to drop steadily.

If pressure remains unchanged, a solid substance melts or freezes at a specific temperature. Similarly the liquid freeze at the same temperature. This temperature is called the *melting point* or *freezing point* of a substance. The melting point of pure ice is 0^0 C and the freezing point of pure water is also 0^0 C under standard atmospheric pressure.

Boiling point

To determine the heating curve for pure water

Activity 9.13 **To determine the heating curve of pure water**

Materials:

- Round bottom flask
- An L - shaped delivery tube
- Pure water
- Tripod stand
- Source of heat
- Thermometer
- Stop watch

Steps

1. Take some pure water at room temperature in a glass heating flask and insert a thermometer as shown in the Fig. 9.14.

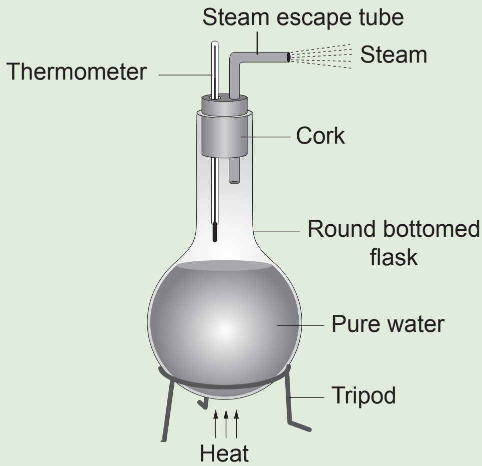


Fig 9.14: Heating pure water

2. Note the initial temperature of the water. What happens to the temperature of water in the initial stages?
3. Heat the water steadily and note the temperature at regular intervals of time. What happens to the mass of water as boiling continues?
4. Continue heating for about 2 to 3 minutes even after the steam is seen to escape from the steam escape tube. What is the temperature when the steam is seen to escape from the escape tube? Suggest the meaning of boiling?
5. Record your result in a tabular form as shown in Table 6.9.

Time(s)	0	30	60	90	120	140	160	180
Temp. (^{0}c)								

Table 9.2: Relationship between temperature and time

6. Plot a graph of temperature against time. Write down your observation from the graph. Determine the boiling point of water from the graph.

From Activity 9.13, you must have observed the following:
- The temperature of water rises steadily.
- Then, temperature remains constant for sometime.
- Finally, the temperature rises again.

Boiling is a process in which a liquid is changes to vapour at a constant temperature. Fig. 9.15 shows the graph for the boiling process of water.

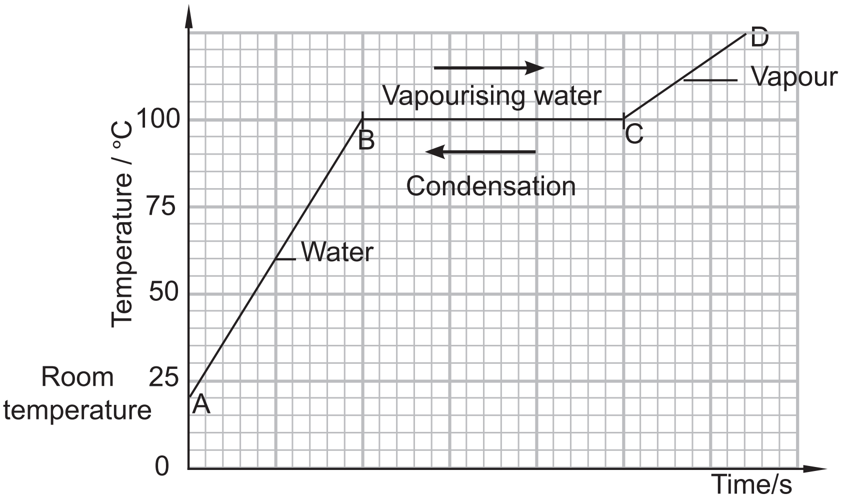


Fig. 9.15: Vaporisation of water

The graph shows that:

1. The temperature of water rises steadily from room temperature. During this time, along AB, water remains as liquid.
2. At 100°C, along the line BC, the temperature remains constant for a period of time. During this period, water is observed to be boiling. At C all the water has turned into water vapour.
3. After water has turned into vapour, the temperature of vapour rises again as seen along the line CD of the graph.

If pressure remains unchanged, a liquid substance always boils at a fixed temperature. This temperature is called the *boiling point of the liquid*. The boiling point of pure water is 100 °C under standard atmospheric pressure.

To determine the boiling point of methylated spirit

Activity 9.14 **To determine the boiling point of methylated spirit**

Materials: column flask, thermometer, methyl spirit, water bath, anti- bumping granules, glass rods, glass wool, Bunsen burner

Safety measures

- Methyl spirit is highly flammable, care must be taken when handling it. Let your teacher guide you in all steps of this activity.
- Ensure that all glassware is securely clamped.

Steps

1. Set-up the micro-fractional column as shown in Fig. 9.16.

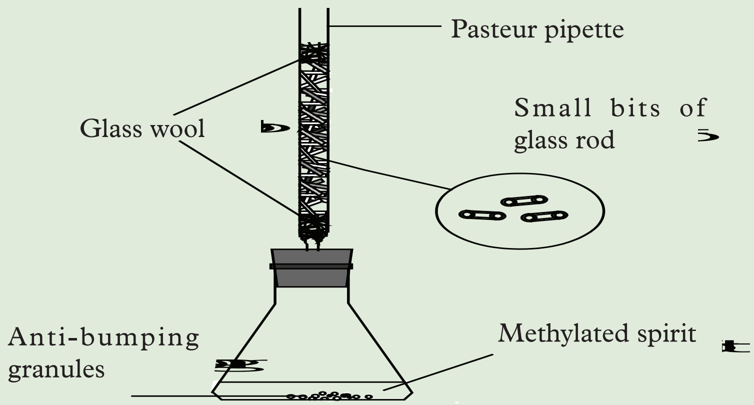


Fig. 9.16: Micro-fractional column

2. Place about 10 cm^3 of the methylated spirit into the small conical flask and add some anti-bumping granules.
3. Place the set-up in a water bath. Suggest a reason for this.
4. Wait for boiling and allow time for attaining thermal equilibrium.
5. Using thermometer, determine the boiling point of the liquid collected at the top part of the micro column. What do you get?. This is the boiling point of methylated spirit?

In Activity 9.4, you should have learnt that the water bath is necessary for even distribution of heat. You must have also discovered that the boiling point of methyl spirit is about 64.6^0C.

To determine the melting point of candle wax

Activity 9.15 **To determine the melting point of a candle wax**

Materials: Bunsen burner, wax, goggles, stopwatch, thermometer, tripod stand

Steps

1. Obtain and wear goggles.

CAUTION

With the Bunsen burner on and a beaker of boiling water on your ring stand, there are changes to be hurt here.

2. Obtain a test tube with the thermometer frozen into the wax. Lower it into a beaker of cold tap water.(Fig.9.17)

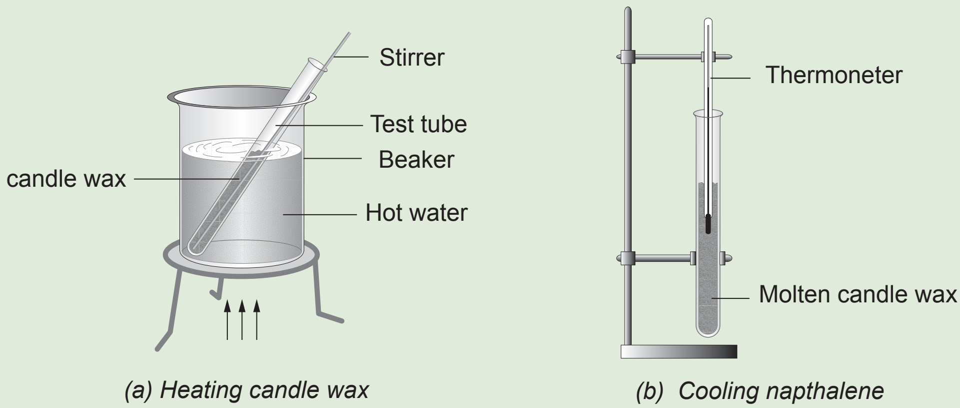


Fig. 9.17: Heating and cooling candle wax

3. Start recording temperature every 30 seconds on the melting data table.
4. Have your teacher come by to light your Bunsen burner (goggles must be on). Make sure the Bunsen burner flame is just touching the wire mesh. You must record temperatures every 30 s.
5. Wait for the wax to melt, and then record temperatures for a full 3 minutes past the point when the wax is completely melted. (Completely melted means clear and transparent).
6. Turn off your Bunsen burner, and call your teacher over to lower the hot water. Clamp everything securely on the ring stand like your teacher shows you.
7. Start collecting data in the freezing table for every 30 s as shown in Table 9.3.

Time (s)	Temp (°C)
0.00	
0.30	
0.60	
0.90	
0.120	
0.150	
0.180	

Table 9.3: Freezing table

8. Draw a cooling curve of temperature against time.
9. Identify and label on your graph the melting point/freezing point of candle wax.

If a graph of temperature (^{0}C) against time t (s) is drawn, we have Fig. 9.18.

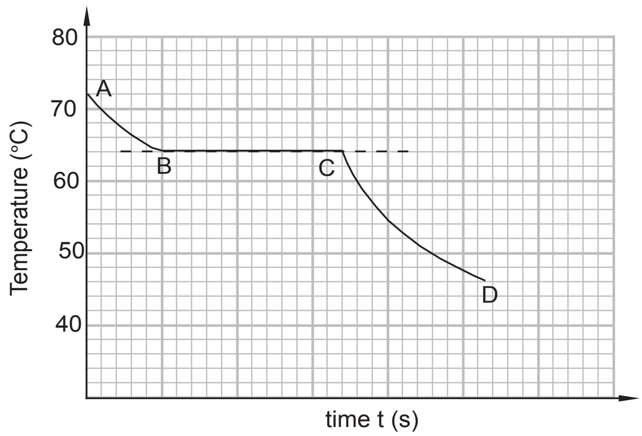


Fig. 9.18: Cooling curve for candle wax

Kinetic theory of matter may be used to explain the cooling curve for candle wax.

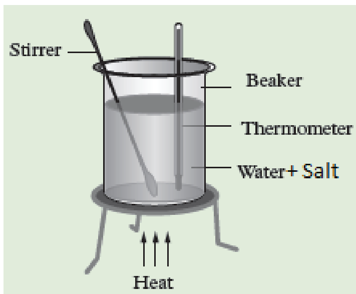
1. The curve AB represents the candle wax in liquid state. The temperature falls as the liquid is above the temperature of the surroundings. As a result the molecules lose both their kinetic and potential energies. This results in a decrease in speed of the molecules and they come close together.
2. The straight line section of the graph (BC) represents the mixture of candle wax in liquid and solid states. At B it is mainly in the liquid state and at C is mainly in the solid state. As its temperature is still above the temperature of the surroundings, heat is given out, but at a constant temperature. Candle wax melts at 64^{0}C
3. The curve CD represents candle wax in solid as it continues to cool since its temperature is still above room temperature.

9.9 Effect of a solute on the boiling point of liquids

Activity 9.16 **To determine the effect of salt on the boiling point of water.**

a. Put some salt water into the beaker. Dip the stirrer and thermometer into the beaker. Record the temperature using a $110^{0}C$ thermometer.

b. Place the beaker and its content onto the stand and place the source of heat below it as shown in figure below:



c. Continue heating salt water as you observe the change in temperature.

d. The temperature reaches a point when the water will start boiling violently. Record the temperature three times after 30 seconds of intervals.

e. Compare your three readings. What do you notice? What is the name of this process?

From Activity 9.16, you must have noted that the value at which salt water boils is higher than that of pure water i.e. more than 100 °C.

We can therefore conclude that solute increases the boiling point of liquids.

Excercise 9.3

1. Define boiling and melting points of a substance?
2. Describe experiments on how to determine the boiling and melting points of pure water and wax respectively.
3. Explain how solutes affect the boiling point of liquids.

Unit summary and new words

- Temperature is the degree of hotness or coldness of a body. It is also defined the average kinetic energy of the molecules of a substance.
- The SI unit of temperature is kelvin (K).
- A thermometer is an instrument used to measure the temperature of a body.
- Liquid-in-glass thermometers commonly use mercury or alcohol as their thermometric substance.
- Clinical thermometer is special type of liquid-in-glass thermometer used to measure the temperature of a human body.
- Lower fixed point is the temperature of pure melting ice at 0ºC at standard atmospheric pressure.
- Upper fixed point is the temperature of steam above pure boiling water at 100ºC at standard atmospheric pressure.
- Different thermometers use thermometric substances of different properties.
- Absolute zero is the temperature at which gases appears to have zero volume.
- Temperature in kelvin = (temperature in ºC + 273).

  Temperature in °C = (temperature in K – 273).
- Heat is a form of energy which passes from a body of high temperature to a body of low temperature. The SI unit of heat is joules (J).
- The lower fixed value and upper fixed value of a Fahrenheit scale are 32 °C and 212 °C respectively.
- To convert Fahrenheit to Celsius, we subtract 32 and then multiply by $\frac{5}{9}$ i.e. °C= (°F-32) × $\frac{5}{9}$
- To convert Reaumur to Fahrenheit, $T_{(°F)} = \frac{9}{4} T_{(°R)} + 32$

Unit Test 9

1. Define temperature and state its unit.
2. Name four temperature scales and state their fixed points.
3. Explain how one can make a liquid-in-glass thermometer which is sensitive to a small change of temperature.
4. The normal human body temperature is 37°C. What is the temperature in Kelvin?
5 Convert each of the following into Fahrenheit.

   (a) 273 K **(b)** 373 K

   (c) 100 K **(d)** 0 K
6. Which of the following statements is NOT true for a clinical thermometer? It is desirable that a clinical thermometer should;

   A. have a very small range

   B. be very sensitive

   C. take time to acquire its maximum reading

   D. retain the reading until shaken
7. What is a thermometer? Name two types of thermometers.
8. Explain the meaning of the following terms: upper fixed point, ice point, steam point.
9. State three characteristics of a good thermometric substance.
10. State the two special features of a clinical thermometer and explain their roles.
11. State one advantage of an alcohol-in-glass thermometer as compared to mercury-in-glass thermometer.
12. A faulty thermometer has its fixed points marked 5˚C and 95˚C. What is the correct temperature in ˚C when this thermometer reads 59˚C?

13. Estimate the room temperature and express it in kelvin.
14. The length of a mercury thread is recorded in three situations: length in melting ice = 20 mm, length in steam = 170 mm and length in liquid X = 50 mm. What is the temperature of liquid X?
15. A thermometer reads 2°C in pure melting ice and 103°C in steam. What is the error when the temperature rise is calculated?
16. Explain how you can use a liquid in thermometer to determine the boiling point of water.

UNIT 10 Magnetism

Key Unit Competence

By the end of this unit, I should be able to differentiate between magnetic and non-magnetic materials.

Unit Outline

- Definition of a magnet.
- Magnetic and non-magnetic materials.
- The poles of bar magnet.
- Test for magnetism.
- Types of magnets.

Introduction

The people of Magnesia in Asia Minor observed that certain kinds of naturally occurring iron ores possessed an iron-attracting property. The ore was discovered near the city of Magnesia and hence it was named as **Magnetite**. Huge lumps of magnetite were often called lodestone meaning " leading" stone or natural magnet. Chemically lodestone consists of iron oxide.

Dr. William Gilbert (1540-1603) did a lot of work with the natural magnets. He published a book called *De magnete* in 1600 in which he gave an account of his research into the magnets and their properties. In one of his works he concluded that the earth was itself magnetic and that is why compasses point to the north of the earth.

10.1 Definition of a magnet

Activity 10.1 **To identify magnets**

Materials: Cooking stick, steel nail, a bar magnet, a spanner, a cork

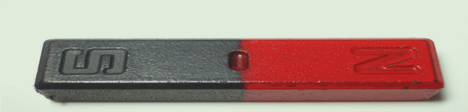
Steps

1. Identify a magnet from the materials provided (see Fig. 10.1) and suggest a reason why you think the material you have identified is a magnet.

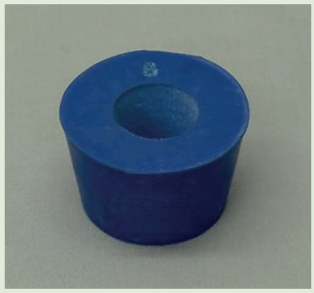
(a)

`(b)

(c)



(d)



(e)

Fig. 10.1: Magnetic and non-magnetic materials

2. Suggest what a magnet is.

From Activity 10.1, you observed that Fig. 10.1 (d) is a magnet. A magnet is a *piece of metal with either natural or induced properties of attracting another metal objects e.g. steel. It can repel also another magnetic.* The common type of a magnet used in school laboratory is a bar magnet (Fig. 10.1 (d)). We shall learn about types of magnets later.

10.2 Magnetic and non-magnetic materials

Materials may be classified according to their magnetic properties. There are those that are attracted by magnets and others that are not.

To identify magnetic and non-magnetic substances

Activity 10.2 **To identify magnetic and non-magnetic substances**

Materials: Iron and steel nails, bar magnet, copper metal, cobalt, wood, zinc, glass rods

Steps

1. Place some iron nails on the table. Bring a bar magnet close to the iron nails and observe what happens. Explain your observations.
2. Repeat the activity with other material such as copper, cobalt, steel, sulphur, brass, wood, cork, nickel, plastic, pens, wax, zinc, glass rods, carbon, aluminium, paper, chalk etc.
3. Record your observations in tabular form as shown in Table 10.1.

Substances attracted by a bar magnet	Substances not attracted by a bar magnet
1.	1.
2.	2.
3.	3.
4.	4.

Table 10.1: Magnetic and non-magnetic materials

4. Discuss your observations in step 3 and suggest the name given to substances that are attracted by a magnet and those that are not.

The results from Table 10.1 shows that some materials are attracted by the bar magnet while others are not.

The materials which are attracted by a magnet are called *magnetic materials* while those which are not attracted are called *non-magnetic materials*. The magnetic materials that are strongly attracted by a magnet are called *ferromagnetic materials*. These include *nickel, iron, cobalt* and *steel*.

Materials that are not attracted by a magnet are called non-magnetic materials. Examples of *non-magnetic materials* include *copper, brass, aluminium, wood, cork, plastic* etc.

When metals are mixed together, they form *alloys*. Some *alloys* are ferromagnetic materials. An example is Al-ni-co which composed of aluminium (Al), nickel (Ni) and cobalt (Co) hence the name *Al-ni-co*. Another example of alloys which are those composed of nickel, iron, copper, chromium or titanium; they are also ferromagnetic.

10.3 Properties of magnets

(a) Polarity property of magnets

Activity 10.3 **To identify the poles of a magnet**

Materials: A bar magnet, iron filing in a container

Steps

1. Dip a bar magnet into the container with iron filings.
2. Remove the magnet from the container. What happens to it? Explain your observation.
3. Suggest the name given to the ends of a magnet.

From Activity 10.3, you must have noted that the iron filings were attracted by a bar magnet. Most iron filings remained clustered around the ends of the magnet as shown in Fig. 10.2.

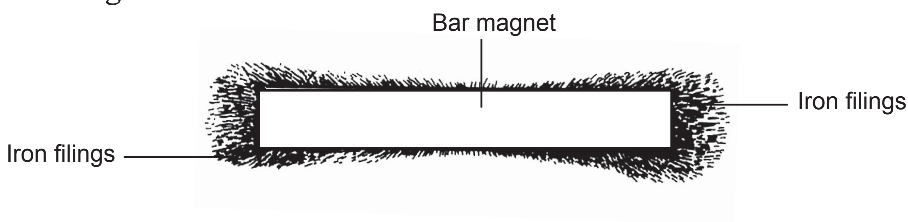


Fig. 10.2: Distribution of iron filings around a bar magnet.

The ends of a magnet where the attraction is strongest are known as the *magnetic poles.* Magnetic poles are the places in a magnet where the total attractive force seems to be concentrated. A straight line drawn passing through these ends is called the *magnetic axis* of the magnet (see Fig. 10.3).

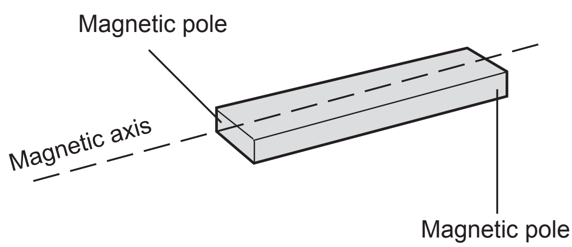


Fig. 10.3: Magnetic poles and magnetic axis of a bar magnet.

A bar magnet has the strongest attraction at the poles.

(b) Directional property of a magnet

Activity 10.4 **To observe the directional properly of a magnet**

Materials: A bar magnet, 1 metre long thread

Steps

1. Suspend a bar magnet freely at its centre by a length of a cotton thread from a support (Fig. 10.4 (a)). Make sure there are no steel or iron objects near the magnet.

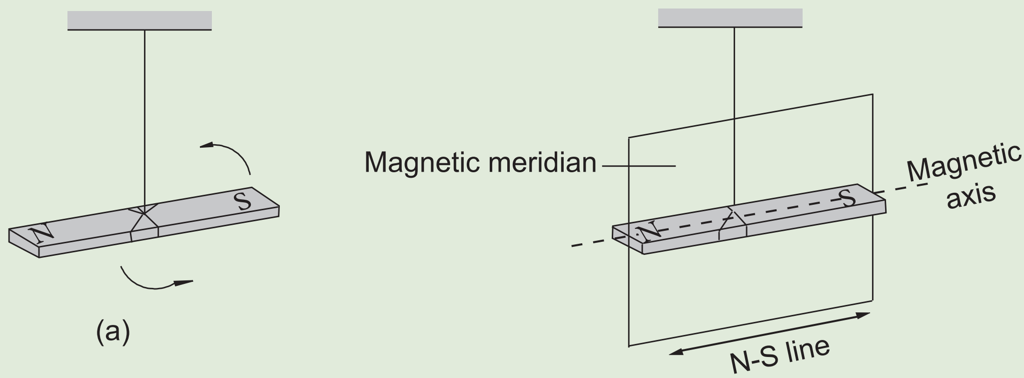


Fig. 10.4: A freely suspended magnet.

2. Displace the magnet slightly so that it swings in a horizontal plane.
3. Note the direction in which the magnet finally comes to rest. Suggest a reason why it rests in that direction.
4. Repeat the activity at different places and note the resting direction of the magnet. What do you observe? Explain.

In Activity 10.4, you observed that the bar magnet swings to and fro and finally rests in a north-south (N-S) direction of the earth.

The magnet comes to rest with its axis in a vertical plane called the *magnetic meridian* (Fig. 10.4 (b)) i.e. a bar magnet rests in a north-south direction.

The pole that points towards the north pole of the earth is called the *north seeking pole* or simply the *north pole* (N). The other pole is called the *south seeking pole* or *south pole* (S).

To identify the poles of a magnet by colour

Activity 10.5 **To identify the poles of a magnet by colour**

(Work in groups)

Materials: A bar magnet, 1 metre long thread

Steps

1. Repeat Activity 10.4.
2. Place a compass at a place far away from the suspended bar magnet. Compare the direction shown by the compass and that of the suspended bar magnet.
3. Note the pole of the suspended bar magnet that is pointing in the same direction as north pole or south pole of the magnetic compass. Deduce the poles of the magnet.

From Activity 10.5, you noted that the pole that points in the direction of the north of the compass is the north pole and the other pole is the south pole.

In order to easily identify the poles of a magnet, the ends are usually painted in different colours. For example, the *N-pole* is painted *red* while the *S-pole* is painted *blue* or *white* Fig 10.5 (a). In other cases the whole bar is painted blue with a red dot or spot on one end to identify the north pole. (See Fig. 10.5 (b)).

Fig. 10.5: Colours used to identify poles of a bar magnet

Hey!!

Do you know that the blue colour in our national flag symbolises happiness and peace? Let us always live happily with one another and keep peace in our beautiful country.

10.4 Test for magnetism

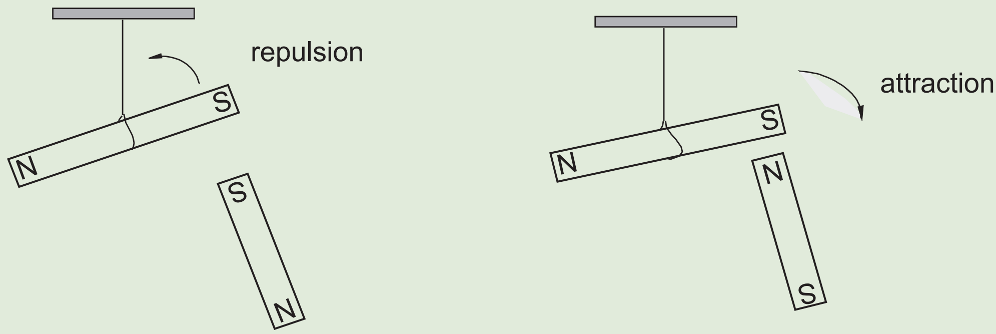
Basic law of magnetism

Activity 10.6 **To establish the basic law of magnetism**

Materials: Two bar magnets, cotton thread.

Steps

1. Suspend a bar magnet using a light cotton thread with its north and south pole clearly marked.
2. Bring a S-pole of a second bar magnet slowly towards the S-pole of the suspended magnet. Observe what happens (Fig. 10.6(a)).
3. Repeat the activity using the S-pole of the suspended magnet and the N-pole of the second magnet (Fig. 10.6 (b)).



(a) **(b)**

Fig. 10.6: Action of magnets on each other.

4. Repeat using the other poles and record your observation in a tabular form as shown in table 10.2.

Poles of suspended magnet	Pole of second magnet	Observation
South	South	______
South	North	______
North	South	______
North	North	______

Table 10.2: Test for magnetism

From Activity 10.6, you must have discovered that a north pole attracts a south pole, a north pole repels a north pole and a south pole repels a south pole.

Therefore, *unlike poles attract each other while like poles repel each other*. This is called the *basic law of magnetism*.

Testing the polarity of magnets using the basic law of magnetism

Activity 10.7 **To test for polarity of magnets using the basic law of magnetism**

Materials: A nail, two bar magnets, a cotton thread

Steps

1. Freely suspend a bar magnet as shown in Fig. 10.7.
2. Bring one pole of the magnet close to a nail placed on a table. What do you observe? Explain.

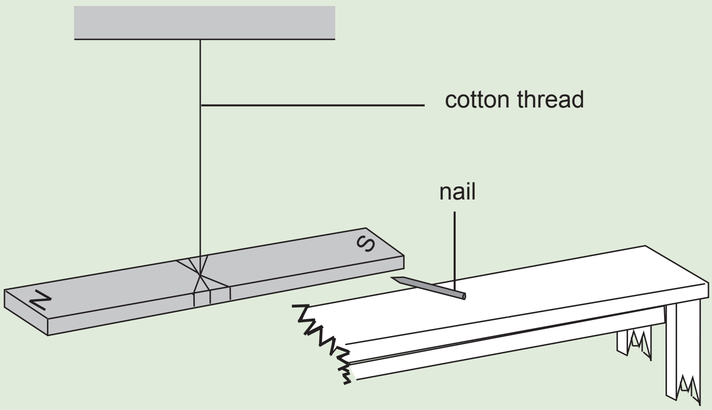


Fig. 10.7: Testing the polarity of a magnet.

3. Repeat with the other pole close to the nail and record your observations.
4. Repeat steps 2 and 3 using a second bar magnet instead of the nail. What do you observe? Discuss your observations.

From Activity 10.7, you must have observed the following:

1. There is attraction when the south or north pole of the suspended magnet is brought near the nail.
2. When the second bar magnet is used, there is attraction with one pole and repulsion with the other pole.

Therefore, there is always attraction between a magnet and a magnetic material and also between the unlike poles of magnets. But there is repulsion only between two like poles of magnets.

Repulsion is therefore, the only sure way of testing for polarity of a magnet.

10.5 Types of magnets

Activity 10.8 **To magnetise a piece of iron nail**

Materials: A piece of soft iron nail (about 3 inches), about 1 m of thin coated copper wire, a fresh size D dry cell, iron filing, cello tape.

Steps

1. Leave about 15 cm of wire loose at one end and wrap part of the remaining section of the wire around the nail.
2. Cut the wire (if needed) but ensure that there is at least 15 cm of wire loose on the other end too.
3. Remove about 2 cm of the plastic coating from each end of the wire. Attach one end of the wire to terminal of the dry cell, and the other end of the wire to the other terminal of the battery using a cello tape (Fig 10.8). Be careful though, the wire might get very hot!

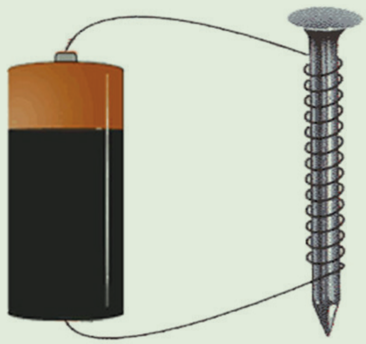


Fig. 10. 8: Magnetising a piece of iron nail

4. Bring one end of the nail near the iron filings. What do you observe? Explain.
5. Disconnect one end of the wire from the dry cell. What happens to the iron filings? Explain.
6. Repeat the activity by replacing soft iron nail with a steel nail and increase current by adding more new dry cells to the circuit. What do you observe?

From Activity 10.8, you must have noted that the soft iron nail attracts the iron filings only when the circuit is complete i.e., when electric current is flowing through the wire. This shows that the iron nail has become a magnet. This kind of a magnet which is made by passing current through a coil is called an *electromagnet*.

When the circuit is disconnected, no current will flow in the wire, hence the iron nail does not attract the iron filings. The electromagnet is a temporary magnet.

When the steel nail was used instead of iron nail and current was increased, the iron filing did not fall off after being attracted and the circuit disconnected. Hence, the steel nail has become a permanent magnet.

Therefore,there are two basic types of magnets; permanent and temporary magnets.

(a) Permanent magnets

Activity 10.9 **To compare magnetism retention of different permanent magnets**

Materials: Dry cell, iron feelings, cello tape, steel nail, 1 m thin coated copper wire

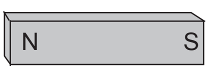
Steps

Repeat steps 1 to 5 of activity 10.8 using a steel nail and iron each at a time. Explain your observation.

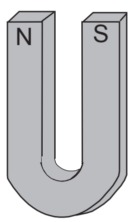
In Activity 10.9, you should have observed that the steel nail retained its magnetism for a longer time. Permanent magnets are those magnets that retain magnetic properties for a long time. They are made from hard magnetic materials e.g steel. An example of naturally occurring permanent magnet is lodestone, which is composed of a mineral called magnetite.

Other permanent magnets are made from mixing magnetic materials (such a mixture is known as an *alloy*). Examples of alloys commonly used to make permanent magnets are *Al-ni-cos* i.e iron alloys containing aluminium, nickel, and cobalt. Steel which is mixture of carbon and iron and materials containing rare-earth elements like samarium, neodymium or ferrites (an oxide of iron).

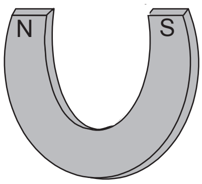
Permanent magnets can be made into any shape to fit the usage. They can be made into round bars, rectangles, horse-shoes, donuts, rings, disks and other custom shapes. Fig 10.9 shows some permanent magnets named according to their shapes.



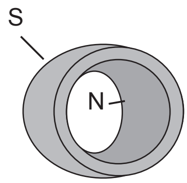
(a) A bar magnet



(b) U-shaped magnet



(c) Horse-shoe magnet



(d) A ring magnet

Fig. 10.9: Shapes of permanent magnets.

Fig 10.10 shows a *ceramic* or *magnadur* magnet. The poles of ceramic magnet are at its *faces* (Fig. 10.10). These types of magnets are stronger than other magnets of comparable size. They are greyish/black in colour. Magnadur magnets consist of basically iron oxide and barium oxide.

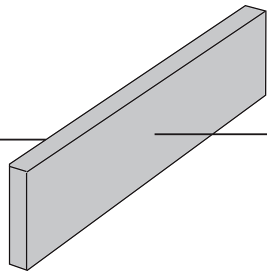


Fig. 10.10: Ceramic magnet (magnadur).

Uses of permanent magnets

Permanent magnets are used to lift heavy loads in industries. They handle loads with extreme easiness in the minimum area. This makes them efficient because they always operate from the top without compressing or deforming the load.

Note:

Note: A permanent magnet system for lifting loads is safe since it is not affected by any electrical power failure. Therefore, no battery or generator backup system is required.

Other uses of permanent magnets include:

1. Removing of iron pieces from the eyes of patients in hospitals.
2. Setting of six's maximum and minimum thermometer in weather stations.
3. To show the direction as in compass needles for navigation.
4. Magnetic tapes use permanent magnets in audio and video recorders.

(b) Temporary magnets

Activity 10.10 **To investigate magnetic property of a temporary magnet**

Materials: Dry cell, iron feelings, cellotape, iron nail, 1m thin coated copper wire

Steps

Repeat step 1 to 5 of Activity 10.8 using an iron and observe what happens. Explain your observation.

From Activity 10.10, you should have established that temporary magnets are those magnets which act as magnets only when there is *a flow of electric current or a presence of a permanent magnet.* They loose magnetism when the permanent magnet is removed or electric current is cut off. Some may retain weak magnetic properties. They are made using *soft magnetic materials* like soft iron, iron-silicon alloys and iron-nickel alloys. An example of temporary magnet is an *electromagnet*.

A simple electromagnet is made by winding a wire carrying current round a soft magnetic material and then connecting the wire in a simple circuit.

Uses of temporary magnets

Electromagnets are used in motors, loud speakers, telephone, earphones and among other devices.

Exercise 10.1

1. Explain the meaning of the following terms:
   (a) a magnet.
   (b) a magnetic substance/material.
   (c) a non-magnetic material.
   (d) a ferro-magnetic material.
2. Group the following materials into magnetic and non-magnetic materials: Zinc, paper, aluminium, graphite, steel and plastic.
3. Explain how you can identify the polarity of a magnet whose poles are not marked?
4. Two steel pins were attracted by a magnet. When a south pole was brought in between the two pins, the pins moved further away, as shown in Fig. 10.11. Explain why the pins moved apart.

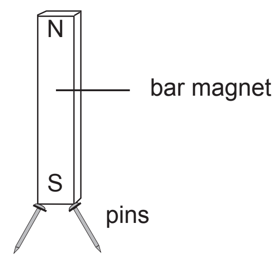


Fig. 10.11: Steel pins attracted to bar magnet

10.6 Magnetic field pattern around a magnet

Activity 10.11 **To investigate the existence of magnetic field around a magnet**

Materials: 2 bar magnets, a magnetic compass

Steps

1. Place a bar magnet on a table.
2. Pass the magnetic compass over the bar magnet and observe what happens. Explain your observation.
3. Now, move the magnetic compass along the sides of the bar magnet. What did you observe? Discuss your observation to your class partner.

In Activity 10.11, you should have observed that in steps 2 and 3 when the magnetic compass was placed near the bar magnet, its direction changes. This shows that there is a magnetic effect in the region around the magnet. In this region, there exist magnetic force of attraction and repulsion. This space or region is called magnetic field, and is represented by the lines of force called magnetic field lines. These field lines forms a pattern called magnetic field pattern.

Drawing magnetic field pattern round a magnet

Activity 10.12 **To investigate magnetic field pattern around a magnet using iron filings**

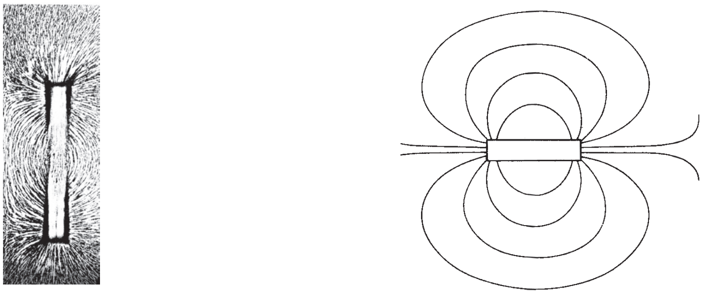
Materials: 2 bar magnets, U-shaped magnet, iron filings , stiff paper

Steps

1. Place a smooth stiff paper on top of a bar magnet.
2. Sprinkle iron filing onto the stiff paper. What do you observe? Explain your observation to your class partner.
3. Tap the paper gently and draw the pattern displayed by the iron filings.
4. Repeat the activity with north poles of two bar magnets close together and then south to north poles. Observe and draw the pattern displayed by iron filings.
5. Repeat steps 1 to 3 by using a U-shaped magnet.
6. Compare and discuss your patterns with other pairs in your class before presenting your finding to the whole class.

In Activity 10.12, you observed that the iron filings are attracted by the magnet, since there is a magnetic effect in the region around the magnet. The pattern displayed by the iron filings represents the magnetic lines of force.

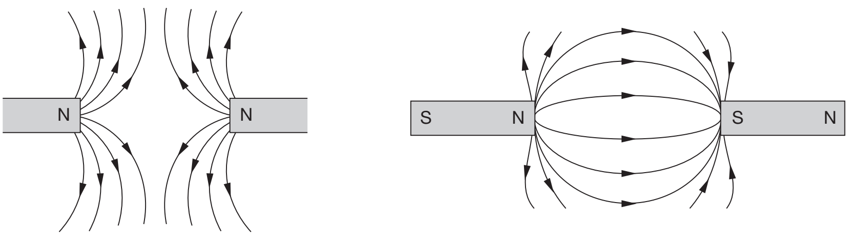
Fig.10.12 shows the photograph and magnetic field lines of the iron filings arrangement around a bar magnet. Note that the lines do not cross each other.



(a) **(b)**

Fig. 10.12: Magnetic field lines around a bar magnet

When the two north poles or north and south pole are placed close to each other and the steps 1 to 3 repeated, the pattern displayed is as shown in Fig 10.13(a) and (b) respectively.



(a) **(b)**

Fig. 10.13: Magnetic field patterns

Note that magnetic field lines originate from the north pole of a magnet to the south pole.

In step 5 of Activity 10.12, the pattern displayed when the U-shaped magnet was used is as shown in Fig. 10.14.

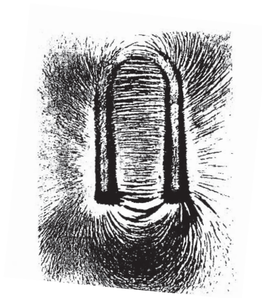


Fig. 10.14: Magnetic field patterns of U-shaped magnet

Unit summary and new words

- A magnet is a piece of metal with either natural or induced properties of attracting other metal objects.
- Materials which are attracted by a magnet are called *magnetic materials* while those which are not attracted are called *non-magnetic materials*.
- The ends of a magnet where the attraction is strongest are known as the magnetic poles. There are two types of poles. North pole and south pole.
- Unlike poles attract each other while like poles repel each other. This is called the *basic law of magnetism* or *the first law of magnetism*.
- Repulsion is the only sure way of testing for polarity of a magnet.
- The space or region around a magnet is called magnetic field. It is represented by the lines of force called magnetic field lines.

Unit Test 10

1. State two properties of a magnet.
2. State the basic law of magnetism.
3. Name *four* types of magnets according to shapes.
4. Describe an experiment to explain the existence of magnetic poles.
5. Explain what would happens to a U-shaped magnet if it is freely suspended as shown in Fig. 10.15.
6. What is the main difference between a ceramic magnet and a bar magnet?
7. You have been provided with the following;
   (a) a rod labelled S, which is a magnetic material.
   (b) a rod labelled N, which is a non-magnetic material.

   Explain how you would identify them.

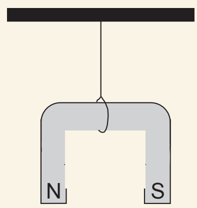


Fig. 10.15: U-shaped magnet

8. The magnets shown in Fig. 10.16, pole B attracts pole P and pole Q attracts pole X. If pole Y is South pole:.

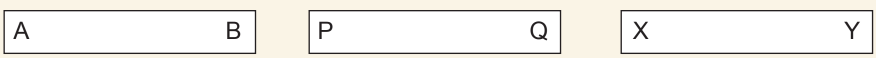


Fig. 10.16: Bar magnet

   (a) What is the polarity of P?
   (b) What would happen if the following poles are brought close together:
   (i) pole B and X **(ii)** pole A and pole Q
   (iii) pole B and pole Y
   (c) Draw a magnetic field pattern when pole B and P are placed near each other.

UNIT 11 Electrostatics (I)

Key Unit Competence

By the end of this unit, I should be able to explain charging of materials and distribution of electric charges on conductors.

Unit outline

- Types of electrostatic charge and SI unit of charge.
- Method of charging bodies.
- Laws of electrostatic charge and Coulomb's law.
- Insulators and conductors.
- Electric field and electric potential.
- Distribution of electric charges on metallic conductors.
- Application of electrostatic charges.

Introduction

You may have observed the following phenomena:

1. Sometimes one can get a shock when getting out of a car or touching the metal knob of the door.
2. Dust particles stick to a window pane when the pane is wiped with a dry cloth on a dry day.
3. A metal chain is usually attached to the trucks carrying petrol or other inflammable materials.

You might have also experienced crackles and sparks that accompany taking off clothes made of materials like nylon, polyster.

These and many more experiences are as a result of *electrostatic phenomena*. The physics behind these observations will be clear after going through this unit.

11.1 Types of electrostatic charges

Activity 11.1 **To observe the attraction between water particles and charged rod**

Materials: A small stream of water and a polythene strip or a comb.

Steps

1. Take the polythene strip or the comb near to a stream of water flowing from a tap. What do you observe? Explain.
2. Now, rub the polythene strip or the comb against your hair or cloth.
3. Slowly bring the polythene strip or the comb near the water stream. What do you observe? Explain your observations to your class members.
4. Now, brainstorm with your class members the different types of electrostatic charges.

In activity 11.1, you should have observed that nothing happens when the comb was brought near the stream of water at first. When rubbed through hair, and brought near the stream, the water bends towards the comb (Fig. 11.1).

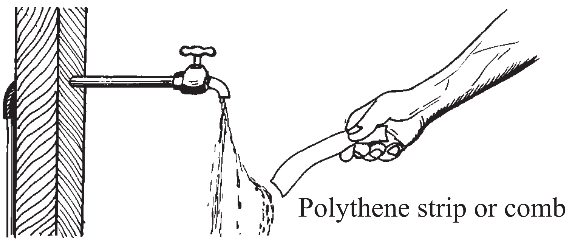


Fig. 11.1: Stream of water attracted to a polythene strip or comb

This happens because the water is attracted towards the charged polythenes strip or comb.

When the polythene strip or the comb is rubbed against hair/cloth, it acquires the *attractive* property. The charged polythene strip *attracts* the thin stream of water.

The charged polythene strip or the comb can also attract bits of paper, tiny pieces of cloth, etc. Many substances such as glass, plastic, ebonite and perspex when rubbed with silk, rubber, fur, cotton wool or cat skin acquire the *attractive* property. The charges developed on the materials are at rest and cannot move. We therefore, call them *static charges*. The study of static charges is called *electrostatics*. There are two types of static charges: *positive charges* and *negative charges*. Scientists like Benjamin Franklin, and Charles Coulomb contributed a lot to the development of this branch of physics.

11.2 Origin of charges

Activity 11.2 **To demonstrate attraction between a balloon and a wall**

Materials: A balloon, Internet, reference books

Steps

1. Take a balloon and fill it with air.
2. Take it near to a wall and try to stick it. What do you see? Explain your observations to your class partner.
3. Now, rub this balloon through your hair.
4. Try to stick it to the wall again. What do you observe now? Explain.
5. Discuss your observations in steps 2 and 4 with your colleagues in class.
6. Conduct a research from reference books and Internet on the origin of charges.
7. In your research, find out:
   (a) structure and composition of an atom. Sketch the structure.
   (b) the definition and SI unit of charge.

In activity 11.2, you must have observed that the balloon doesn't stick to the wall in the first step. However, after it was rubbed against the hair, it stuck to the wall.

In general, when a material of one kind is *rubbed* with some other material, both materials get charged by friction. Where do the charges come from? A simple idea of the *structure of an atom* will enable us to understand the mechanism of charging.

In Unit 8, we learnt that matter is made up of tiny particles called *atoms*. For a long time, scientists thought that the atoms were the smallest building blocks of matter and that they could not be subdivided further. However, in 1897, a new particle smaller than an atom was discovered. It was called *electron*. Later, other particles called *protons* and *neutrons* were discovered. Today we have a better picture of the atom than in 19th century.

An atom is made up of two parts: a central core called the *nucleus*, and outer orbits where electrons go round the nucleus. The nucleus contains protons and neutrons closely and tightly packed (Fig. 11.2). The electrons are extremely light compared to protons and neutrons. They carry a *negative charge*. Protons carry a *positive charge*. Neutrons carry *no charge*. The number of protons and electrons in an atom are equal and hence an atom is electrically neutral.

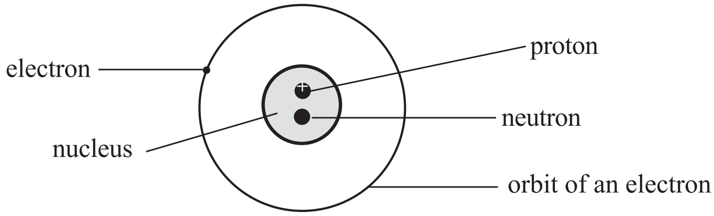


Fig. 11.2: Structure of an atom

Therefore, a charge can be defined as a *characteristic of matter that express the extent to which it has more or fewer electrons than protons and vice versa*.

The SI unit of quantity of charge is the *coulomb (C)*, named after a famous scientist called *Charles Augustin de Coulomb (1736-1806)*.

The knowledge we have learnt about protons and electrons in an atom is used to explain how a body is charged.

We conclude that there are two types of static charges: *positive charges* and *negative charges.*

11.3 Methods of charging bodies

(a) Charging by friction method

Activity 11.3 **To charge a body by friction**

Materials: A pen made of plastic material and some small pieces of paper or tissue

Steps

1. Take a pen near to small pieces of paper or tissue. What do you observe? Explain.
2. Now, rub the pen on your hair and take it near to the small pieces of paper or tissue. What do you observe in this case? Explain your observation.
3. Place the pen near to your arm and observe how your hair on your arms behave. Why do you think the hair behaved the way it does ?
4. Discuss your observations and thoughts in steps 1, 2 and 3 to your colleagues in class.

In activity 11.3, you should have observed that, nothing happens when the pen was brought near the small pieces of paper in the first step. However, in the second step, the pen attracted pieces of paper when it was rubbed against the hair. This is because it got charged i.e gained charges that are opposite to that on pieces of paper.

When the charged pen was brought near the hair of your hand, the hair was seen bending to the opposite side. This is because of the repulsion force between the charged pen and hair. This indicates that the two (charged pen and hair) have similar charges on them.

In general, when two *materials* are rubbed against each other, the heat energy developed due to friction, can move some of those loosely held electrons from one material and transfer them to the other i.e. the electrons may be *rubbed off* from one material to the other because in some materials, the electrons are not tightly bound to the nucleus.

Materials like polythene *gain* electrons from flannel cloth (cotton wool) when rubbed and become negatively charged. Flannel cloth loses electrons and becomes positively charged (Fig. 11.3).

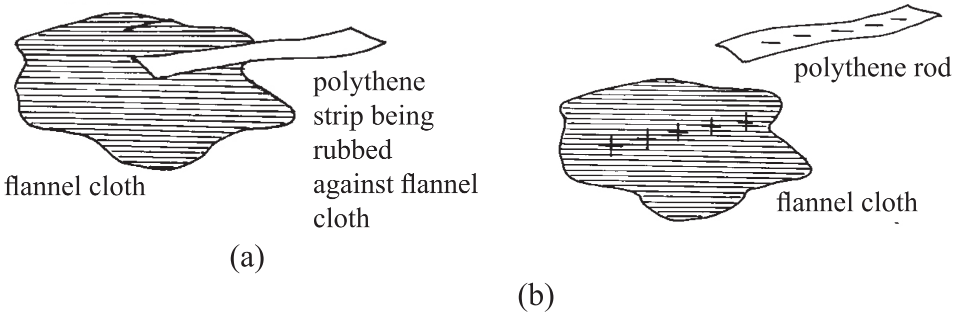


Fig. 11.3: Rubbing polythene against flannel cloth

Materials like glass *lose* electrons when rubbed with silk cloth or far and become positively charged. The silk material gains electrons and becomes negatively charged (Fig. 11.4).

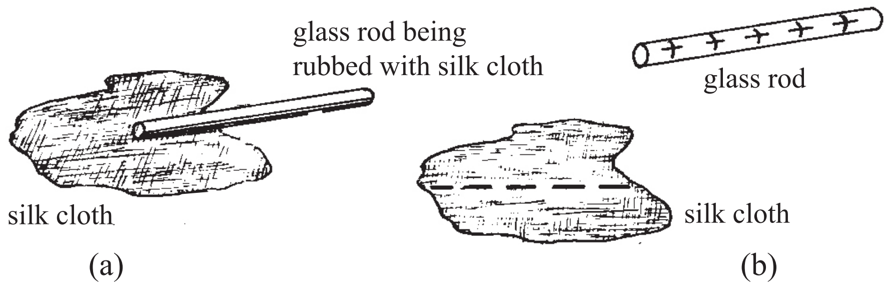


Fig. 11.4: Rubbing glass against silk cloth

A body is said to be negatively charged if it has an excess or surplus of electrons. It is said to be positively charged if it has a deficiency or shortage of electrons.

It is important to note the following points when materials are charged by friction method:

- The excess negative charges on one body is equal to the excess positive charges on the other. No new charges have been created.
- During the rubbing process, some materials always acquire the same kind of charge whereas some materials may acquire either negative or positive charges.

- The quantity of charge produced in some cases may be small and in some cases the charges may escape before they are detected. A dry atmosphere and a clean dry state of the body are essential for holding the electrical charges.

Experiments shows that the nature of charge on a rubbed substance depends upon the nature of the rubbing material. From experience, physicists have classified the substances in a particular order. The list in Table 11.1 shows such a classification where the substance higher in the list acquires a negative charge while the lower one acquires a positive charge. The table only covers some commonly used substances.

Polythene
Ebonite
Metals
Silk
Flannel or wool
Glass
Fur

Table 11.1: Classification of substances

Example 11.1

Polythene is rubbed with wool. What charge does:

(a) polythene acquire?

(b) wool acquire?

Solution

(a) Polythene acquires negative charge because polythene is higher in the list than wool.

(b) Wool acquires a positive charge.

Example 11.2

Glass is rubbed with silk. What charges do the two materials acquire?

Solution

Glass is lower in the list than silk. Therefore, glass acquires positive charge while silk acquires a negative charge.

(b) Charging by induction method

Activity 11.4 **To charge a body by induction method**

Materials

- Insulated uncharged metal sphere
- Conducting wire
- Glass rod
- Polythene rod

Steps

1. Rub a glass rod with silk cloth. What type of charges does it acquire?
2. Bring the charged glass rod close to but not touching the insulated uncharged metal sphere (Fig. 11.5 (a)).

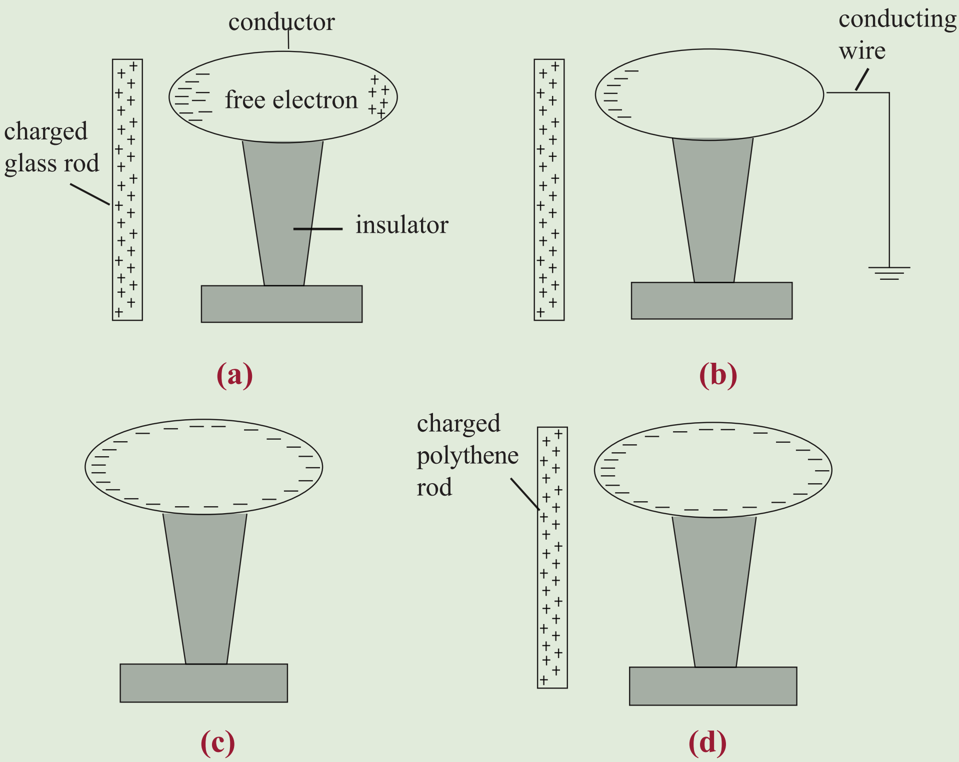


Fig. 11.5: Charging a conductor by induction method

3. Touch the metal sphere with a conducting wire on the opposite side and connect the wire to the ground (Fig. 11.5 (b)). What do we call this process?
4. While holding the glass rod near the space, withdraw the conducting wire first then the glass rod (Fig. 11.5 (c)).
5. Bring charged polythene and glass rods in turns close but not touching the sphere (Fig 11.5 (d). Observe and explain what happens.
6. Touch the conductor and repeat step 5 above.
7. Discuss your observations and report your findings to the whole class.

From your discussion, you should have established that the glass rod becomes positively charged when rubbed against silk cloth. When the rod was brought near the insulated conductor, the negative charges on the the conductor were attracted while the positive ones were repelled (Fig. 11.5(a))The process is called electrostatic induction.

When the sphere was earthed (connected to the ground with the wire) the negative charges moved from the earth into the sphere and neutralised the positive charges on the sphere (Fig. 11.5 (b)).

When the rod was removed, the negative charges redistributed themselves uniformly on the surface of the conductor (Fig. 11.5 (c)).

In step 5, you should have established that the conductor has been charged. The charge on the conductor is opposite to that of the charged glass rod. This is because it attracts the glass rod (positively charged) and it repels the polythene rod (negatively charged). On touching the conductor after it had been charged (step 6), it got discharged (negative charges on it moved to the ground) hence could not attract nor repel the charged rods again.

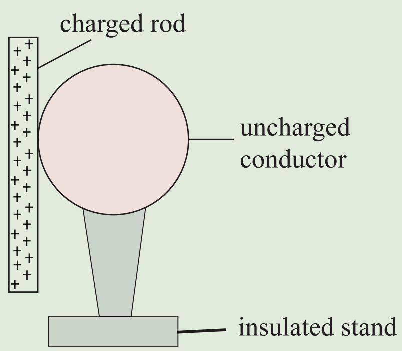
This method of charging objects is called induction method. The charge acquired by the conductor being charged is opposite to that of the charging rod.

(c) Contact (conduction) method

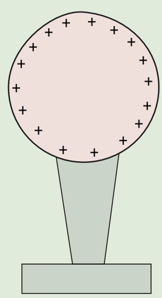
Activity 11.5 **To charge a body by contact method**

Steps

1. Using the same materials used in Activity 11.4 (b), bring a charged glass rod in contact with uncharged conductor and observe what happens (Fig. 11.6(a)).
2. Remove the charged glass rod (Fig. 11.6 (b)).
3. Bring the charged glass rod and polythene rod in turns close to the conductor and observe what happens. (Fig 11.6(c)).
4. Have a discussion on your observation in steps 1 and 3. Note down your findings.
5. Have a class presentation on your findings.



(a)



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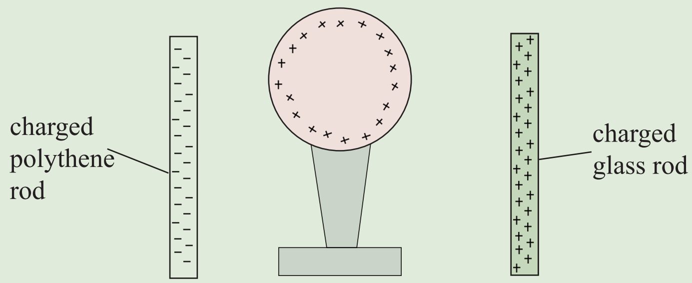


(c)

Fig. 11.6: Charging by contact method

In Activity 11.5, you should have observed that the conductor is attracted by the polythene rod and repelled by the glass rod.

When a positively charged glass rod is brought in contact to the conductor, it neutralizes the negative charges on the conductor and repel the positive charge away from the side of the glass rod (Fig. 11.6(a)).

When the positively charged glass rod is removed (contact broken), the positive charges on the conductor repel each other and spread throughout its body, hence the conductor becomes positively charged.

The positively charged conductor repel the glass rod and attracts polythene rod when they are brought close to it one at a time.

Therefore, the conductor becomes charged by contact method. The charge on the ball is the same as the charge on the charged glass rod (charging rod).

(d) Separation method

Activity 11.6 **To charge a body by separation method**

Materials

- Two metal spheres (A and B)
- Polythene rod

Steps

1. Place two metal spheres on insulating stands in contact with each other (Fig. 11.7 (a)).
2. Bring a charged polythene rod close but not touching sphere A (Fig. 11.7(b)).
3. Move sphere B away while holding the charged polythene rod in position so as to break the contact (Fig. 11.7(c)).
4. Remove the polythene rod (Fig. 11.7(d))

5. Test the two spheres (A and B) using the negatively charged polythene rod and observe what happens.
6. Hold a discussion on your observations in step 5.

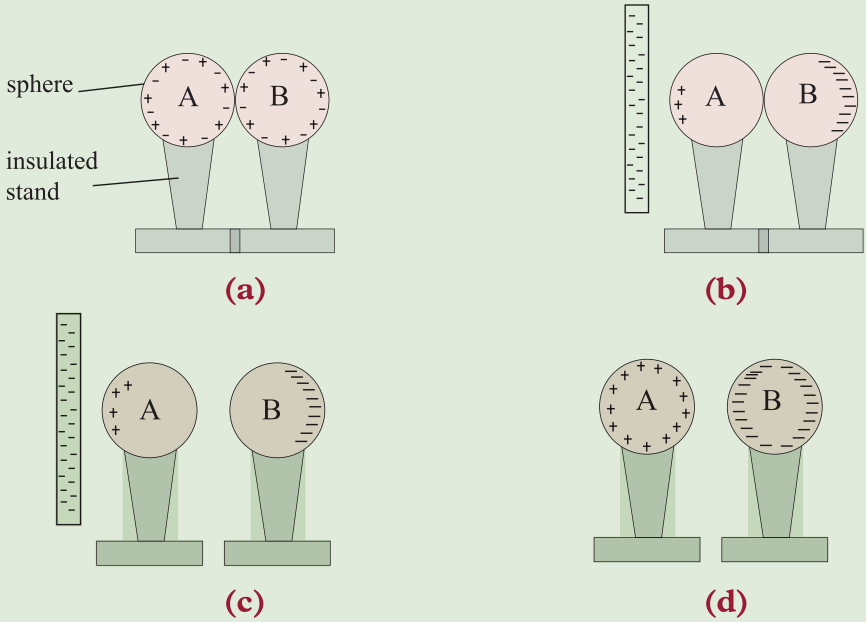


Fig. 11.7: Charging by separation method

In Activity 11.6 before,the polythene rod was brought near spheres (Fig. 11.7(a)), the positive and negative charges were balanced in each sphere hence the spheres were uncharged (neutral).

When the polythene was brought closer to the two spheres, charge separation occur i.e. negative charges from both spheres were repelled to sphere B and positive charges from both spheres were attracted to sphere A.When the spheres were separated, positive charges remained in sphere A and negative charges in sphere B.When the charged polythene rod was removed, the charges distributed themselves uniformly on the sphere. A negatively charged rod would be attracted by sphere A and repelled by sphere B.

From Activity 11.6, we conclude that:

- The two spheres have become *charged by separation.*
- It can be seen from Figure 11.7(c) that sphere A has acquired a charge opposite to that of the charging rod while sphere B has acquired a charge similar to that of charging rod.

11.4 The law of electrostatics

Activity 11.7 **To investigate the electrostatic force between two negatively charged rods**

Materials: An ebonite rod, silk, a thread, polythene rod

Steps

1. Rub an ebonite rod with silk and suspend the rod with a stirrup (support) and thread.
2. Bring a charged polythene rod near one end of the ebonite rod and observe what happens (Fig. 11.8).
3. Discuss with your partner the observations in case 2.

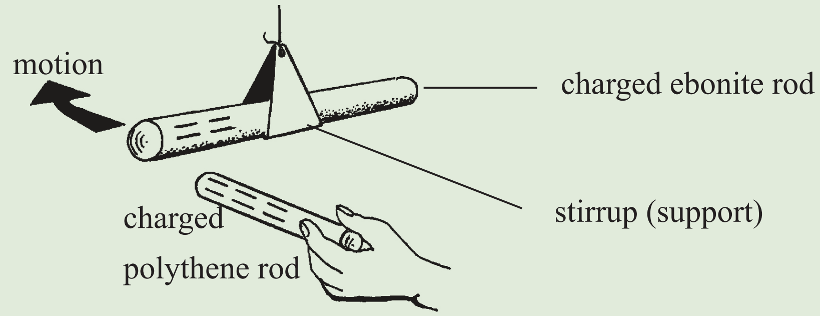


Fig. 11.8: Charged polythene repels charged ebonite rod

In activity 11.7, you must have observed that the charged polythene rod repels the charged ebonite rod. This shows that there is a force of repulsion between the two rods with the same charges.

Therefore, *two materials repels each other if they have same charges*.

Activity 11.8 **To show the electrostatic force between two positively charged rods**

Materials: Two glass rods, a silk cloth, a thread

Steps

1. Rub two glass rods with a silk cloth vigorously and suspend them with stirrups and thread.

2. Bring the two suspended rods close to each other and observe what happens (Fig. 11.9).
3. Discuss the observations you made in case 2 and 3 and deduce a general law of electrostatic.

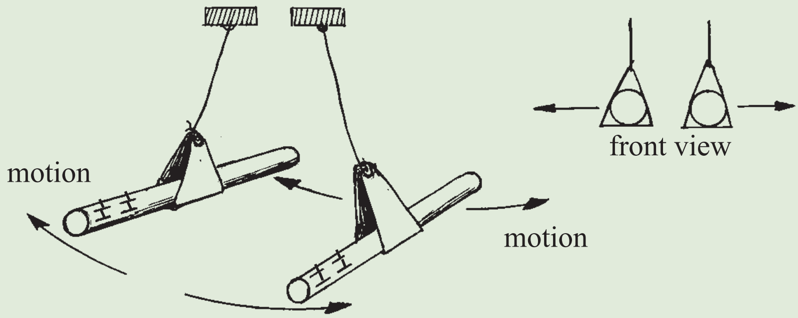


Fig. 11.9: Like charges repel

In activity 11.8, you should have observed that the two positively charged glass rods move away from each other. This shows that the glass rods repelled each other.

Therefore, *like charges or similar charges repel each other*.

Activity 11.9 **To investigate the electrostatic force between unlike charges**

Steps

1. Repeat Activity 11.7 by taking a charged glass rod near one end of the suspended charged ebonite rod and observe what happens this time (Fig. 11.9).
2. Discuss your observations in case 1 with your colleague.

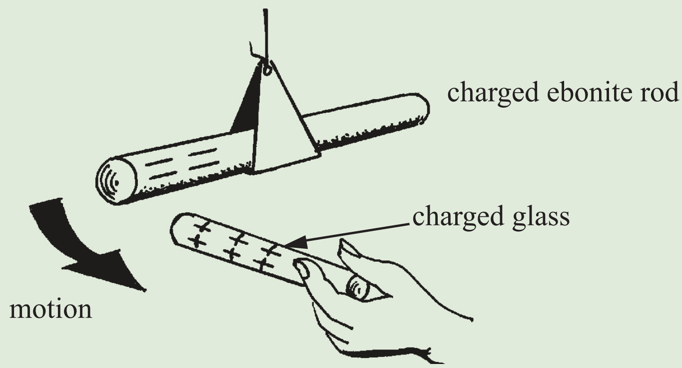


Fig. 11.9: A charged glass rod attracts a charged ebonite rod

In your discussion, you should have noted that the charged glass rod *attracts* the charged ebonite rod.

This activity show that the charges on polythene and glass are unlike. Hence, we conclude that *unlike charges attract each other*.

From Activities 11.7, 11.8 and 11.9 we can conclude that:

- Unlike charges attract each other.
- Like charges repel each other.

This is summarised in the basic law of electrostatics that states *that like charges repel and unlike charges attract.*

Activity 11.10 **To confirm that a body is charged**

Materials: Glass rod, ebonite rod, silk, thread, pieces of papers, polythene rod

Steps

1. Rub both the glass and ebonite rods with a silk cloth.
2. Bring each rod at a time to near the pieces of paper. What do you observe?
3. Suspend one rod with a string and bring the other one close to it. What do you observe?
4. Suspend the glass rod and ebonite rod with a stirrup (support) and thread.
5. Charge a polythene rod by rubbing it with silk, pass it over the pieces of paper and bring it near the suspended ebonite rod and then to the glass rod. What do you observe?
6. Discuss you observations in steps 2, 3 and 5 with your partner and then report to the whole class.

In Acivity 11.10, you should have observed that both the ebonite and glass rods attracted the pieces of paper because they were charged. They attracted each other because they were oppositely charged by friction. i.e negatively and positively respectively.

When the negatively charged polythene rod attracted pieces of papers and the positively charged glass rod but, repelled the ebonite.

From this Activity it is clear that:

- Attraction occurs when a charged body is brought either near an uncharged body or near an oppositely charged object.
- Repulsion only occurs between two like charged bodies.
- Uncharged bodies are not repelled by charged bodies.

This why repulsion, is the best test to confirm that a body is charged.

11.5 Coulomb's law

Activity 11.11 **To research on Coulomb's law**

Materials: Internet, reference books

Steps

1. Access the Internet and reference books and do a research on Coulomb's law. What does it state?

The summary from Activities 11.12 and 11.13 actually leads to coulomb's law.

The law was first developed by a French physicist called Charles Augustin de Coulomb and it states that:

Two electrically charged bodies experience an attractive or repulsive force F, which is inversely proportional to the square of the distance(d) between them and directly proportional to the product of their electric charges Q_1 and Q_2, that is:

$$F \alpha \frac{1}{d^2}$$

$$F \alpha Q_1 . Q_2$$

$$F \alpha \frac{Q_1 . Q_2}{d^2}$$

Removing the proportionality sign, we introduce in a constant k

Therefore, force becomes

$$\boxed{F = k \frac{Q_1 . Q_2}{d^2}}$$

Where, the constant, $k = \frac{1}{4\pi\varepsilon}$ and is equal to 8.988×10^9 Nm^2c^{-2}. A covenient value of 9×10^9 Nm^2c^{-2} is sometimes used for charges in free space.

Force is in newtons(N), the charges in coulombs(C) and distance (d) in metres (m).

Coulomb (C) can also be expressed as:

1 coulomb = 10^{-6} micro coulombs

1 coulomb = 10^{-9} nano coulombs

11.6 Factors affecting the magnitude of the force between two charged objects

Activity 11.12 **To determine the effect of the quantity of charge on the magnitude of the force between two charged particles**

Materials: Two identical polythene rods A and B, one perspex rod C, two clamps and stands.

Steps

1. Charge polythene rod A *strongly* by rubbing it with a piece of dry cloth and suspend it on a stand Fig. 11.12 (a).
2. Charge polythene rod B *lightly* by rubbing it with a piece of dry cloth and suspend it on a stand Fig. 11.12 (b).
3. Charge perspex rod C strongly by rubbing it with a piece of dry cloth. Bring the charged perspex rod in turns near the suspended polythene rods A and B. Compare the magnitudes of the force of attraction in both cases. What do you observe?

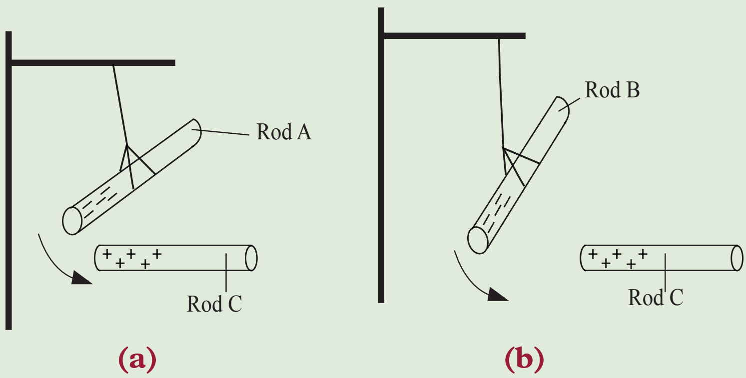


Fig. 11.12: Effect of magnitude of a force

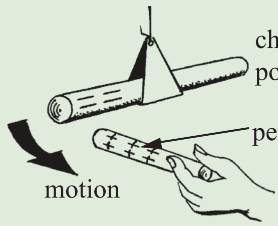
In Activity 11.12, you should have observed that there is a strong force of attraction between rods A and C than between rods B and C.

Therefore, the electrostatic force between two charged objects depends on the quantity of the charge on the two objects. The *greater the quantities of charge on the two objects, the greater the force between them*.

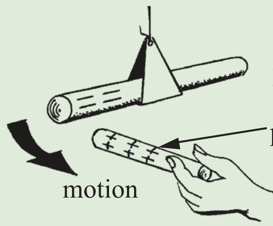
Activity 11.13 To determine the effect of the separation distance on magnitude of the force between two charged objects

Steps

1. Use the set-up in Fig 11.12 (a) to carry out this activity.
2. Bring the charged perspex rod C very close to the suspended charged polythene rod A. Observe the strength of the force of attraction between the two rods (Fig 11.13(a)).
3. Bring the charged Perspex C near the suspended charged polythene rod A, a distance far than in step 2 (See Fig 11.13(b)). Observe the strength of the force of attraction between the two rods. What do you notice?



(a) Charges close



(b) Charges far apart

Fig. 11.13: Effect of separation distances on the magnitude of force

4. Hold a discussion on your observations and summarise your discussion by pointing out the effect of separation distance on the magnitude of a force between two charged objects.
5. Give a report to the whole classs on your findings.

In Activity 11.13, you should have observed that there is a stronger force of attraction between rods A and C when the separation distance between them is short and vice versa.

Therefore, electrostatic force between two charged objects depends on the separation distance between the two charged objects. The greater the distance, the smaller the force and vice versa.

We can summarise from the Activities 11.12 and 11.13 above that the magnitude of the force between two charged objects depends on:

- The quantity of charge – the greater the quantity of charge, the greater the force between the two objects.
- The distance of separation – the greater the distance, the smaller the force.

Exercise 11.1

1. State two types of charges.
2. State the basic law of electrostatics.
3. State the SI unit of charge.
4. Mary rubbed a pen (biro) with a handkerchief and held it near a stream of water running slowly from a tap. She observed that the stream of water curved and followed the movement of the charged pen. When she touched the water with the pen, the curving stopped. Explain these observations.

Example 11.3

Suppose two point charges each with a charge of +1.0 C are separated by a distance of 1m. Determine the magnitude of the electrostatic force between them. Is the force attractive or repulsive? ($k = 9 \times 10^9\ Nm^2c^{-2}$).

Data given

$$Q_1 = +1.0\ C,\ Q_2 = +1.0\ C,\ d = 1\ m$$

Since, $F = k\dfrac{Q_1 . Q_2}{d^2} = \dfrac{9 \times 10^9 \times 1.0 \times 1.0}{1^2}$ then,

$F = 9 \times 10^9$ N. The force is repulsive since it is from two similar charges.

11.7 Conductors and insulators

Activity 11.14 To differentiate between conductors and insulators

Materials: a metal sphere, insulating stand, glass rod, cotton cloth, stand and clamp copper wire, stick, fingers, paper strip, nail, plastic strip.

Steps

1. Suspend the glass rod with a string on the clamp. Charge the rod positively by rubbing it with the cloth.
2. Place the metal sphere on the insulating stand and charge it positively by rubbing it with the cloth.
3. Bring the metal sphere near the suspended charged glass rod and observe what happens to the rod (Fig 11.14 (a).

5. Repeat steps 1 to 4 several times, each time holding a different material (copper wire, stick, papers tick and so on), and using it to touch the surface of the charged metal sphere. Note down the observation in each case.
6. Group the materials that lead to the same observation. How many categories of materials do you get based on the observations. Suggest the names of the categories.

In Activity 11.14, you should have observed that the positively charged metal sphere repelled the suspended positively charged glass rod before being touched with any of the materials. When the charged sphere was touched with the hand negative charges moved from the ground through your body and finger to the sphere neutralizing it. Therefore, the sphere could not repel the suspended rod. This shows that the human body is a good conductor of charge.

Similarly, when the charged sphere was touched with the copper wire, and nail, it also got discharged and could not repel the suspended rod. This shows that the copper wire, and nail are good conductors of charge.

However, when the charged sphere was touched with the stick, paper strip and plastic strip, it still repelled the suspended rod meaning that it was not discharged. This shows that negative charges were not able to flow through these materials to the metal sphere. Thus, the stick, paper strip and plastic strip are insulators.

Let us now discuss conductors and insulators in details.

Conductors

These are materials which allow the flow of charges (electrons) through them. They are made of atoms whose outer electrons in the atoms loosely bound and free to move through the material. Some examples include; *copper, aluminium, gold, silver, water, aqueous solutions of salts and graphite. Human body, and living trees are also conductors.*

If a charged conductor is touched with another object, the conductor can transfer its charge to that object. The transfer of charge between objects occurs more readily if the second object is made of the same material as the conductor.

Insulator

They are materials which do not allow free flow of electric charges (electrons) from within them. Examples include most non-metals *glass, porcelain, plastic, dry air, paper, rubber, styrofoam, mica* and so on.

If charges are transferred to an insulator at a given location, the excess charges will remain at the initial location of charging.

Insulators play a critical role in real life. For example, conductors e.g electric cables are usually covered with insulators to protect us from electric shock.

11.5 Electric field and electric potential

Activity 11.15 **To demonstrate the existence of an electric field around a charged object**

Materials: A pen, pieces of paper, reference books and internet

Steps

1. Rub a pen using a silk cloth or hair a number of times.
2. Lower the pen gradually until when it comes very close to pieces of papers. What do you observe when the pen is at ifferent heights from the papers? Explain you observations to your group members.
3. Discuss your observations with your colleagues in class.
4. Now, conduct a research from reference books and Internet on:
   (a) What electric field lines are and sketch them in your exercise book.
   (b) electric field strength.
   (c) electric potential.
5. Compare and discuss your findings with your colleagues in your class.

In Activity 11.15, you should have observed that the pen did not attract the pieces of paper when it was very far from them, but it attracted them when it was at the region near them. The region around a charge where the electrostatic force attraction or repulsion is experienced is called an electric field.

The electric field around a charged object is represented by lines showing the direction in which the electrostatic forces act. These lines of force are called *electric field lines* as shown in Fig. 11.11

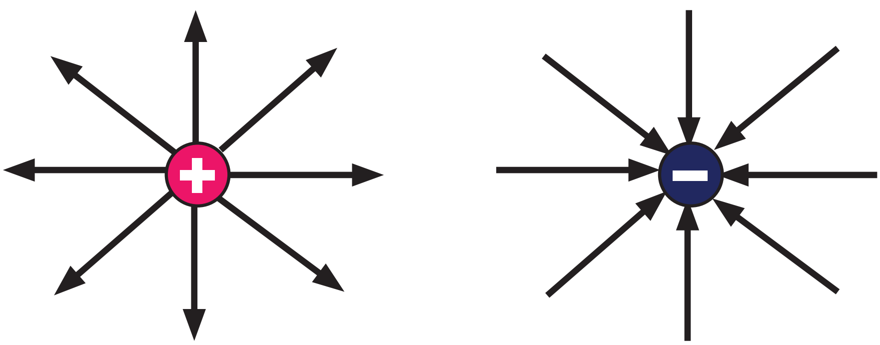


Fig. 11.11: Electric field lines

The electric fields *move away from a positive point charge* and *into the negative point charge*.

Electric field strength (E) is defined as the force per unit charge. It's given as;

$$E = \frac{F}{Q}$$

Where Q is the charge, and F is the force acting on the charge. Its SI units are $\frac{N}{C}$ or NC^{-1}.

The concentration of field lines in a magnetic field is an indication of electric field strength. The more close the field lines are the stronger the electric field strength.

Electric potential (V) is defined as the work done in bringing a unit positive charge from infinity to that point. It is given as:

$$V = \frac{1}{4\pi\varepsilon} \cdot \frac{Q}{d}$$

Where Q is the charge moved, *d* is the distance moved, ε is the permitivity of the medium which separates two charges. The material can be a vacuum or an insulator. The material with a high permittivity is one which reduces appreciably the force between two charges.

11.9 Distribution of charges on metallic conductors

Activity 11.16 **To investigate the distribution of charges on metallic conductors**

Materials: A spherical conductor, a sharp pointed conductor, a gold leaf electroscope, a proof plane, Internet, reference books

Part I

Steps

1. Conduct a research from internet and reference books on how charges are distributed on a conductor.
2. In your research, also find out:
   (a) What a proof plane is and its uses.
   (b) The meaning of the charge density.
3. Compare and discuss your findings in step 1 and 2 with other groups in your class.

Part II

Steps

1. Charge the spherical, oval and sharp pointed conductors by any one of the methods of charging described earlier.
2. Press the proof plane into contact with various places on the surface of the conductors each at a time at, and then transfer the charge to the gold leaf electroscope. What do you observe on the divergence of the gold leaf?

A proof plane is a small metal plane supported by an insulating handle. It is used to transfer a small fraction of electric charge on the body to the gold leaf electroscope.

In part II of Activity 11.16, you should have noted that when the proof plane was placed on the various points on the surface of the spherical conductor, the divergence of the leaf was the same. This shows that charge is distributed uniformly on the surface of a spherical conductor (Fig. 11.25)

However, for the sharp pointed conductor, the greatest divergence was obtained when the proof plane transfered charges from the sharp pointed end of the object. This shows that charge is highly concentrated at places where the surface is sharply curved or pointed. This is particularly noticeable at the end point of the pear-shaped conductor.

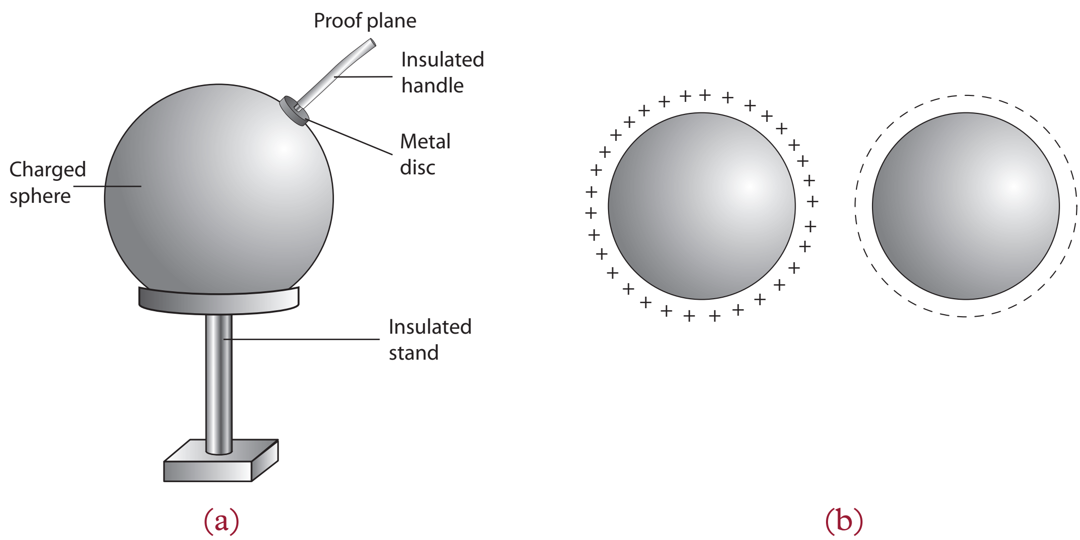
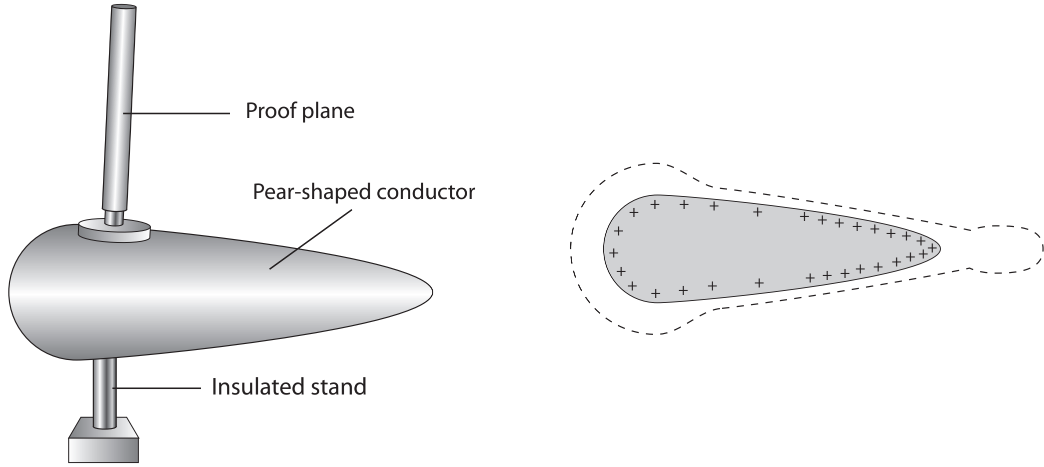


Fig 11.22: Distribution of charges on a sphere



(c) (d)

Fig. 11.15: Distribution of charges on a pear-shaped conductor

The quantity of charge per unit area of the surface of a conductor is known as charge density.

11.10 The law of conservation of charge

Activity 11.17 **To do research on the law of conservation of charge**

Materials: Polythene rod, dry cloth, pieces of paper.

Steps

1. Rub a polythene rod with a dry cloth.
2. Bring the rod near small pieces of paper. What happens?
3. What charge does the rod posses?
4. During the charging process, what do you think happened to the particles of the cloth?
5. What conclusion can you make about charge as depicted by charging process?

In activity 11.17, the cloth acquired a charge and of equal magnitude but opposite to that acquired by the rod. This shows that if an object (or part of the object) gains a charge, another object must have lost the charge. The net charge of an isolated system remains constant.

The law of conservation of charge simply states that *electric charge can neither be destroyed nor created.*

Charge can only be transferred from object to object, but it cannot be created or destroyed.

Other examples involving conservation of charge

1. If you rub a comb through your hair, it will become negatively charged. The only way for this to happen is for your hair to also become positively charged. So if the comb's charge becomes -1μC the charge in your hair must become +1μC .
2. Rubbing a rubber rod with animal fur. The system is made up of rubber rod and fur. At first the total charge of the system is zero (that is each object has equal numbers of electrons and protons in their atoms) before rubbing. When rubbed, the rubber rod acquires negative charges by gaining electrons from the fur, leaving the fur becomes positively charged. So the total charge of the system is zero.

Note; the only way to change the net charge of a system is to bring in a charge from elsewhere or remove the charge from the system.

For instance, two identical metal spheres are charged, sphere A has a net charge of +7 C sphere B has -3 C. The spheres are brought together, allowed to touch and then separated. What is the net charge on each sphere now?

When the spheres are touched the net charge (+4 C) will spread out evenly over the two spheres, each sphere will have a net charge of +2C on separation.

Exercise 11.2

1. What is meant by 'charging by induction'?

2. Three metallic spheres A, B and C are mounted on insulated stands. Sphere A is positively charged. Using illustrations, describe how you can use the positively charged sphere A, to charge both spheres B and C negatively at once by induction.

3. Explain how a charged body attracts a neutral material.

4. **(a)** State four differences between charging by induction and charging by contact.

(b) State and explain two ways of discharging a charged plate.

(c) Describe how to charge two conductors positively by induction.

5. Determine the electrical force of attraction between two balloons with separate charges of $+3.5 \times 10^{-8}$ C and -2.9×10^{-8} C when separated a distance of 0.65 m.

6. Two balloons with charges of +3.37μC and -8.2μC attract each other with a force of 0.0626 N. Determine the distance between the two balloons.

7. A balloon with a charge of 4μC is held a distance of 0.7 m from the second balloon with the same charge. Calculate the magnitude of the repulsive force.
8. Fig. 11.24 shows a model of a lady's head having nylon hair. When the hair is charged by combing with a dry plastic comb, it spreads out as shown.
   - **(a)** Explain the appearance of the hair.
   - **(b)** State the factors that affect the magnitude of the force between two charges.

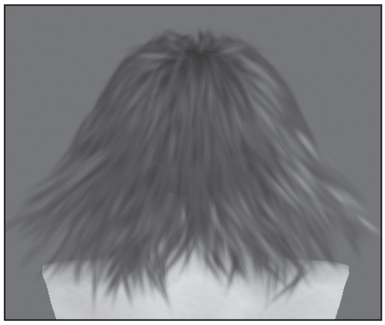


Fig. 11.16

9. Draw and show how charges are distributed on the surfaces of the metallic conductors with the following shapes.
   - **(a)** Spherical
   - **(b)** Triangular
   - **(c)** circular
   - **(d)** Oval shaped

11.11 Effects and applications of electrostatics

Activity 11.18 **To investigate real life effects of electrostatics**

Materials: Two mirrors, a dry cloth, wet cloth, chalk dust

Steps

1. Rub the first mirror with a dry cloth for some time.
2. Rub the second mirror with a wet cloth.
3. Sprinkle both mirrors with very fine chalk dust and observe what happens to the particle.
4. Where does the dust/ chalk stick so much? Explain your observation.

In Activity 11.18, you should have observed that when the mirror was rubbed within a dry cloth, it got charged by friction hence attracted the chalk dust particles. This is why most window glasses are usually dusty. The following are some other effects of electrostatics:

1. One gets a shock on touching the metal knob of the door of a car while getting out of the car. Electric charges build up on the surface of a car due to friction with the road as well as with the air molecules. When the metal knob is touched, charges flow from the knob to the earth through the person. The discharging of the charges on the surface of the car through the person gives a shock. If a metal chain is attached to the car on the outside, the charges can pass easily to the earth and the charges cannot build up.

   It is for this reason that metal chains are attached to a petrol tanker. If large charges are allowed to *pile up* on the tanker, even a small spark produced can cause a fire and the tanker can explode.
2. When a mirror is cleaned with a dry cloth, both the mirror and the cloth get charged due to friction. The charged mirror acquires the attractive property. Dust, thin hair or fluffs can therefore stick to the mirror.
3. Cars are painted using a spray gun. The car is usually earthed and the paint droplets coming out of the spray gun are given a positive charge. The car attracts these charged droplets of paint uniformly.
4. Dust and smoke particles are extracted from the inside of the chimney by electrostatic attraction. This reduces the air pollution which is a health hazard.
5. Electrostatic induction is used in the photocopying machines.
6. Though rubber is an insulator, special materials called conductive rubber is used to make aeroplane tyres. The conductive rubber tyres reduce the risk of an explosion during refuelling the aircraft. When the metal sprout of the fuel pipe touches the petrol tank sparks can be produced leading to an explosion.

Unit summary and new words

- A charge is a characteristic of matter that express the extent to which it has more or fewer electrons than protons and vice versa.
- Materials can be charged by rubbing. The charge acquired can be positive or negative.
- A body acquires a negative charges if it gains electrons from the substance with which it is rubbed. The body that looses electrons become positively charged.
- The law of electrostatic states that like charges repel and unlike charges attract.
- Coulomb's law states that two electrically charged bodies experience an attractive or repulsive force *F* which is inversely proportional to the square of the distance *d* between them and proportional to the product of charges Q_1 and Q_2 i.e

  $$F = k \frac{Q_1 . Q_2}{d^2} \text{ where k is constant.}$$
- SI unit of charge is coulomb (C).
- A gold leaf electroscope is used to:
  - detect and distinguish charges.
  - test insulating or conducting properties of a material
  - test for the sign of a charge in a body
- The law of conservation of charge states that charges can neither be created nor destroyed but can only be redistributed in a body in the presence of another charged body.
- Charges are mostly concentrated at places where the surface is sharply curved or pointed.
- All substances can be classified as either conductors or insulators of electricity. Conductors allow electrons to flow through them freely, but insulators do not.

Unit Test 11

1. When do we say that a body is negatively charged?
2. **(a)** What is meant by 'charging by contact'?
   (b) What is earthing?
   (c) What happens during earthing if an object is:
      (i) negatively charged?
      (ii) positively charged?
   (d) Why is it not possible to charge a metal rod held in the hand by rubbing with a cloth?
3. A plastic rod is rubbed with a dry cloth and becomes positively charged. Explain why the rod become positively charged?
4. A glass rod is rubbed with silk. Explain how both the silk and the rod acquire charges.
5. What does the study of electrostatics deal with?
6. What is an electroscope?
7. State the law of electrostatic. Explain the law with a suitable example.
8. Two balloons inflated with air are tied with strings and held 1 metre apart. Both the balloons are rubbed with fur. Why do the balloons move apart when brought close together?
9. When a charged rod is held close to a metal sphere placed on an insulated stand, the charge distribution on the sphere is as shown in Fig. 11.27

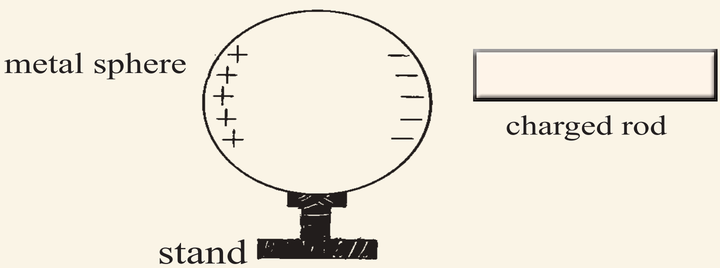


Fig. 11.17:Charge distribution on a sphere

   (a) What is the sign of charge on the rod?
   (b) Describe a simple method to charge the rod.

(c) Explain why the far side of the metal sphere has a positive charge.

(d) What happens to the charges on the metal sphere, if the charged rod is moved away from the sphere?

10. A container with dry chalk powder is covered with a clean glass plate. The top surface of the plate is rubbed with a piece of fur (Fig. 11.28).

State and explain the effects of:

(a) Rubbing the lid with fur.

(b) Touching the lid with a finger after sometime.

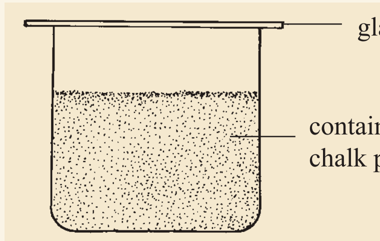


Fig. 11.18: Container with dry chalk powder

11. A negatively charged polythene rod is placed on the pan of a balance. State and explain what happens to the balance reading if another charged polythene rod is brought closer to the first (Fig. 11.29).

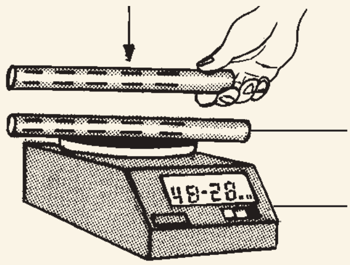


Fig. 11.19: A beam balance

12. Copy the following diagrams and show the distribution of charges on the conductor BC placed on an insulated stand. I is a charged rod close to the end B (Fig. 11.30).

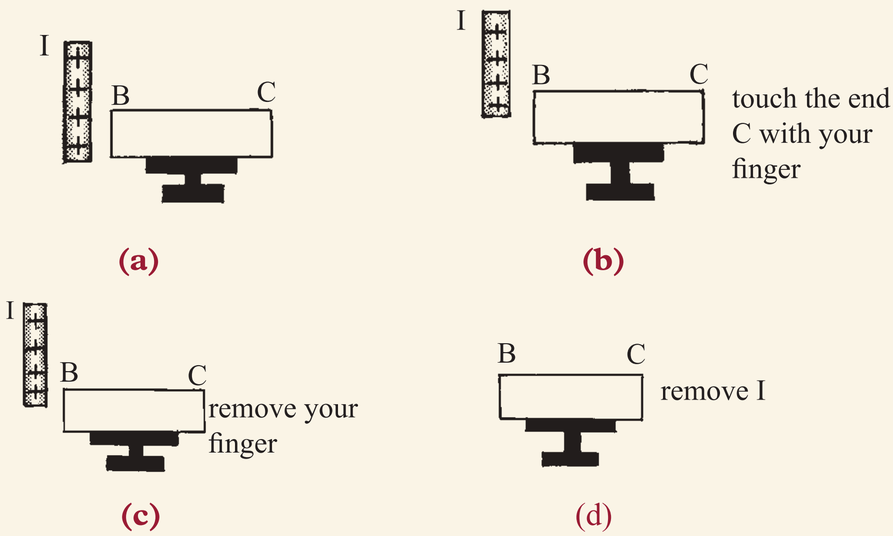
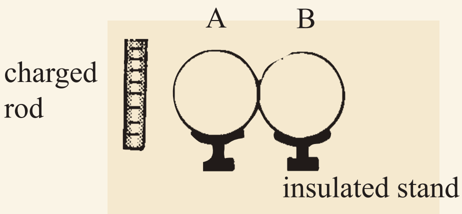
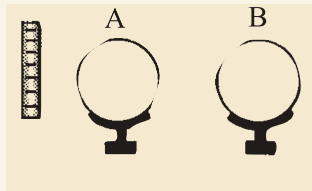


Fig. 11.20: Conductor BC placed on insulated stand

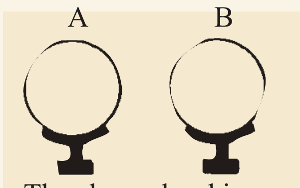
13. Copy the following diagrams and show the charge on each metal sphere placed on insulated stands (Fig. 11.31).



(a) Two spheres touching each other



(b) Sphere B is moved away from A



(c) The charged rod is removed

Fig. 11.21: Spheres A and B

14. What are conductors and insulators? Give three examples of each.

15. Why are metal chains attached to the trucks carrying petrol or other inflammable materials?

16. Determine the electrical force of attraction between two balloons that are charged with opposite type of charge but the same quantity of the charge. The charge on the balloon is 7.0×10^{-7} C and they are separated by a distance of 0.50 m.

17. Two balloons are charged with an identical quantity of charge; -6.25nC. they are held apart at a separation distance of 61.7cm. Determine the magnitude of the electrical force.

UNIT 12 Current Electricity (I)

Key Unit Competence

By the end of this unit, I should be able to explain the different effects of electricity and the safety precautions to observe while using electricity.

Unit Outline

- Simple electric circuit and its components.
- Electric current.
- Electric potential difference.
- Measurement of current and voltage.
- Ohm's law.
- Electrical energy and power.
- Effect of electric current.
- Safety precautions to observe when handling electrical applications.

Introduction

One of the most convinient types of energy is electrical energy. It has played a vital part in making our lives easier. We use electrical energy in lighting, heating and operating devices like television sets, radios, telephones, computers and electrical train. In this unit, we shall take a closer look at current electricity and find out its effects and safety precautions to be taken while using it.

12.1 Simple electric circuit and its components

Activity 12.1 To set up a simple electric circuit

Materials

- Switch
- Cell holder
- Dry cell
- Two connecting wires
- Bulb in a bulb holder

Steps

1. Place a dry cell in a cell holder.
2. Connect one end of the connecting wire to one of the terminals of the cell holder. Screw the bulb in the bulb holder.
3. Connect the other free end of the wire from the dry cell to the bulb holder (Fig. 12.1).
4. Use the second wire to connect the other end of the dry cell to the bulb through a switch (Fig. 12.1).

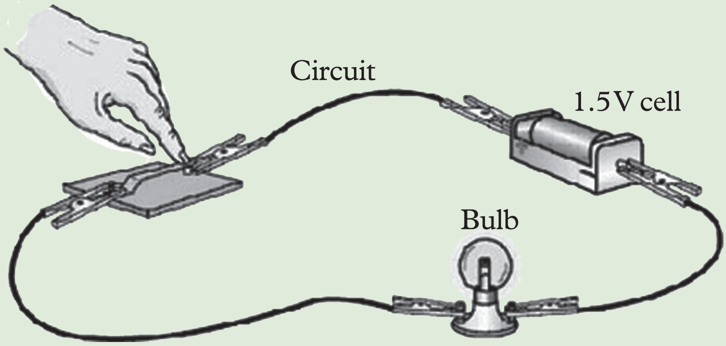


Fig. 12.1: A simple electric circuit diagram showing actual components

5. Close and open the switch in turn. What happens to the bulb? Explain your observation.

From Activity 12.1, you must have observed that when the switch is closed, the bulb lights.

The cell provides electrical energy needed to light the bulb. The bulb converts electrical energy into light and heat energy. A cell is a kind of a 'pump' which provides electrical energy needed to drive charges along a complete path formed by the wire through the bulb switch and back again to the cell. This complete path along which the charges flow is called electric circuit.

When the switch is open, the bulb does not light. This is called an open circuit. When the bulb lights the circuit is called closed circuit.

Electric circuit components and their symbols

In electric circuit diagrams, we represent the actual components with symbols. Table 12.1 shows some of the components, their symbols and definition that are used in electric circuit diagrams.

Name of component	Symbol	Definition
Cell	+ −	Small source of electric energy.
Battery	+ −	Large source of electric energy.
Power supply		D.C mains.
Open switch		Breaks the circuit.
Closed switch		Completes the circuits.
Wires joined		Junctions.
Connecting wires		Wires that joins two or more components in an electric circuit.
Lamp/bulb		Convert electric energy to heat and light.
Ammeter	A	Measures electric current.
Voltmeter	V	Measures p.d and voltage.

Table 12.1: Circuit components and their symbols

The simple electric circuit in Fig. 12.1 can be drawn using symbols as shown in Fig. 12.2.

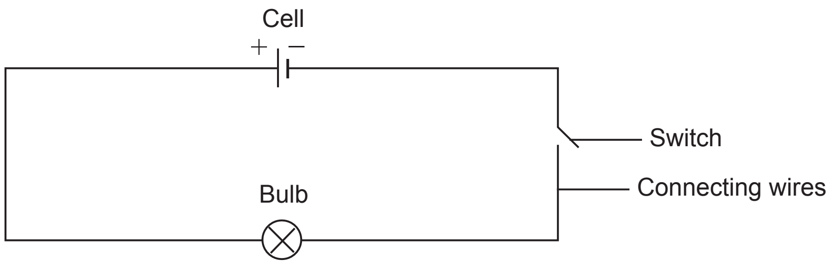


Fig. 12.2: Simple electric circuit diagram using symbols

12.2 Simple cells and batteries

Activity 12.2 **To make a simple cell with improvised material**

Materials

- Lemon
- Copper plate or rod
- Milliameter or galvanometer
- Zinc plate or rod
- Connecting wires with clips
- Knife

Steps

1. Cut two small slits on the skin of the lemon.
2. Push the copper and zinc plates into the slits. Make sure the plates do not touch each other.
3. Connect each plate to the milliameter using connecting wires as shown in Fig. 12.3.

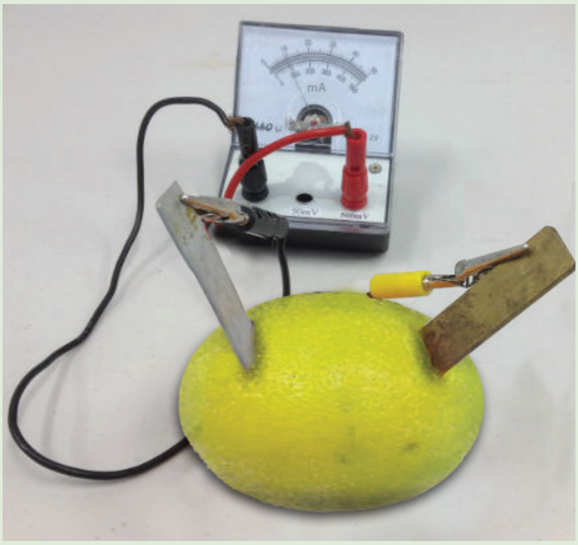


Fig. 12.3: Simple cell circuit of a lemon

Observe what happens to the pointer of the milliameter. Suggest a reason for your observation.

The set up of the lemon, the metal plates and connecting wires make up a simple electric cell that generates some electric current. The electric current produced makes the pointer of the milliameter to deflect.

The working of a simple cell

Activity 12.3 will help us to understand how a simple cell works.

Activity 12.3 **To investigate the working of a simple cell**

Materials

- Zinc plate
- Dilute sulphuric acid
- Connecting wires
- Copper plate
- A bulb

Steps

1. Dip the zinc and copper plates into a beaker containing dilute sulphuric acid as shown in Fig. 12.4.

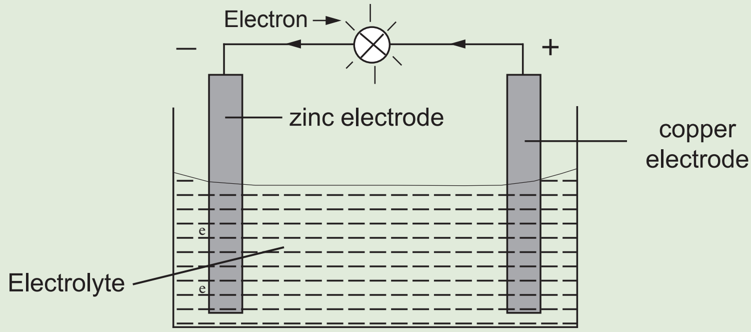


Fig. 12.4: Working of a simple cell

2. Connect the two plates to a bulb and observe what happens to the bulb immediately it is connected.
3. Suggest how a simple cell works.

In Activity 12.3, you must have observed that when the bulb is connected, it lights brightly before diming down slowly after sometime.

A simple electric cell consists of two different metal plates called electrodes and a conducting liquid called electrolyte. In activity 12.3, the zinc and copper plates are the electrodes while sulphuric acid is the electrolyte. When the two plates are dipped in the electrolyte and then connected through a wire, the electrolyte creates a negative charge in the zinc plate. The electrons move from the zinc plate through the wire and bulb to the copper plate. The electric current produced by the flow of electrons makes the bulb to light.

An example of an enhanced simple cell is the dry Leclanche cell that we use in our torches, radios and cameras. Fig 12.5 shows an example of a dry cell.

Fig. 12.5: A dry cell

A battery

Activity 12.4 **To demonstrate how a battery works**

Materials

- Two lemons
- Two copper plates or rod
- Milliameter or galvanometer
- Two zinc plates or rod
- Connecting wires with clips
- Knife

Steps

1. Repeat Activity 12.2 and observe the extent of the milliameter pointer.
2. Now connect another one lemon in series with the first one as shown in Fig. 12.6. Observe the extent of the milliameter pointer.

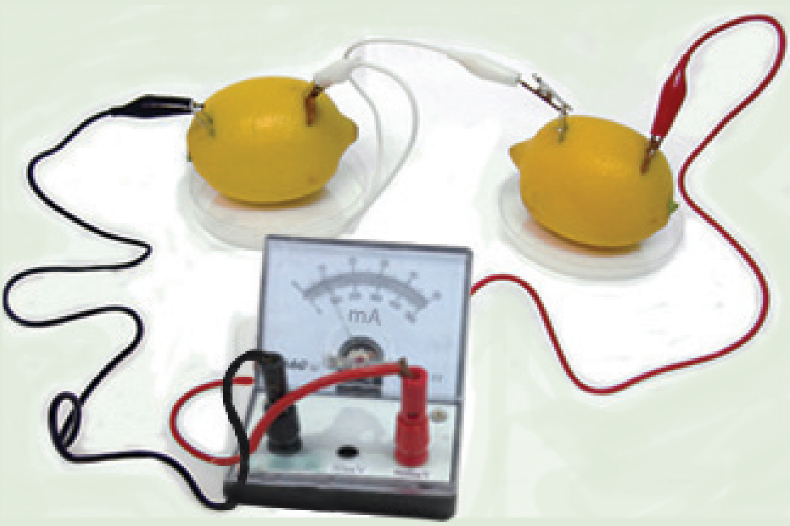


Fig 12.6: Two simple cells connected in series

3. Compare the deflection of the pointer when two lemon simple cells are used in step 2 and when one was used in step 1. What do you notice? Draw a conclusion for this observation.

When two or more simple electric cells are connected in series (positive terminal to negative terminal), they constitute a battery. The electric current produced by the battery is more than that produced by one cell.

An example of a practical battery is a car battery shown in Fig. 12.7.

Fig. 12.7: A car battery

Fig. 12.8 shows the symbol for a battery in a circuit as used in a circuit diagram.

Fig. 12.8: Battery symbol

Exercise 12.1

1. Define the term electric circuit.
2. Draw a diagram for a simple circuit.
3. What is an open circuit?
4. Draw a labelled diagram of a simple cell.
5. The following are some symbols of electric components.

Fig. 12.9: Symbols of electric components

   (a) Name the electric components represented by these symbol.

   (b) Using these symbols, draw a simple circuit diagram.

12.3 Electric current

Activity 12.5 To demonstrate the flow of charge in a circuit

Materials

- Straw
- Beaker with water

Steps

1. Make a rectangular shape using a straw as shown in Fig. 12.10

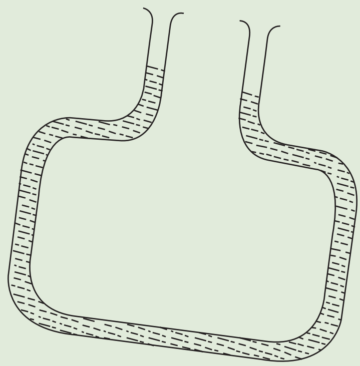


Fig. 12.10: Rectangular shaped straw

2. Pour some water to one opening of the straw and rise it slightly. What do you observe? Explain.
3. Using the analogue of water in step 2, discuss in your group how electric charges flow in an electric circuit.

Be responsible

Avoid misusing water. Without water there is no life.

From step 2 in Activity 12.5, you should have observed that water come out from the other opening of the straw because the water is flowing through it. Similarly electric charges flow through an electric circuit.

In an electric circuit, bulbs light because charges (electrons) flow through them. The rate of flow of charges from one point to the other in an electric circuit is called an electric current. i.e

$$\text{Current (I)} = \frac{\text{Quantity of charge (Q)}}{\text{Time (t)}}$$

$$I = \frac{Q}{t}$$

The unit of quantity of charge is the coulomb, C. The unit of time is the second (s). Then the unit of current, I, is the coulomb per second (C/s). 1 coulomb per second is also called 1 ampere (A). The SI unit of electric current is the ampere (A).

Direction of the flow of electric current

The direction of the flow of electric current is usually shown by an arrow in an electric circuit (Fig. 12.11). Conventionally, it is from the positive terminal to the negative terminal of a cell through the connecting wire. However electrons move from the negative to positive terminal.

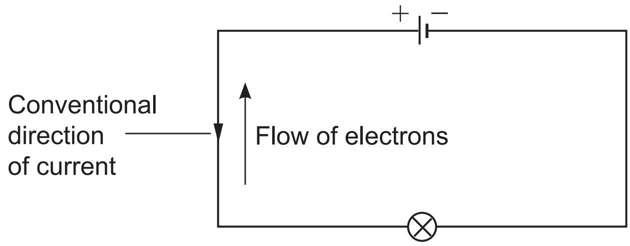


Fig. 12.11: Conventional direction of electric current and electron flow

Example 12.1

Calculate the amount of charge that passes through a point in a circuit in 3 seconds, if the current in the circuit is 0.5 A.

Solution

Charges Q = It

= 0.5 A × 3 s = 1.5 C

Example 12.2

How long would it take for a charge of 1.2 C to flow when a current of 0.01 A is flowing in a circuit?

Solution

From Q = It, we make, *t*, the subject of the formular

$$t = \frac{Q}{I} = \frac{1.2\ C}{0.01A} = 120 \text{ seconds or } 2 \text{ minutes}$$

Example 12.3

Find the amount of current passing through a lamp, if 600 Coulomb of charge flows through it in 4 minutes.

Solution

Q = It. We make, I, the subject of the formula.

$$I = \frac{Q}{t} = \frac{600\ C}{(4 \times 60)s} = 2.5\ A$$

Measurement of electric current

Activity 12.6 **To measure electric current**

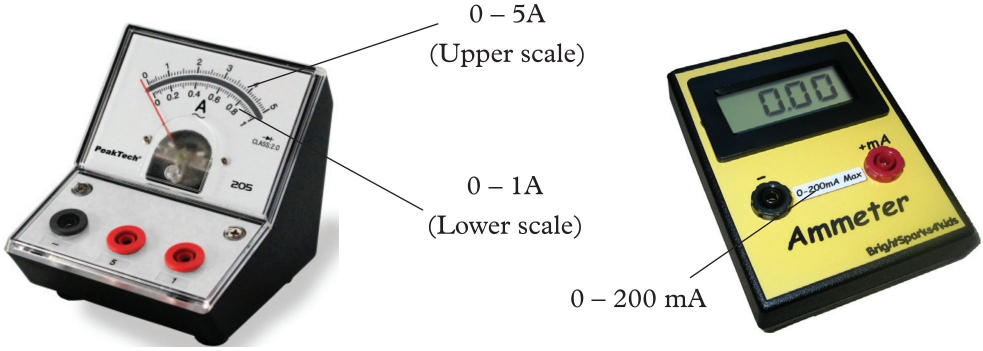
Materials

- Digital ammeter
- Analogue ammeter

Steps

1. Study the instruments given to you. What is the name of the instrument?
2. Note the range of their scales.
3. Suggest what the apparatus is used for.

In your discussion, you should have identified the instruments as ammeters. They are used to measure electric current in a complete electric circuit. Fig. 12.12(a) shows an analogue multiammeter. It has two positive terminals and one negative terminal. Fig. 12.12 (b) shows a digital ammeter.



(a) An analogue ammeter **(b)** A digital ammeter

Fig 12.12: Ammeters

An analogue ammeter may have more than one scale (Fig. 12.12(a)). The magnitude of the current determines the scale to be used.

Smaller currents are measured in milliamperes (mA) and microamperes (μA).

$$1 \text{ mA} = \frac{1}{1\,000} \text{ A} = 1 \times 10^{-3} \text{ A}, 1 \mu\text{A} = 1 \times 10^{-6} \text{ A}.$$

Fig. 12.13 shows the symbol of an ammeter.

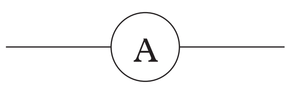


Fig 12.13: Symbol for an ammeter

How to use an ammeter to measure current in a circuit

Activity 12.7 **How to connect and use an ammeter to measure current in a circuit**

Materials

- An ammeter
- A bulb
- Connecting wire
- A switch
- A dry cell

Steps

1. Discuss in your group, how an ammeter is connected in an electric circuit.
2. Connect the circuit as shown in Fig. 12.14.

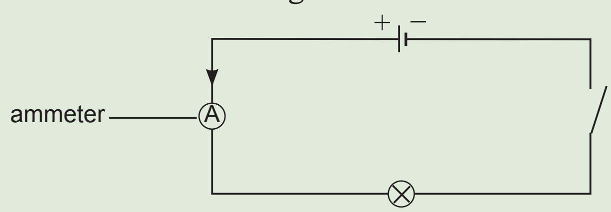


Fig. 12.14: An ammeter connected along the path of an electric current

3. Close the switch and observe what happens to both the bulb and the pointer of the analogue ammeter. In case of the digital ammeter, observe what happens to the display on the screen?). Suggest a reason for this.
4. Repeat the activity but connect the ammeter to the right of the bulb as shown in Fig. 12.15. Observe what happens to the bulb and the ammeter reading. Explain your observations to others.

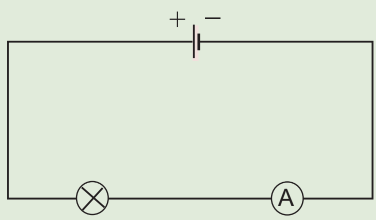


Fig. 12.15: An ammeter connected to the right of the bulb

5. Brainstorm on how to read the magnitude of current from an analogue ammeter.

You should have established that an ammeter is connected in series with the circuit components through which current is to be measured. In step 1, the bulb lights and the ammeter records some reading. The same is observed when the bulb and ammeter are interchanged in the circuit, i.e same brightness and same ammeter reading. This shows that an ammeter consumes negliglible electric current.

Reading an analogue ammeter

Activity 12.8 **How to read an analogue ammeter**

1. Repeat Activity 12.7 by connecting the ammeter scale in Fig. 12.12(a) to the negative terminal of the power source leading to the negative terminal of the ammeter (referred to as the common terminal (usually black) and positive terminal leading to the 1 A or 5 A terminal positive terminal (usually red or brown in colour) depending on the amount of current to be measured. What do you observe?
2. Sketch in your exercise book the range of the scales used. What does one division represent?
3. Discuss with your members how to read the magnitude of current from an analogue ammeter.

Fig 12.16 shows the scale on an analogue ammeter that measures current in the range 0 – 1 A, or 0 – 5 A.

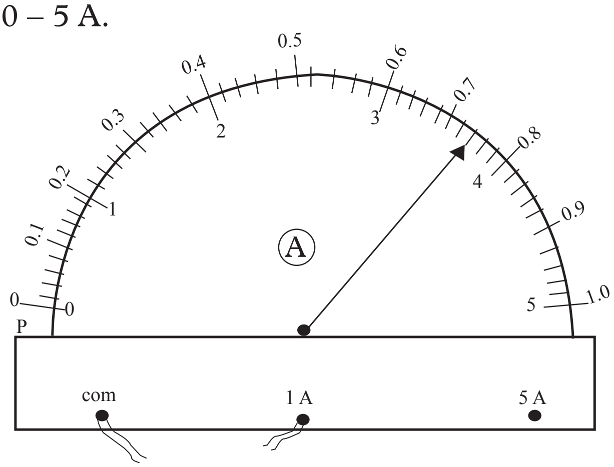


Fig. 12.16: An ammeter with a scale range of 0 – 1 A, 0 – 5 A

When connected to the 1 A terminal, the upper scale running from 0 - 1 A should be used.

We determine the current represented by each smallest division on the upper scale as follows:

5 divisions correspond to .... 0.1 A

1 division corresponds to .... $\frac{0.1\text{A}}{5} = 0.02$ A

In Fig. 12.16, the pointer is on the second mark after the 0.7 mark, hence the ammeter reading is:

0.7 A + (2 divisions × 0.02 A) = 0.7A + 0.04 A = 0.74 A

Example 12.4

What is the reading shown by the pointer in Fig. 12.17, if the full scale range is:

(a) 0–100 mA?

(b) 0–250 mA?

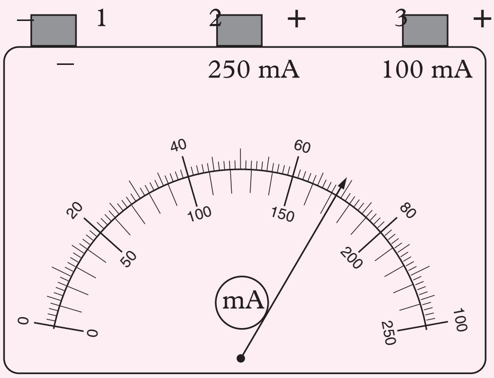


Fig. 12.17: Ammeter reading scale

Solution

(a) Full scale deflection = 100 mA. (Use the upper scale)

The pointer is at 69$^{\text{th}}$ division.

The reading is 69 mA.

(b) Full scale deflection = 250 mA. (Use the lower scale)

The pointer is between 170$^{\text{th}}$ and 180$^{\text{th}}$ divisions. There are 4 divisions of the upper scale corresponding to 10 mA in the lower scale.

1 division represents 2.5 mA.

Reading = 170 mA + 2.5 mA = 172.5 mA.

The reading is 172.5 mA.

Exercise 12.2

1. Define an electric current and state its SI unit.
2. A car battery circulates charge round a circuit for 5 minutes. If the current is held at 15 A, what quantity of charge passes through the wire?
3. A charge of 40 coulombs flows through a point on a conducting wire in 15s. Calculate the current flowing in the conductor.
4. Calculate the number of electrons which carry a charge of 1 C. (charge of an electron = 1.6×10^{-19} C).

5. If a charge of 1.5 C passes through a point in a circuit in 0.5 s, calculate the current in the circuit.
6. If the current in a circuit is 2 A, calculate:
   (a) the charge that passes through a point in the circuit in 0.6 s,
   (b) the number of electrons possive + through the point per second.
7. What is the reading shown in the ammeter below?

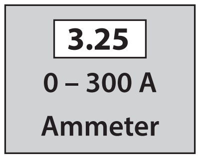


Fig. 12.18: A digital ammeter

12.4 Potential difference (p.d)

Activity 12.9 **To define potential difference and identify its SI unit**

Materials

- Reference books
- Internet

Steps

1. Conduct a research from internet and reference books on potential difference, be guided by the following questions:
   (a) What is potential difference?
   (b) What is the SI unit of potential difference?
   (c) Define a volt.

We can use a water model to explain potential difference (p.d). This model consists of a water pump, water and pipes as shown in Fig. 12.19 (a). Fig. 12.19 (b) shows an electric circuit which can be compared with the water model.

When the pump is on, water is lifted to point A. At this point water has the maximum potential energy. This potential energy drives the water down the inclined pipe. On reaching point B, the water has lost all the potential energy it had. The pump then provides the water with the necessary energy to climb up to A again. The water therefore flows round the water circuit as long as the pump is on.

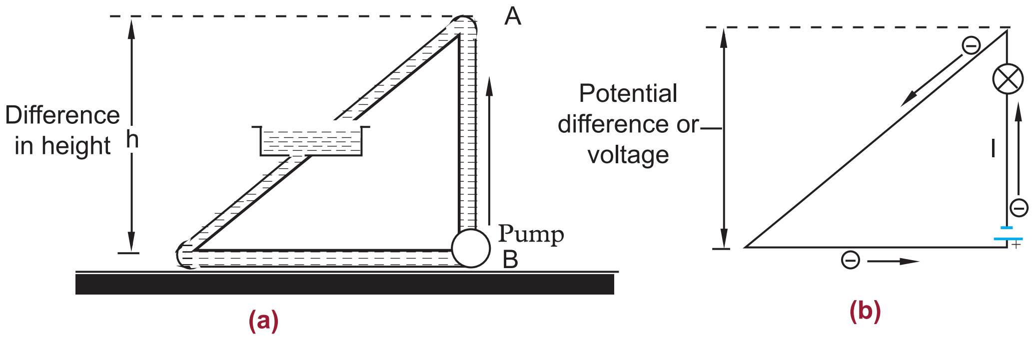


Fig. 12.19: (a) A water model and (b) An electric circuit

In the electric circuit, the electrons move towards the positive terminal of the battery. The battery lifts the electrons up through an electrical height. This electrical height is called a potential. The positive and the negative terminals have a difference in potential. This difference in potential or potential difference (p.d) is the one responsible for driving the electric current round the circuit. In the water model, the difference in the height causes water current. If there are no differences in the water levels, as in ponds, water would not flow. Similarly, in electrical circuits the absence of a potential difference results in no electric current.

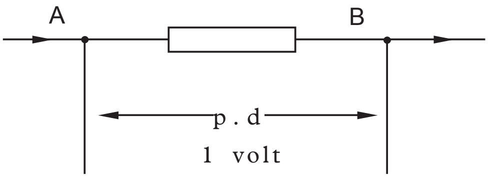
Potential difference is defined as the work done in moving one coulomb of charge from one point to the other in an electrical circuit. The SI unit of potential difference is the volt (V).

$$\text{Volt} = \frac{\text{work done (joule)}}{\text{charge (coulombs)}}$$

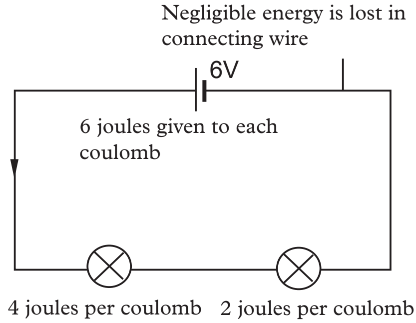
The potential difference is also known as the voltage.

The volt

In Fig. 12.20 (a), points A and B are at a potential difference of one volt if the work done in moving one coulomb from A to B is one joule. 1 volt is therefore defined as the energy needed to move one coulomb of charge from one point to another. The voltage between the terminals of a cell indicates the energy supplied to each coulomb of charge in the circuit. For example, a battery with a potential difference of 6 V supplies 6 joules of energy to each coulomb of charge in the circuit. This energy is then converted into other forms of energy like light and heat in bulbs (Fig. 12.20(b)).



(a)



(b)

Fig. 12.20: Energy carried by a coulomb of charge

Measurement of voltage

Activity 12.10 **To measure voltage using a voltmeter**

Materials

- Digital and analogue voltmeters

Steps

1. Study the instruments given to you. What is the name of the instruments? Write down its symbols in your exercise book.
2. Note down the range of its scales .
3. Discuss the use of the apparatus and how they are connected in an electric circuit.

In Activity 12.10, you should have identified the instruments as a voltmeters. Fig. 12.21(a) and (b) shows an analogue and digital voltmeter respectively. Fig 12.12 (c) shows the symbol for a voltmeter. A voltmeter is used to measure voltage across a device in an electric circuit.

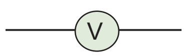
(a)

Analogue Voltmeter

(b)

Digital voltmeter

(c)



A symbol for a voltmeter

Fig. 12.21: Voltmeters

The positive terminal of voltmeter is connected to the wire from the positive terminal of the cells and the negative terminal to the wire leading to negative terminal. A voltmeter is always parallel to the device whose voltage is to be measured. (See Fig. 12.23).

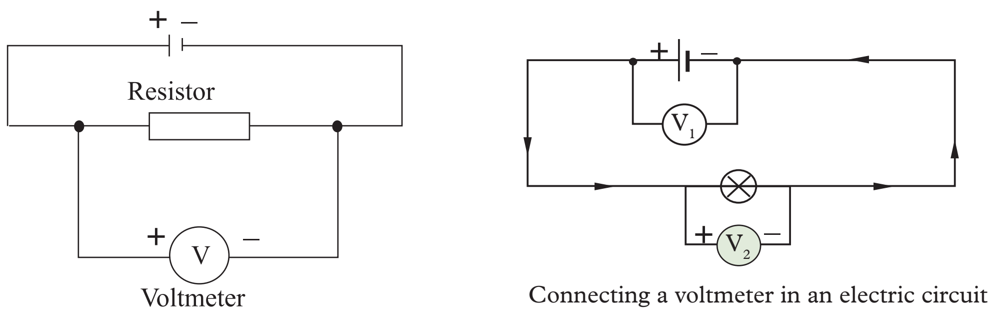


Fig. 12.23: Connecting a voltmeter in a circuit

Voltmeters have uniform scales calibrated in volts or millivolts. The most used scales have a range of 0 – 5 V and 0 – 1.5 V. Fig. 12.22 shows a scale of a voltmeter.

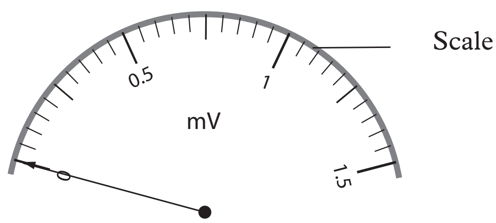


Fig. 12.22: Voltmeter scale

The voltmeter scale is read in the same way as the ammeter.

Note:

- If the pointer of an ammeter or voltmeter moves in an anticlockwise direction, then interchange the wires on the terminals.

Exercise 12.3

1. Define the term potential difference and state its SI units.
2. Name the instrument used to measure voltage.
3. Define a volt.
4. In a circuit, 5 joules are used to drive 2 coulombs of charge across a bulb in a simple circuit. Find the potential difference across the bulb?
5. Name the instrument used to measure potential difference.

6. Two cells, A and B connected in parallel are in series with a bulb as shown in Fig. 12.24.

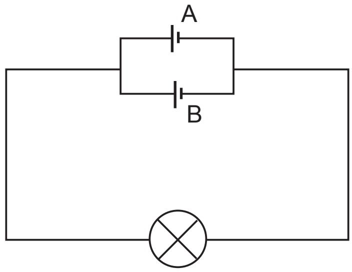


Fig. 12.24: Circuit with parallel cells

Copy the diagram and show where the:

(a) ammeter should be connected in order to measure the current through cell A.

(b) voltmeter should be connected to measure the potential difference across both the bulb and cell B.

7. Fig. 12.25 shows a dual scale of voltmeter.

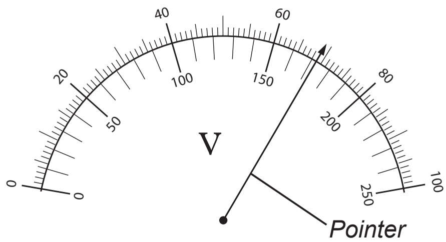


Fig. 12.25: Dual scale of a voltmeter

(a) What is the reading shown by the pointer in Fig. 12.25, if the range is:

(i) 0 – 100 mV	**(ii)** 0 – 250 mV
(iii) 0 – 2.5 V	**(iv)** 0 – 0.1 V
(v) 0 – 10 V	**(vi)** 0 – 25 V

(b) Why are different ranges used in ammeters and voltmeters?

12.5 Ohm's law

Activity 12.11 **To observe the variation of current (I) with change in potential difference (V) across a conductor**

Materials

- Nichrome wire, ammeter, variable resistor, switch, cells, voltimeter

Steps

1. Using the nichrome wire, make a coil of many turns as possible.
2. Connect the set-up as shown in Fig. 12.26.

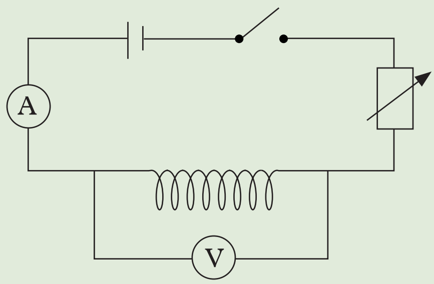


Fig. 12.26: Circuit to verify Ohm's law

3. Varry the potential difference (V) across the wire by adjusting the variable resistor. Observe what happens and answer the following questions.

(a) What happens to the current reading when the potential difference is increased?

(b) What happens to the current reading when the potential difference is reduced.

(c) Using your observation in (a) and (b) summarise the relationship between (I) and (V).

You should have observed that as the potential difference (V) across the wire is increased the current also increases and vice versa. This observation is summarised by Ohm's law.

Ohm's law states that the current (I) flowing in a conductor is directly proportional to the potential difference (V) across it, if the temperature and other physical quantities of the conductor remains constant i.e. $V \alpha I \Rightarrow \frac{V}{R} = I$.

The following activity will help us to verify Ohm's law.

To verify Ohm's law

Activity 12.12 To verify Ohm's law

Materials

- dry cells, cell holder
- Variable resistor
- ammeter
- 100 cm of nichrome wire
- connecting wires
- voltmeter and a switch

Steps

1. Using the nichrome wire, make a coil of many turns as possible.
2. Connect the set-up as shown in Fig. 12.27.
3. Close the switch and adjust the variables resistor so that the p.d across the conductor reads 0.5 V. Record the corresponding value of current as indicated by the ammeter.

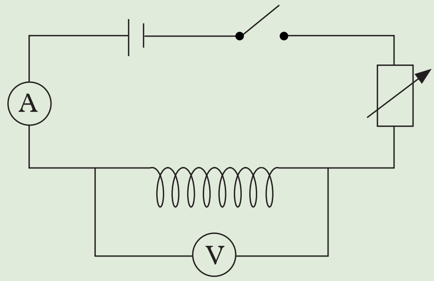


Fig. 12.27: Circuit to verify Ohm's law

4. Increase the voltage across the conductor in steps of 0.5 V, each time noting and recording the corresponding values of the current through the conductor. Record your results in a tabular form as shown in Table 12.2.

p.d across the conductor (V)							
Current through the conductor (A)							

Table 12.2: Relationship between p.d and current

5. Draw a graph of p.d against current, I.
6. Determine the gradient/slope of the graph at different points. What do you notice? Discuss.
7. Suggest the relationship between voltage across the conductor and current through it.

The results show that as the potential difference across the conductor increases, the current through the wire also increases.

The graph of V against I is a straight line passing through the origin (Fig. 12.28).

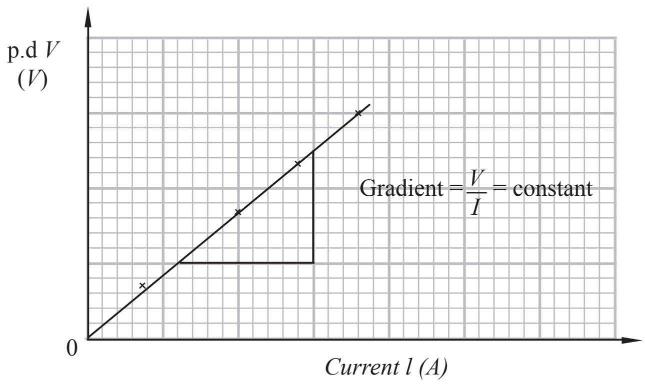


Fig. 12.28: Graph of p.d. (V) against current (I)

The graph in Fig. 12.28 shows that the current is directly proportional to the applied potential difference, i.e., $I \propto V$ or say $V \propto I$. The gradient of the graph is also constant.

$$\text{Gradient} = \frac{\Delta V}{\Delta I} = \text{Constant}$$

$$\therefore \frac{V}{I} = \text{Constant}$$

Thus, Ohm's law is verified.

This constant is the resistance (R) of the conductor, i.e

$$\frac{V}{I} = R$$

$$\boxed{V = IR}$$

Resistance (R) is the ratio of potential difference (V), across the ends of a conductor to the current (I), passing through it. The SI unit of resistance is the ohm (Ω).

From $V = IR$, then $R = \frac{V}{I}$ and $I = \frac{V}{R}$

The equation $V = IR$ is the mathematical expression of Ohm's law named after a famous physicist George Simon Ohm. He was the first scientist to establish the relationship between current and potential difference.

Example 12.5

The voltage and current through a device in a circuit are 2 V and 0.02 A respectively. Calculate the resistance of the device.

Solution

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}}$$

$$R = \frac{V}{I} = \frac{2\ \text{V}}{0.02\ \text{A}} = 100\ \Omega$$

Example 12.6

A resistor rated 10 Ω allows a current of 2 A to flow through it in a simple circuit. The resistor is replaced with another one of 30 Ω. Calculate the amount of current passing the 30 Ω resistor if the source of voltage is the same.

Solution

In the first case

$$V = I_1 \times R_1 = 2\ \text{A} \times 10\ \Omega = 20\ \text{V}$$

The voltage is the same in the second case,

$$V = I_2 R_2 \Rightarrow I_2 = \frac{20\ \text{V}}{30\ \Omega} = 0.6667\ \text{A}$$

Example 12.7

A current flows through a coil of wire of resistance 80 Ω when it is connected to the terminals of a battery. If the potential difference is 60 V, find the value of the current.

Solution

$R = 80\ \Omega, V = 60\ V$

From Ohm's law,

$$I = \frac{V}{R} = \frac{60\ V}{80\ \Omega} = 0.75\ A$$

Exercise 12.4

1. State Ohm's law.
2. A p.d of 12 V is required to drive a current of 1.5 A to flow through a filament. Find the resistance of the filament.
3. A resistor of value 20 Ω allows a current of 0.3 A to pass through. Calculate the voltage across the resistor.
4. Fig. 12.29 is an ohmmeter connected in a circuit.

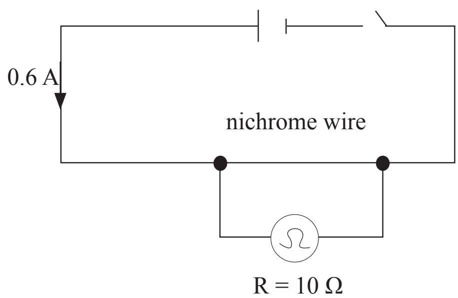


Fig. 12.29 A diagram of a circuit

If the switch is closed, find the voltage across the nichrome wire.

12.6 Electrical energy and power

Electrical energy

Activity 12.13 **To describe energy transformation involving electrical energy**

Steps

1. Suggest energy transformation in an electrical circuit with:

(a) A heater (b) A bulb and battery

(c) A bicycle dynamo

2. Do a presentation on the chalkboard to the rest of the students on how energy is converted from one form to the other.
3. In your representation, identify electric energy and how it is converted to other forms of energy.
4. Now, suggest what electrical energy is.

From your discussion, you should have established the following:

Electrical energy is the energy that drives in charge through a circuit. The following are some energy transformations involving electrical energy.

1. A circuit with a heater.

   Electrical energy → Heat energy

2. A circuit with a bulb and battery.

   Chemical energy (battery) → Electrical energy (wire) → Light energy (bulb)

   Electrical energy (wire) → Heat energy (bulb)

3. Bicycles dynamo.

   Kinetic energy → Electrical energy → Heat energy

   Electrical energy → Light energy

Electrical energy equation

Activity 12.14 **To establish the formula for calculating electrical energy**

Consider a current, I, flowing through a conductor of resistance, R, if there is a potential difference, V, between the ends of the conductor (Fig. 12.30).

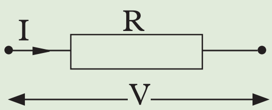


Fig. 12.30: Current (I) passes through resistance,

Using this information, how to derive the following electrical energy equations $E = VIt$, $E = I^2Rt$ and $E = \frac{V^2t}{R}$?

In your discussion, you should have noted that potential difference is the work done per unit charge to drive it through the current, i.e

$$\text{Potential difference, } V = \frac{\text{Work done (W)}}{\text{charge (Q)}}$$

$$V = \frac{W}{Q} \text{ or } W = VQ \text{ .... (i)}$$

Where; W is the electrical work that is converted into heat energy E.

But current is the rate of flow of charges i.e.

$$\text{Current, I,} = \frac{\text{charge (Q)}}{\text{time t}}, \text{ in symbols, } I = \frac{Q}{t}$$

$$Q = It \text{ .... (ii)}$$

From equations (i) and (ii), we obtain.

$$\boxed{E = VQ = V(It)}$$

The SI unit for electrical energy is the joule (J).

Alternative equations for finding electrical energy, E are obtained by replacing V or I in the equation, $E = VIt$ as shown below:

From ohm's law $V = IR$

Substituting for V in equation $E = VIt$, we get,

$$E = (IR)It$$

$$\boxed{\text{Electrical energy, } E = I^2Rt}$$

Also, from ohm's law $I = \frac{V}{R}$

Substituting for I in equation $E = VIt$, we get

$$E = V(V/R)t$$

$$\boxed{\text{Electrical energy, } E = \frac{V^2t}{R}}$$

Example 12.8

A current of 2.0 A is passed through a resistor of 20 Ω for 1.0 hour. Calculate the electrical energy converted into heat energy in the resistor.

Solution

$$\text{Electrical energy } E = I^2Rt = (2.0)^2 \times 20 \times (1 \times 60 \times 60)$$

$$= 288\ 000 \text{ J}$$

$$= 2.88 \times 10^5 \text{ J}$$

Example 12.9

An electric iron consumes 2.592 MJ of energy in 1 hour when connected to the mains power supply of 240 V. Calculate the current through the filament in the electric iron.

Solution

Energy consumed $VIt = 2.592\ MJ = 2.592 \times 10^6\ J$

$= 2\ 592\ 000\ J$

$\therefore 240 \times I \times (1 \times 60 \times 60) = 2\ 592\ 000$

$\therefore$ current, $I = 3\ A$

The current through the filament is 3 A.

Electric power

Activity 12.15 To establish the formula for calculating electrical power

Materials

- Stopwatch
- Immersion heater
- Water in a bucket

Steps

1. Observe and record the voltage rating of the heater.
2. Connect the immersion heater to the socket.
3. Immerse the heater in the bucket.
4. Put the switch on and start the stopwatch immediately.
5. Note and record the time the water takes to boil.
6. Simplify the expression to get the expression for electric power in various quantities. Establish an expression relating electric power energy and time.

When the heater was immersed in Activity 12.15, the electrical energy was converted to heat energy that makes water to boil. The rate at which electrical energy is converted to heat energy is called electrical power.

Therefore, for an electrical device,

Power, $P = \frac{\text{electrical energy transformed}}{\text{time}} = \frac{VIt}{t} = VI$

The SI unit of power is Watts (W).

The other common unit used is kilowatts 1KW = 1000W

Alternative, equations for finding power P are obtained as follows:

$$\text{Power} = \frac{\text{Electrical energy}}{\text{time}} \text{ i.e } P = \frac{E}{t}$$

but $E = I^2Rt \quad \Rightarrow P = \dfrac{I^2Rt}{t} \quad \therefore P = I^2R$

Also $E = \dfrac{V^2t}{R} \quad \Rightarrow P = \dfrac{V^2t}{R \times t} \quad \therefore P = \dfrac{V^2}{R}$

Example 12.10

A torch bulb is labelled 2.5 V, 0.3 A. Calculate the power of the bulb.

Solution

Electrical power, $P = VI = 2.5V \times 0.3\ A = 0.75\ W$

The power of the bulb is 0.75 W.

Example 12.11

An electric bulb is labelled '40 W, 240 V'. Calculate:

(a) the resistance of the filament used in the bulb.

(b) the current through the filament when the bulb works normally.

Solution

(a) Labelling of the bulb is '40 W, 240 V'

$$P = VI$$

$$= V\left(\frac{V}{R}\right) = \frac{V^2}{R}$$

$$R = \frac{V^2}{P} = \frac{240^2}{40} = 1\ 440\ \Omega$$

The resistance of the filament = 1 440 Ω

(b) $P = I^2R$

$$\Rightarrow I^2 = \frac{P}{R} = \frac{40}{1440}$$

$$I = \sqrt{\frac{40}{1440}}$$

$$= 0.167\ A$$

Example 12.12

In 5 seconds, an electric iron takes 10 000 joules of energy from the main supply. What is its power:

(a) in Watts? **(b)** in Kilowatts?

Solution

(a) Power $= \dfrac{\text{energy}}{\text{time}} = \dfrac{10\ 000}{5} = 2\ 000\ W$

(b) 1 000 W = 1 kW (Kilowatt)

2 000 W = 2 kW

Example 12.13

What is the power dissipated in a 6 Ω resistor when the current through it is?

(a) 2A **(b)** 4A

Solution

(a) $P = I^2R = 2^2 \times 6 = 24\,W$ **(b)** $P = I^2R = 4^2 \times 6 = 96\,W$

Example 12.14

A 3 kW immersion heater is used to heat water. Calculate the electrical energy converted into heat energy in 40 minutes.

Solution

$$\begin{aligned}\text{Electrical energy (E)} &= \text{Electrical power (P)} \times \text{time (t)}\\ &= (3 \times 1\,000) \times (40 \times 60)\ J\\ &= 7\,200\,000\ J\\ &= 7.2 \times 10^6\ J\\ &= 7.2\ MJ\end{aligned}$$

Conserve energy to save on consumption costs. Use energy saving bulbs and switch off the lights during the day to conserve electrical energy.

Exercise 12.5

1. How much electric energy in joules does a 150 watts lamp convert to heat and light energy in:
   (a) 15 seconds
   (b) 5 seconds
   (c) 1 min
2. Define electrical power as used in electrical circuit.
3. Calculate the (a) current through (b) resistance of the filament of
   (a) a bulb rated at 240 V, 60 W.
   (b) an electric kettle rated at 2 kW, 240 V.
4. **(a)** A washing machine is marked 240 V, 3 kW. What does this mean?
   (b) Calculate the electrical energy consumed by this machine in 1 hour.

5. (a) Which bulb in Fig. 12.31 is the brightest? Explain your answer.
   (b) Both the bulbs in Fig. 12.31 are dimmer compared to the normal brightness, when each bulb is connected in turn to the same power supply. Why?

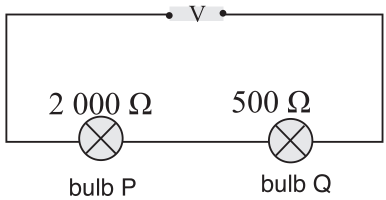


Fig. 12.31: An electric circuit

6. A 2 kW immersion water heater is switched on for 3 hours. Calculate the amount of heat energy given off by the heater.
7. If an electric heater consumes a current of 4 A when connected to a 240 V supply, what is its power.
8. How much current flows through a bulb rated 150 W when a potential difference of 240 V is supplied to the bulb when operating normally?

12.7 Earth wire, switch and fuses

Earth wire

Activity 12.16 **To investigate the importance of an earth wire**

Materials

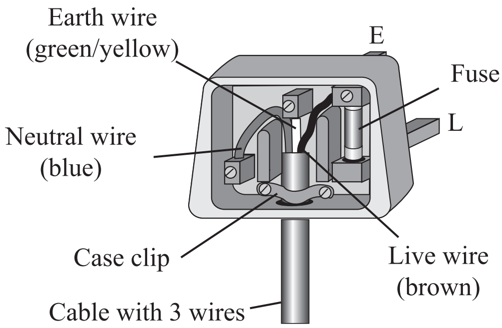
- A 3-pin plug
- Screwdriver

Steps

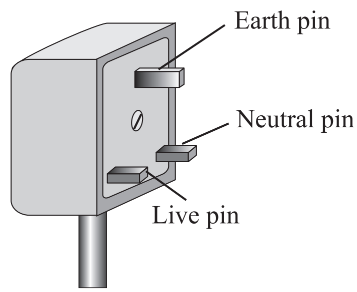
1. Take a closer look at a 3-pin plug. Try to identify the parts can you see.
2. Using a screwdriver, open the 3-pin plug. Note down colours of each wire from the cable.
3. Give a reason why different colours are used.
4. Which colour represents the Earth wire? Explain.
5. Discuss how the earth wire is connected and its importance.
6. Give examples of electrical appliances with 3-pin plug.
7. Present your findings to the whole class through your group secretary.

In Activity 12.16, you should have observed that one pin is longer than the other two. The longer pin is called the earth pin while the other two are live pin and neutral pin. The earth pin is longer than live and neutral so that it is connected to an electrical circuit first then live and neutral pins later.

Most modern electrical appliances like the electrical iron, kettle, toaster, electric geyser, immersion heater, refrigerator and hot plates are supplied with a 3-pin plug, while some systems like television set, record players, hair-blow dryer, key boards have only 2-pin plugs. A 3-pin plug has its three pins, usually marked with letters L, N and E standing for live, neutral and earth respectively (Fig.12.32 (a) and (b)).



(a) *Inside view*



(b) *Side view*

Fig. 12.32: A 3-pin plug

The three wires of a cable in the 3-pin plug are distinctively coloured to denote the live, neutral and earth wires. The basic idea of using different colours is to easily identify the wires so that correct connections are made with care. The present international convention is brown for live, blue for neutral and green with yellow stripes for earth.

Earth connection

The earth wire connects the metal case of an appliance (e.g. an electric iron) to the ground and prevents it from becoming live, if a fault develops. If, for example, the cable insulation wears out due to the heating effect of the current, there are chances that a few fine strands of the bare live wire could touch the metal case. When such a fault occurs, a current flows through the live wire and the earth wire in series. The fuse in the live wire will blow and cut off the power supply. If on the other hand, there was no earth wire connection, a person touching the metal case would get an electric shock.

In appliances like television set, record player etc; the outer case is not metallic and hence 2-pin plugs are sufficient. It is dangerous to use the 2-pin plug with any appliance which has out metal case.

In a socket for 3-pin plug, the holes for the live and the neutral pins are usually closed by an insulating material called a 'blind' (Fig. 12.33). This is a safety measure, especially to children who like to play with nearly everything and might cause short circuiting by putting in wires in the socket. The 'blinds' are opened by the longer earth pin of the 3-pin plug. The moment the earth pin touches and opens the socket, any leakage current through the metal case will straightaway be earthed hence making the appliance safe.

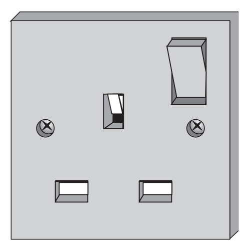


Fig. 12.33: A socket

Short circuits

Activity 12.17 **To find out what happens if bare over head live eletrical cables touch each other**

Discuss what happens when bare overhead electrical cables with electrical current touch each other.

If a few strands of the fine bare live wire those of neutral wire touch by chance, a large current can flow between the live and the neutral wires of the supply cables. This is due to the fact that current tends to take the path of least resistance. This is called the short-circuiting of the appliance.

On such occasions, the fuse usually blows off. Otherwise if no fuse is in use, the 'sparking' produced by the large current might burn the cable and there are risks of fire being produced.

Live wire is dangerous if handled carelessly. It can give electrical shock.

Switch and circuit breaker

Activity 12.18 **To establish how a switch works**

(Work in groups)

Material

- A switch

Steps

1. Identify the electrical component provided and tell your members its functions.
2. How is it connected in a circuit? Give a reason.
3. Compare and discuss your findings with others in class.

In Activity 12.18 you should have identified the component as a switch. A switch is an electrical component that can break an electrical circuit, interupting the current or diverting it from one conductor to another. A switch should be fitted in the live wire in an electric circuit, so that when the switch is off, the high voltage is disconnected from the appliance. This prevents electrical shocks and fire outbreaks incase of electrical faults.

A special automatic switch known as a circuit breaker is also fitted in the live wire of a house wiring circuit. It automatically goes off when the current in the circuit exceeds a given value when the circuit is overloaded hence disconnects the circuit.

> Save energy
> Switch off lights when not using them. There are cost implications incurred if left on.

Fuses

Activity 12.19 **To establish how a fuse works**

Materials

- Fuses of different values

Steps

1. Identify the power rating different types of fuses provided.
2. In your own words, tell your group members what a fuse is.
3. Discuss the importance of a fuse in an electrical appliances and suggest what is likely to happen to appliances without the fuse.
4. Suggest to your members the value of power and voltage in an electrical appliance e.g 3000 W, 240 V and let them choose a fuse to be used.

A fuse is a short thin piece of wire of low melting point. The wire melts as soon as the current through it exceeds its rated value. Fuses are usually fitted in all electrical circuits to prevent dangerous flow of a large current due to overloading of an electrical circuit or any other electrical faulty.

A melted or 'blown' off fuse stops the current and protects the electrical appliance and therefore the house against the risk of fire caused by the heat. Just like the switch, the fuse should be fitted in the live wire.

The fuse used should be of a value just higher than the normal current required by the appliance. The common standard values of available fuses are 2 A, 5 A and 13 A, although 1 A, 3 A, 7 A and 10 A fuses are also made. If the value of power and voltage of an electrical appliance is given as '2 000 W, 250 V', the required current through it is 8 A. The correct fuse to protect the appliance is 10 A. Similarly, if the required current for an appliance is 4 A, the correct fuse to be used is 5 A.

> Stay safe!!
> Always put off the main switch first incase of a fire outbreak caused by electrical faulty.

12.8 Effects of an electric current

(a) Heating effects of an electric current

Activity 12.20 **To show the heating effect of an electric current**

Materials

- 2 immersion heaters of different sizes
- Thermometer
- Cold water
- Switch and connecting wires
- Stopwatch
- A small bucket
- Battery
- Variable resistor

Steps

1. Dip an immersion heater into water in a bucket and switch on the power supply (Fig. 12.34).

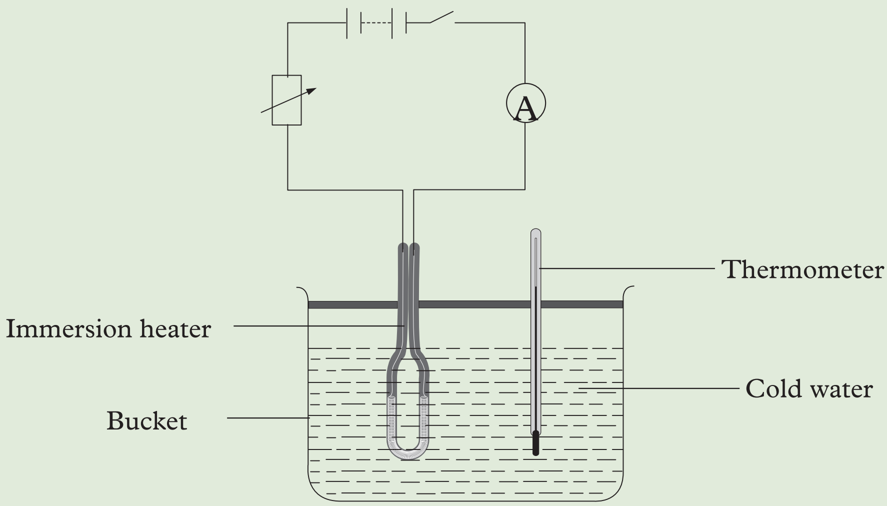


Fig. 12.34: A setup to demonstrate heating effect

2. After a couple of minutes, switch off the power supply and slightly touch the water in the bucket. What do you feel? Discuss.
3. Measure the temperature of the water using thermometer and record it down.

In Activity 12.20, you should have observed that water becomes warm after sometimes. The electrical energy has been converted into heat energy.

Scientists have done numerous activities to help in the advancement of the relationships between electric current and heat. For instance, James Joule observed that electric current flowing through a conductor causes the temperature of the conductor and the surrounding to rise as observed in Activities 12.20.

We can therefore conclude that an electric current has a heating effect on a substance. But what are the factors that affect the heating effect of an electric current?

Factors affecting heating effect of an electric current

Activity 12.21 **To find out the factors affecting the heating effect of an electric current**

1. Repeat Activity 12.20 by:
   - **(a)** Increasing the amount of current (i.e reducing resistance using variables resistor) through the same coil for the same amount of time. Note down the temperature of the water. Compare with the reading obtained in Activity 12.20. What do you notice? Discuss.
   - **(b)** Passing the same amount of current through different coils of different resistance (lengths). Record down your observation.
   - **(c)** Passing the same amount of current through the same coil for different time intervals such as 30 seconds, 60 seconds or 5 minutes. What do you notice?
2. From your observations made in 1(a), (b) and (c) suggest the factors that affect heating effect of an electric current.

You should have established that the heating effect of an electric current is affected by the following:

1. Amount of current.
2. Resistance of a conductor/substance.
3. Time for which the current flows.

Joule's Law of Heating

Joule's law is a mathematical description of the rate at which resistance in a circuit converts electric energy into heat energy.

The English physicist James Prescott discovered that the amount of heat per second that develops in a current-carrying conductor is proportional to the electrical resistance of the wire and the square of the current.

The heat that is generated because of the current flow in an electric wire is described in Joules. The mathematical expression of Joule's law is as explained below.

The joule's law shows the relationship between heat produced by flowing electric current through a conductor.

$Q = I^2 R t$

Where,

- Q indicates the amount of heat
- I show electric current
- R is the amount of electric resistance in the conductor
- t denotes time
- The amount of generated heat is proportional to the wire's electrical resistance when the current in the circuit and the flow of current is not changed.
- The amount of generated heat in a conductor carrying current is proportional to the square of the current flow through the circuit when the electrical resistance and current supply is constant.
- The amount of heat produced because of the current flow is proportional to the time of flow when the resistance and current flow is kept constant.

Example

1. Calculate the heat energy produced in resistance of 5 Ω when 3 A current flows through it for 2 minutes.

Solution

The amount of heat produced by the conductor is given by the formula:

$Q = I^2 R t$

Substituting the values in the above equation we get

$Q = 3^2 \times 5 \times 2 \times 60 = 5400$ J

2. A heater of resistance 300 Ω is connected to the main supply for 30 mins. If 10 A current flows through the filament of the heater then what is the heat produced in the heater?

The amount of heat produced by the heater is calculated as follows:

$Q=I^2Rt$

substituting the values in the equation, we get

$Q = 10^2 \times 300 \times 30 \times 60 = 54000000$ J or 54 MJ.

Applications of heating effect of an electrical current

Activity 12.22 **To investigate the application of heating effect of an electrical current**

Materials

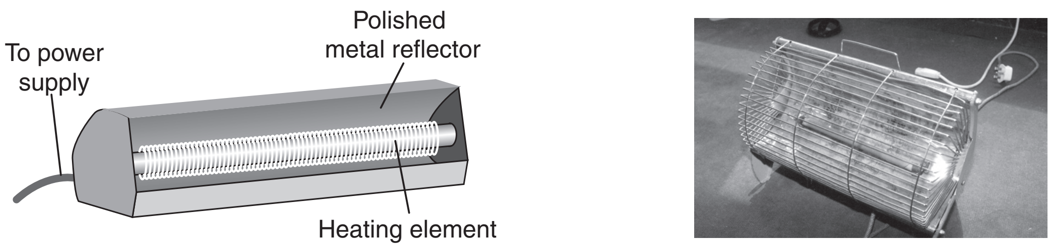
- Iron box, cloth (hankie) socket, water

Steps

1. Plug the iron box into the socket. After 2 minutes, sprinkle little water on to the bottom (metalic part). What do you observe? Explain.
2. Pass the iron box on top of cloth once folded. What do you observe?

Common household electrical appliances like electric kettle, laundry iron, heater, hotplate, toaster, roaster etc. which convert electrical energy into heat are all constructed essentially in the same way. In all the cases, the heating elements are made from a metal like nichrome. This is an alloy of nickel and chromium which is not easily oxidised when it turns red hot. The nichrome wire is made into a coil and wound round substances like porcelain ceramic which are heat resistant and non conductors.

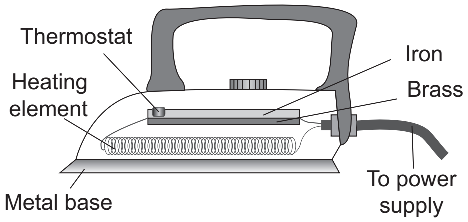
The heating element in a radiant electric heater is red hot at about 900°C and the radiation emitted by the heater is directed into the room by polished metal reflectors (Fig. 12.35 (a) and (b)).



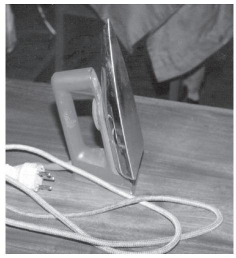
(a) (b)

Fig. 12.35: A radiation room heater

In an electric iron, when a current flows through the heating element, the heat energy developed is conducted to the heavy metal base and the temperature of the metal base increases. This heat energy is used to press clothes. An electric iron also incorporates a thermostat (a device containing a bimetallic strip) which is used for regulating the temperatures of the hot plate. Fig. 12.36 (a) shows the labelled parts of an electric iron while Fig. 12.36 (b) shows a commercial electric iron.



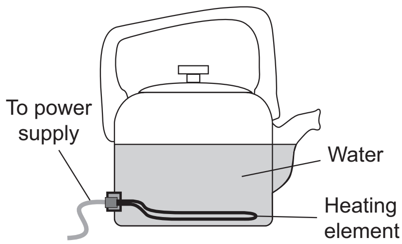
(a)



(b)

Fig. 12.36: An electric iron

In an electric kettle (Fig. 12.37(a) and (b)), the heat energy developed in the heating element is used to heat water. The temperature of water rises in a comparatively shorter time as compared to water being heated using burning charcoal or firewood.



(a)

(b)

Fig. 12.37: An electric kettle

The latter releases carbon dioxide gas to the atmosphere which has a bad effect on the environment.

> Cutting trees for charcoal and firewood leads to deforestation which may lead to desertification.

Exercise 12.6

1. A bulb rated 200 W is used for 12 hours. Calculate the energy it consumed in kWh.
2. Name any four devices that have electric heating elements.
3. If energy costs 182 FRW per unit and the energy saving bulbs are used on average, for 5 hours per day, what will the annual saving be if the bulb is rated 5 kWh?
4. State the international colour conventions for the live (line), neutral and earth leads of a 3-core flex.
5. Define a fuse and state its function in an electrical circuit.
6. Sketch and name a 3-pin plug.
7. Explain why the earth connection is important.

(b) Magnetic effects of an electric current

Activity 12.23 **To demonstrate the magnetic effect of an electric current**

Materials

Insulated copper wire, soft iron core, source of current, switch, 3 nails

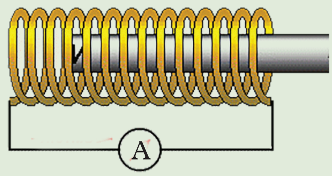


Fig. 12.38: Insulated copper wire

Steps

1. Wind several turns of insulated copper wire around a core made of soft iron (Fig. 12.38). This turns make up a solenoid.
2. Remove the insulation from the ends of the solenoid wound around the soft iron core, and connect the solenoid to the circuit using the bare end as shown in Fig. 12.38.
3. Switch on the current through the switch bring the other nails near or touching the solenoid. What do you observe?

In Activity 12.23, you should have observed that the solenoid attracts the nail when the current is on. In 1819, Oersted observed that the direction of a compass needle near a current-carrying conductor changed immediately the current was switched off. He also observed that the direction on the compass needle depended on the relative position of the compass from the current-carrying wire, and the direction of the current.

From Oesterd experiment it was discovered that there exists a relationship between an electric current and magnetism. The interaction between the two fields is known as electromagnetism.

Applications of magnetic affect of an electric current

The magnetic effect of an electric current has many applications e.g in electromagnets, loudspeaker, ammeter, voltmeter, electric motors etc. We will learn in details each of the applications in our next levels. Fig. 12.44 (a), (b) and (c) shows an ammeter, a motor and loudspeaker.

(a) Ammeter **(b)** Motor **(c)** Loudspeaker

Fig. 12.44: Applications of magnetic effects of an electric current

Exercise 12.7

1. Explain why a magnetic compass deflect when brought near a conductor carrying current.
2. Give any three applications of electromagnetic effect

(c) Chemical effects of an electric current

To investigate chemical effects of an electric current

Activity 12.24 To investigate chemical effect of an electric curent

Materials

- A 250 ml beaker
- A battery
- Two carbon rods
- Water

Steps

1. Put some pure water in a beaker. Dip two carbon rods into the water. What is the name of the two rods dipped in water?
2. Connect one of the carbon rod to the negative terminal of a battery. Connect the other carbon rod to the positive terminal of the same battery as in Fig. 12.46.

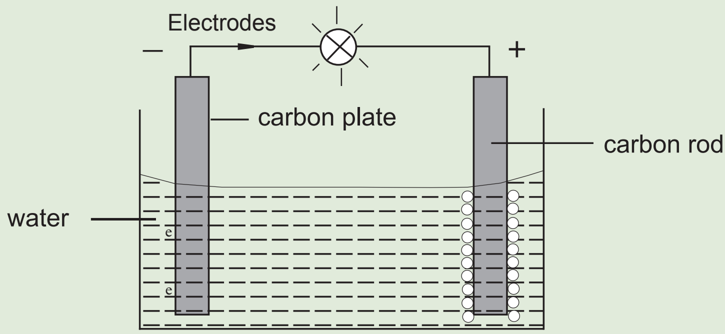


Fig. 12.46: electrolysis of water

3. Connect a light bulb and a switch. Close the switch and note what happens to the bulb.
4. Add a few drops of diluted sulphuric acid to the pure water and repeat the activity.
5. Repeat the activity with other liquid/solution e.g. copper sulphate solution, common salt solution and record your observations.

In Activity 12.24, you should have observed that with pure water, the bulb did not light. However, with a few drops of sulphuric acid, the bulb lights.

Sulphuric acid helps to break water molecules into ions. Water with a few drops of sulphuric acid is known as acidulated water. These ions produce the electrons that flow in the circuit hence the bulb light. The rod or plates that are dipped in solution to direct the current are called electrodes. The electrode connected to the positive terminal of the battery is known as the anode and that connected to the negative terminal is called cathode.

A close observation at the surface of the electrodes in contact with the electrolytes shows that chemical actions occur. The chemical changes in a liquid due to flow of an electric current is called electrolysis. Not all liquids allow electric current to pass through them. It is only those liquids which are at least partly dissociate into oppositely charged ions that allow current to pass through them. Such liquids are called electrolytes. Solution of many inorganic chemical compounds (e.g. sulphuric acid, copper sulphate, common salt) etc are examples of electrolytes.

To investigate the chemical effect of an electric current through copper sulphate solution with copper electrode

Activity 12.25 To investigate the chemical effect of an electric current

Materials

- Copper sulphate solution
- A 250 ml beaker
- An ammeter
- Copper electrodes
- A variable resistor
- measuring balance

Steps

1. Measure the mass of copper electrodes provided. Note it down.
2. Set the apparatus as shown in Fig. 12.47.

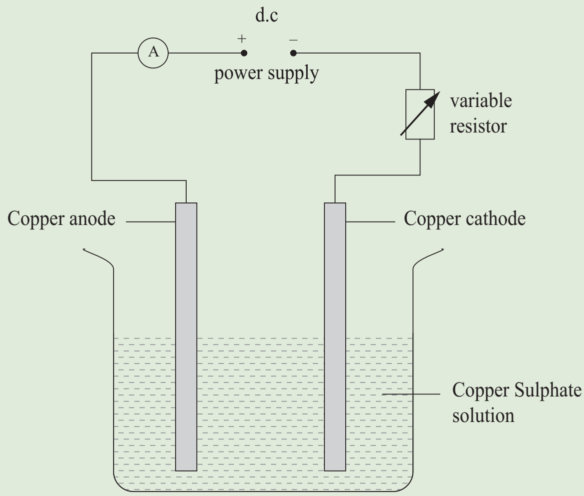


Fig. 12.41: Copper electrodes immersed in Copper Sulphate solution

3. Adjust the variable resistor such that a current of 0.5 A passes through the copper sulphate solution.
4. Allow the electric current to flow for about 30 minutes. Remove copper cathode and anode from the solution, and observe what happens to their surfaces. Reweigh them.
5. Compare the mass in steps 1 and 4. What do you notice?
6. Discuss the applications of chemical effect of an electric current.
7. Carry out a research from the Internet and reference books to compare your findings from the discussion in case 6.

In Activity 12.29, you should have observed that the copper cathode electrode that was dipped in the copper sulphate solution was covered with a bright fresh deposit of copper. The cathode showed an increase in mass and the anode showed a decrease in its mass. The increase and decrease in mass at the cathode and anode respectively is equal. The colour of the copper sulphate solution remain unchanged. The net effect is that copper is dissolved off the anode and deposited on the cathode, with the electrolyte remaining unchanged.

12.9 Applications of chemical effect of an electric current

(a) Electroplating is mainly used in depositing a layer of material on a metal surface e.g. chromium to achieve a desired property. For instance, protection against corrosion and aesthetic qualities. It is also used to build up thickness on undersized parts.

For example, chromium plating is done on bath taps, car bumpers, bicycle handlebars, towel rails. Chromium does not corrode and resists scratches and wear. It can be polished to give a bright attractive appearance. Silver plated items are also common to find in our daily use. Cutlery and jewellery items are often silver plated to have the appearance of silver but be less expensive.

(b) Electrolysis is used to manufacture pure metals such as pure copper commercially from compound solutions. This method is covered in details in Chemistry.

(c) Electrolytic capacitors are widely used in radio receivers i.e the capacitor is made by the electroysis of annonium borate.

Electrical hazards and safety measures

Activity 12.36 **To identify electrical hazards and safety measures**

Materials

- Internet
- Reference books

Steps

1. Conduct a research from internet and reference books on common electrical hazards in places such as homes, schools, industries and offices.
2. In your research, identify some of the safety measures to be taken to prevent or during the occurrence of electrical hazards.

In your discussion, you should have established that hazards are situations that pose a threat to life, health, property or environment.

The following are some common electrical hazards in our homes, offices and factories.

- Poor wiring and defective electric wires can lead to electric shock and fires.
- Water outlets being close to electric outlets can cause electric shock when it gets in contact with live wires.
- Pouring water on electrical fire. This can lead to electric shock.
- Overloading the outlets may lead to overheating and electrical fire.
- Use of long extension cords which can cause tripping or accident.
- Touching electrical appliances with wet hands leading to shocks.
- Broken sockets and electrical appliances leading to electrical shock and sometimes fire.

Safety measures

Every electricity user should observe safety measures when using electricity and electrical appliances. The following are some of the electrical safety measures.

- Do not touch naked electric cables with bare hands to avoid electric shock.
- Always pay attention to the warning signals given out by your appliances. For instance, if a circuit breaker repeatedly trips, you should confirm the problem.
- Use the right size circuit breakers and fuses to avoid overloading.
- Ensure that potentially dangerous electrical devices or naked wires are out of reach of children.
- You should avoid cube taps and other outlet-stretching devices.
- Always replace broken plugs and naked wires.
- Use the correct appliances in a socket to avoid overload.

12.10 Project work

Making a simple cell from locally available materials

Suggested materials

Citrus fruit, potatoes or onion to provide the electrolyte, zinc plates from old dry cells, thick copper wire.

Assembly

- Assemble the apparatus as shown in Fig. 12.48.

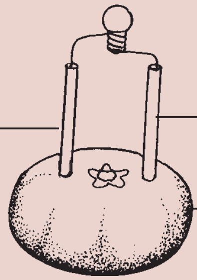


Fig. 12.42: A symbol cell

- Pierce through the skin and insert the two electrodes. The current from this cell is very small. Try and connect a number of them in series and see whether a small bulb can be lit.

Unit summary and new words

- Electric circuit is a complete path through which charge flow.
- An ammeter is an instrument used to measure current.
- A voltmeter is an instrument used to measure potential difference (p.d.).
- Potential difference (V) is the work done in moving a unit charge between two points in a closed circuit.
- Potential difference (p.d.) = work done per unit charge.

  $$\text{p.d. (V)} = \frac{\text{work done (in joules)}}{\text{charge (in coulombs)}} \quad \text{i.e. } V = \frac{W}{Q}$$

  Its SI unit is the volt (1 volt = joule per coulomb 1 J/C)
- Electric current is the rate of flow of charge.

  $$\text{Current, } I = \frac{\text{charge, } Q}{\text{time, } t}$$

- Whenever an electric current passes through a conductor, electrical energy is converted to other forms of energy e.g. heat, light.
- Heating effect by current depends on the;
  - current passing through conductor.
  - resistance of the conductor.
  - time for which current flows.
- Electrical energy dissipated in a conductor in a time *t*, is given by:

  $E = VIt = Pt$
- Power is the rate at which work is done.

Electrical power is given by:

$$P = VI \qquad \text{also} \qquad I = \frac{V}{R}$$

$$\text{but } V = I^2R \qquad \text{Hence, } P = V \times \frac{V}{R} = \frac{V^2}{R}$$

$$P = I^2R$$

- Energy in kilowatt is calculated as:
  Energy (kWh) = kW × hours
- Most electrical appliances are manufactured to be used on the same main supply, but have different power outputs.
- SI unit of energy is the joule and SI unit of power is the watt.
- We use a tungsten coil as the heating element in an electric bulb.
- Effects of an electric current include:
  - heating effect
  - magnetic effect
  - chemical effects
- The magnetic field around current-carring conductor has the following characteristics:
  - they are circular.
  - they are strongest close to the wire.
  - increasing the current increases the strength of the fields.
- Electric current causes chemical break down of solutions when passed through them.
- Primary cells cannot be recharged while secondary cells are rechargeable.
- Electric cells provide energy to drive an electric current in a circuit.
- Secondary cells can last for a long time if they are well maintained.

Unit Test 12

1. Define the following terms:

(a) Electrical circuit.

(b) Electric current.

(c) Potential difference.

2. A charge of 200 coulombs flows through a lamp in 10 minutes. Determine the current flowing the lamp.

3. Find the amount of charge that will pass through a certain point in a circuit, if 5 mA flows through the point for 6 hours.
4. Fig. 12.49 shows two circuit diagrams.

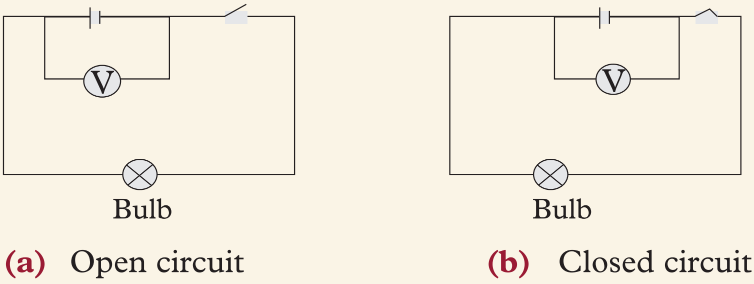


Fig. 12.49: An electric circuit

What type of voltage is measured when:

(a) the switch is open.

(b) the switch is closed.

5. With the aid of a diagram, describe how conventional current and electrons flow in an electric circuit.
6. A current of 0.12 A flows in a circuit for 9 minutes. How much charge passes through a given point in the circuit?
7. 1 800 coulombs of charge are passing through a point in an electric circuit in 15 minutes. Determine the amount of electric current in the circuit.
8. What instrument is used to measure electric current? How is it connected in a circuit?
9. Identify the instruments in Fig. 12.50 and state the reading on them in SI units.

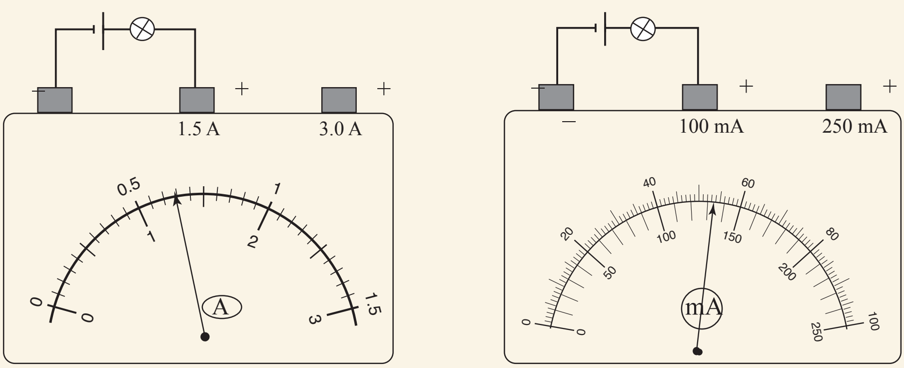


Fig. 12.50: Electrical instruments

10. Which of the following is not an effect of an electric current?

(a) heating effect (b) magnetic effect
(c) growing effect (d) chemical effect

11. Heat produced by a conductor carrying current depends on the following except ____________.

(a) the colour of the material
(b) the amount of current
(c) the resistance of the conductor
(d) time for which the current flows

12. State two characteristics of the magnetic field around a conductor-carrying current.

13. Suggest suitable fuse to be used with an appliance rated 9 A?

(a) 15 A (b) 10 A
(c) 7 A (d) 3 A

14. Describe energy transformation when lights are switched on at the main switch.

15. What do you understand by the terms 'heating effect'?

16. Starting from electrical work done W = VIt, show that electrical power (P) generated in a conductor is given by $\frac{V^2}{R}$, where the symbols have the usual meaning.

17. A current of 6 A is passed through a resistor of 30 Ω m for $1\frac{1}{2}$ hours. Calculate the electrical energy converted into heat energy in the resistor.

18. State four household electrical appliances where electrical energy is converted into heat energy.

19. The filament of a bulb is made of tungsten as the heating element, explain why tungsten is a suitable material for the filament?

20. Electrical heaters are said to be environmentally friendlier than the heating devices which use firewood or charcoal. Explain this statement.

21. Highlight five electrical hazards in our homes and suggest the appropriate measures that can be taken.

22. Which of the bulb in the circuits shown in Fig. 12.51 will light if the switch is closed? Explain your answer.

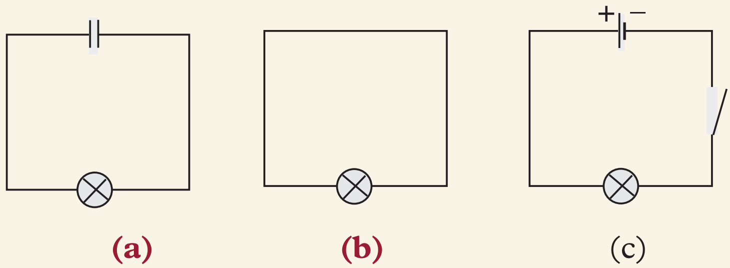


Fig. 12.51: Bulbs in a circuit

23. Which materials are used in the construction of a simple cell?

24. Explain why the current in a simple cell decreases rapidly when in use. Describe how to minimise this decrease in current.

25. Describe a project to make a simple battery.

UNIT 13 Rectilinear Propagation of Light

Key Unit Competence

By the end of this unit, I should be able to explain the nature of light, rectilinear propagation of light and reflection at plane surface.

Unit Outline

- Different sources of light.
- Rays and beams.
- Classifications of materials as transparent, translucent and opaque.
- Experiments on light propagation.
- Rectilinear propagation of light.
- Types of reflection.
- Formation of shadows and eclipses.
- Lunar and solar eclipses.
- Law of reflection.
- Characteristics of images formed in mirrors.
- Ray diagrams and numbers of images formed in inclined mirrors.
- Pinhole camera, image formation and magnification.

Introduction

Most of us are familiar with the biblical story of creation. It tells us that the first thing God created was light by uttering "let there be light" and the story says that immediately there was light. We experience 12 hours of day light and darkness everyday. The former is very pleasant to all of us but the latter is not very pleasant. So what is this light that is so precious to us all? Throughout history different theories have been developed on the nature of light. Some great scientists have argued that light is a stream of tiny particles while others have argued that it is a wave. In this unit, we will learn about the nature of light and how it travels.

13.1 Nature and source of light

13.1.1 Nature of light

Activity 13.1 **To find out the meaning of light and its sources**

Out of your interaction with light, discuss in your group:

1. What light is and how it travels.
2. Sources of light and give examples.
3. Sources that produce their own light and those that depend on the light produced by other sources.

Light is a form of energy. It enables us to see the surrounding objects. Light itself is not visible but its effect is felt by the eye. For example, the track of light entering a room cannot be seen; but the track becomes visible, if some dust particles are present in the room. In a cinema theatre, light from the projector to the screen is visible due to the dust or smoke moving through the path of light.

Light is actually a form of energy in a wave form. It travels at a speed of approximately 300 000 000 m/s or 3×10^8 m/s.

13.2 Sources of light

In your research in Activity 13.1, you should have discovered that there are two sources of light: luminous and non-luminous sources.

(a) Luminous sources of light

These are sources (objects) that emit(give out) their own light.

Examples of non-living luminous objects are sun, stars, fire, candle flame and electric bulb.

Examples of living things that are luminous objects are fireflies and glow worm.

(b) Non-luminous sources of light

These are objects that do not emit (give out) their own light. We get to see these objects when they reflect the light falling on them from luminous source onto our eyes.

The moon is a good example of a non-living thing that is non-luminous source of light. Others are a wall and a car. Examples of a living things that are non-luminous sources are trees and animals.

Fig 13.1 shows how the moon reflects light from the sun to the earth.

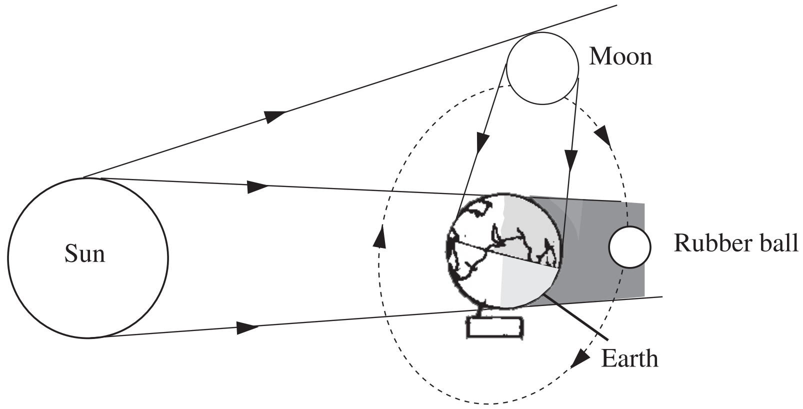


Fig. 13.1: How the moon reflects light to Earth

13.2 Rays and beams

Activity 13.2 **To demonstrate the difference between a ray and a beam**

Materials

- A torch
- A small tin open on one side
- Nail
- Hammer
- Dark room

Steps

1. Make several small holes at the closed end of the tin using the nail and hammer.
2. Go into a dark room with the container. Switch on the torch and foas its light inside the tin. What do you observe?
3. With the help of this activity, suggest what rays and beams are? Suggest types of beams of light.

In activity 13.2, you should have observed that when the stream of light from the torch was focused into the container, the beam of light was split into rays to pass through different holes of the container. But what is a ray? *A ray of light is the path along which light travels in a medium.* In diagram, a ray of light is represented with a straight line and an arrow pointing from the source to the destination of light as shown in Fig 13.2

Fig 13.2 : Ray of light

A beam of light is a collection or group of light rays. There are three types of beam of light rays:

(a) Parallel beam: consists of rays that are parallel to one another (Fig. 13.3).

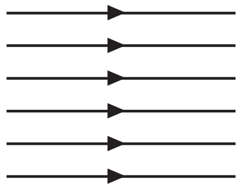


Fig. 13.3: Parallel beam

(b) Convergent beam: consists of rays of light that meet at a point i.e converge (Fig. 13.4).

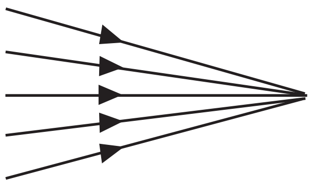


Fig. 13.4: Convergent beam

(c) Divergent beam: consists of rays of light originating from a point source and diverge(spread) to different directions (Fig 13.5)

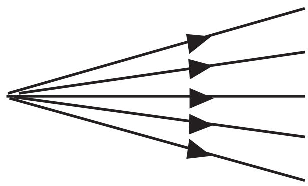


Fig. 13.5: Divergent beam

13.3 Transparent, translucent and opaque materials

To find out what transparent, translucent and opaque materials are

Activity 13.3 **To differentiate between transparent, translucent and opaque objects**

Materials

- Reference books
- Internet
- Oil
- Piece of paper
- Glass window plane
- A cardboard

Steps

1. Look through the glass window pane of your classroom or any of your school building. Do you see through it?

2. Smear some cooking oil or fat on a piece of paper. Look through the oiled piece of paper and the cardboard in turn. Do you see through each of them? What are such materials called.
3. Conduct research from books and the internet on what transparent, translucent and opaque materials are.
4. In your research, identify four examples of each.

From activity 13.2 should have identified three types of materials with regard to their ability to allow light to pass through them

Transparent materials – These are materials that allow all the light falling on them to pass through them freely. Therefore, we are able to see clearly through these materials.

Examples of transparent materials are air, water and clear glass.

Translucent materials – These are materials that allow some light falling on them to pass through. The light get scattered as it passes through. Therefore, objects on the other side of such materials appear blurred and cannot be seen clearly.

Examples of translucent materials are frosted glass, oiled paper, wax paper, ice, tinted windows and some plastics.

Opaque materials – These are materials that do not allow light to pass through. When light strikes an opaque object, none of it passes through. Therefore, we cannot see through such materials. When light falls on these materials, much of it is reflected away by the objects some while of it absorbed and converted to heat energy.

Examples of opaque materials are rocks, wood, soil, metals and exercise book.

13.4 Rectilinear propagation of light

Activity 13.4 **To investigate how light travels**

Material

- A huge tree

Steps

1. Stand at a distance infront of a huge tree.
2. Hold your finger close to and infront of one of your eyes.

3. Close the other eye and try to look at the tree. Can you see the tree? Suggest a reason for your observation.

The tree in Activity 13.4 cannot be seen. This property of light will become clear to you after doing Activity 13.5.

Activity 13.5 To verify rectilinear propagation of light

Materials

- Soft board
- A plane mirror
- Plasticine
- White sheet of paper

Steps

1. Take three cardboards P, Q and R of equal sizes mounted on wooden stands (Fig. 13.3).
2. Make small holes on the cardboards at the same height and also at equal distances from the edges on each cardboards.
3. Place the cardboards on a flat surface (bench) and pass a thread through the holes to ensure they lie on a straight line.
4. Remove the string without disturbing the setup of the three cardboards.
5. Place a lit candle infront of the hole in cardboard P and view from the the hole in R as shown in Fig. 13.6. What do you see? Explain.

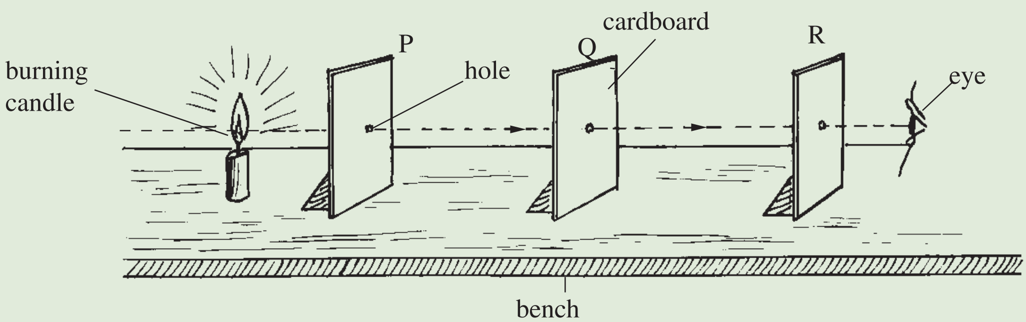


Fig. 13.6: Investigating how light travels

6. Disorganise the arrangement by moving cardboard Q slightly to one side. Try viewing the candle from the hole in cardboard R. Record your observation.
7. What conclusion can you make about the alignment of the three holes and the manner in which the light travels?

In Activity 13.5, you should have observed that when the holes are aligned, light from the candle is seen through the three holes in a straight line. When the holes are not aligned, the light is not seen.

The observations in Activity 13.4 and 13.5 suggests that light travels in a straight line.

Scientists use the word "*rectilinear*" instead of the phrase "in straight lines" and "propagated" in place of "travel". Instead of stating that *light travels in a straight line*, we can say that *light has the property of rectilinear propagation*.

13.5 Formation of shadows and eclipses

Shadows

Activity 13.6 **To demonstrate how shadows are formed**

Materials

- A white screen
- A candle
- 2 cardboard with a large and narrow opening
- A tennis ball

Steps

1. You must have seen a shadow of yourself or any other object when standing in the sun. Based on that experience suggest to your partner the possible answers to the following questions:
   (a) What is a shadow?
   (b) How is a shadow formed?
   (c) Share your thoughts with the rest of your class in a class discussion.
2. Now, place a burning candle infront a narrow opening cardboard and the white screen behind the cardboard. Place the tennis ball between the cardboard and screen and observe the shadow cast on the screen. Sketch it.
3. Repeat step 2 using a cardboard that has a wide hole.
4. Identify the total and partial darkness from your drawing. Suggest appropriate names for them.
5. Draw and label the diagrams on how the shadows were formed on the chalkboard.

In activity 13.6, you should have established that a shadow is a partial or total darkness cast by an object blocking the direct rays of light.

Formation of shadows with a point source of light

A narrow opening through a cardboard forms a point source of light, when illuminated with light. An opaque object PQ, placed between opening L and a white screen, obstructs rays of light (Fig. 13.7).

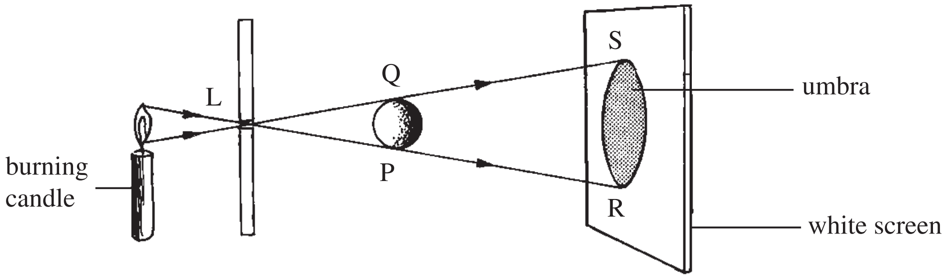


Fig. 13.7: Shadow formation using a point source of light

The area between the lines PR and QS receives no light at all. A shadow of PQ is cast on the screen. The area between R and S is in complete darkness. The region of complete darkness is called umbra (latin term meaning shadow).

Formation of shadows with an extended source of light

A large opening through cardboard forms an extended source of light when illuminated with light. An opaque object PQ placed between EL and a white screen obstructs light rays (Fig. 13.8).

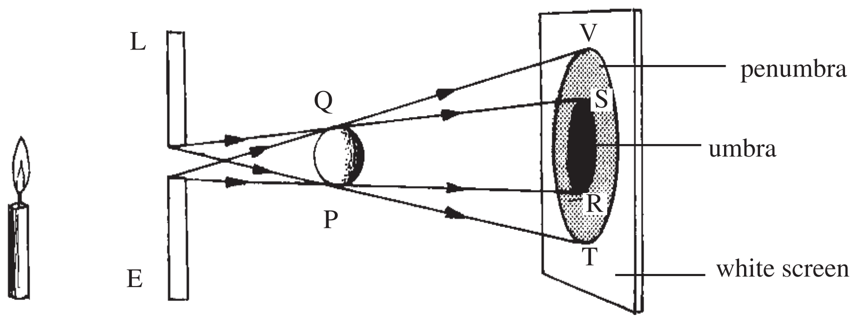


Fig. 13.8: An extended source of light

The region RS on the screen is in complete darkness. The region RT and SV are in partial darkness because light comes from only one part of the extended source. This region of partial darkness is called penumbra (latin term meaning almost shadow).

Eclipses

Activity 13.7 **To find out how different types of eclipses are formed**

Materials

- Reference books
- Internet
- Earth globe
- Rubber ball
- Source of light (torch)

Steps

1. At least once in your lifetime you may have experienced an eclipse (partial darkness) during day time. Tell your partner your experience and what you think or understand causes that to happen after some years.
2. Now, conduct a research from books and the internet on eclipses.
3. In your research, find out the types of eclipses and suggest a reason why the sun looks like a very bright ring during the occurrence of one of the eclipses.
4. Draw on the chalkboard the formation each type of eclipse and label it.
5. Using your diagrams, demonstrate the formation each type using a source of light (torch), earth globe and rubber.

An important example of the formation of shadows is the occurrence of eclipses. The term eclipse means that light is blocked or cut off from region of observation. Let us discuss two types of eclipses namely solar and lunar eclipses.

(a) Solar eclipse

When the moon, revolving around the earth, comes in between the sun and the earth, the shadow of the moon is formed on the earth. This is called the solar eclipse or the eclipse of the sun. Depending on the position of the moon, some parts of the earth lie in the region of umbra and some in the region of penumbra. Total eclipse occurs in the regions of umbra and partial eclipse in the regions of penumbra (Fig. 13.9).

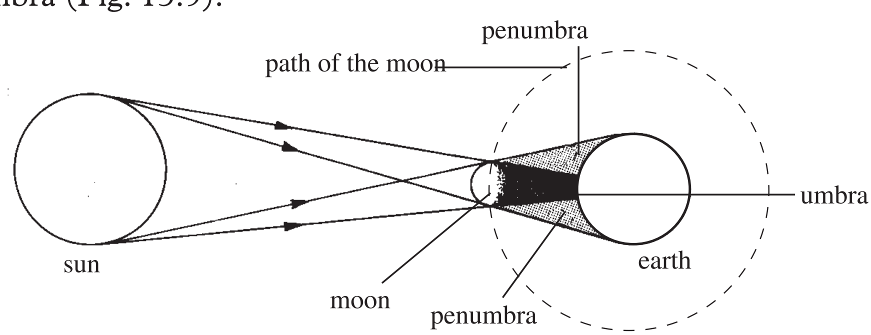


Fig. 13.9: The solar eclipse

(b) Lunar eclipse

The moon is a non-luminous object. It can only be seen when light from the sun falls on it. When we look at the moon, we see only the shape of the lighted portion. When the earth comes in between the sun and the moon, lunar eclipse (eclipse of the moon) occurs. Depending on the position of the moon, a total eclipse or partial eclipse of the moon will occur. Total eclipse will occur if the moon is in the region of umbra. Partial eclipse will occur if any part of the moon is in the region of penumbra (Fig. 13.10).

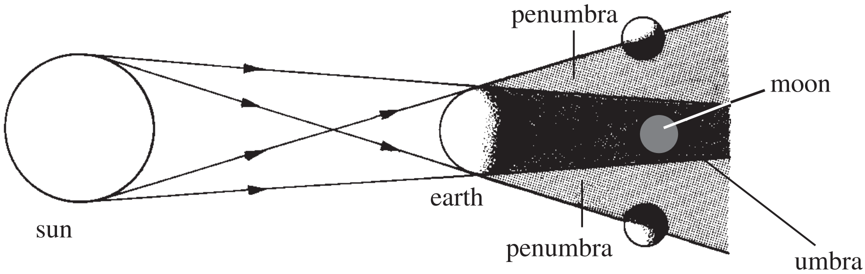
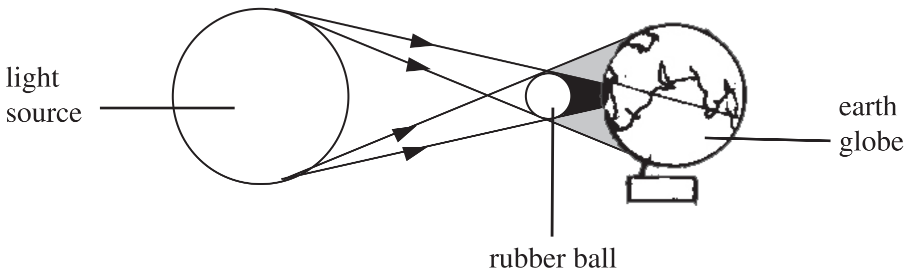


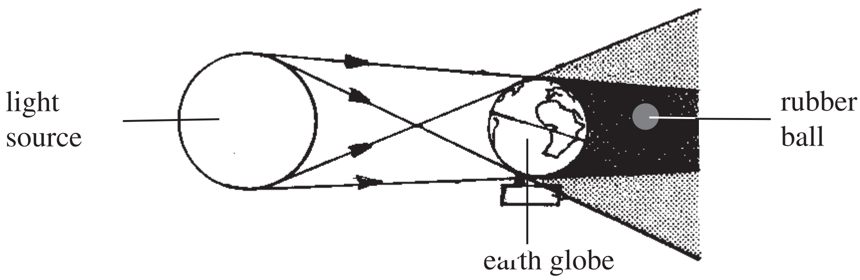
Fig. 13.10: The lunar eclipse

Demonstration to show solar and lunar eclipses

In Fig. 13.11(a) and (b) shows setups to demonstrate solar and lunar eclipses formation respectively. In both setups, the source of light represents the sun and the rubber ball represents the moon revolving around the earth (globe).



(a) Solar eclipse



(b) Lunar eclipse

Fig. 13.11: Demonstration of solar and linar eclipses formation

Exercise 13.1

1. What is light?
2. (a) What do scientists mean by the phrase rectilinear propagation of light?
   (b) Suggest a simple experiment to illustrate this property of light.
3. Explain the meaning of the following terms:
   (a) A non-luminous object. (b) An opaque object.
   (c) A ray and a beam of light. (d) A shadow.
4. With a simple well labelled diagram, distinguish between the terms umbra and penumbra.
5. Describe with well labelled diagrams the formation of (a) the total solar eclipse and (b) annular eclipse.
6. Fig 13.12 shows the formation of the eclipse of the sun.

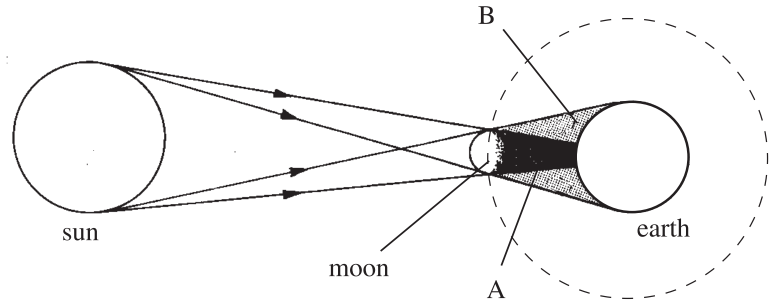


Fig. 13.12: An eclipse of the sun

   (a) What type of shadow is formed at:
      (i) A (ii) B
   (b) Draw the appearance of the sun at points:
      (i) A (ii) B
7. Classify the following materials as either transparent, transluscent or opaque: distilled water, tainted car window and your book's cover.

13.6 Pinhole camera

Activity 13.8 To demonstrate the working of a pinhole camera

Materials

- Reference books
- Internet
- Pinhole camera

Steps

1. Conduct a research from the internet and books on the working of a pinhole camera.
2. In your research, find out
   (a) the characteristics of images formed by a pinhole camera.
   (b) the magnification of a pinhole camera.
3. Now, go outside your classroom. Let one of you stand at a reasonable distance from the rest of the group members.
4. Let another member of your group observe the image of the member standing at a distance with a pinhole camera. Let the two members interchange their roles.
5. Explain what will happen to the images formed by the pinhole camera if its pinhole is enlarged.
6. Repeat the activity in pairs until every group member gets the opportunity to view the image of at least one group member with the pinhole camera.
   Note: The group member with visual challenges (if any) should stand at a distance and the ones without such challenges view his/her image. Not the other way round.
7. Discuss the characteristics of the image formed by the pinhole camera, guided by the following questions:
   (a) Is the image inverted or erect?
   (b) Is the image virtual or real?
   (c) How does the image size compare with that of the object?

A pinhole camera consists of a box with a pinhole on one side and a translucent screen on the opposite side. Light rays from an object, pass through the pinhole and form an image on the screen (Fig. 13.13).

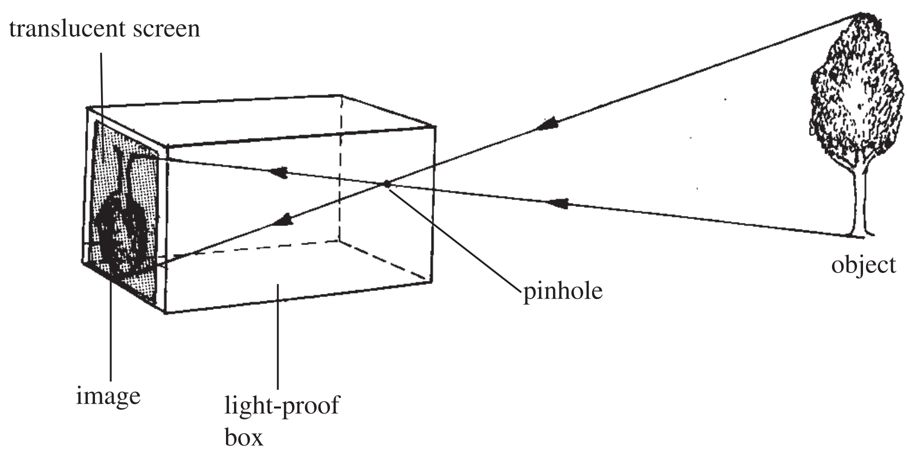


Fig. 13.13: Image formed on a pinhole camera

A pinhole camera has a large depth of field or a large depth of focus.

This means that objects, both far and near from the camera form focussed images on the screen. A lens camera has a limited depth of focus as seen in the photograph in Fig. 13.14. Whereas the frog is in focus, the other details in the background are out of focus.

Fig. 13.14: A picture taken with limited field of focus in lens

Hey!!

Are you aware that any kind of water pollution for instance, releasing untreated sewage into water bodies, oil spillage from ships e.t.c will result to death of aquatic animals e.g frogs and plants? Always let us avoid polluting our water bodies for the survival of beautiful plants and different species of animals in our country.

If the pinhole is made larger, the image becomes blurred (out of focus), bigger and brighter due to overlapping of many rays (Fig. 13.15). A large pinhole of a pinhole camera is like having several pinholes put together. The overlapping images form a bigger but blurred image. A large hole allows more light hence a brighter image.

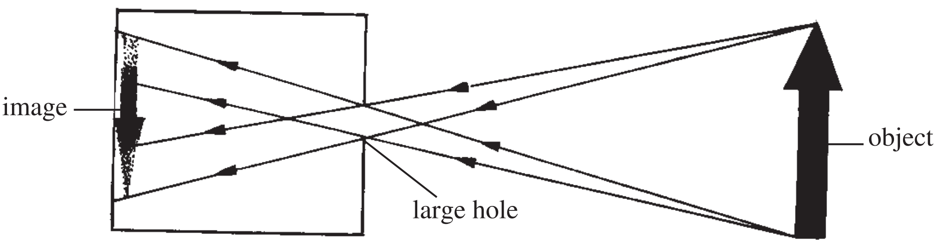


Fig. 13.15: Formation of blurred image due to a large pinhole

Characteristics of the image formed by a pinhole camera

1. The image formed is real. A real image is an image that can be formed on a screen. An image that cannot be formed on a screen is called a virtual image.
2. The image is inverted i.e upside down.
3. The image is magnified i.e bigger than the object.

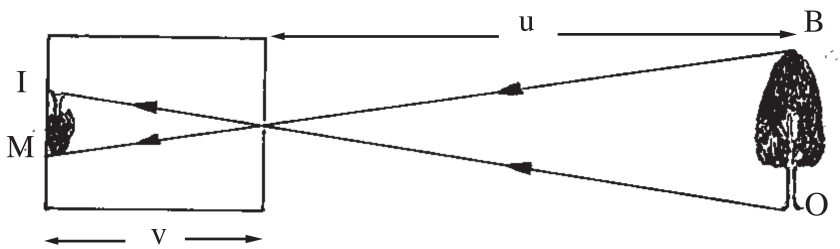
Magnification produced by a pinhole camera

The term magnification refers to how big or small the image is compared to the object. Magnification is defined as the *ratio of the height of the image to the height of the object*.

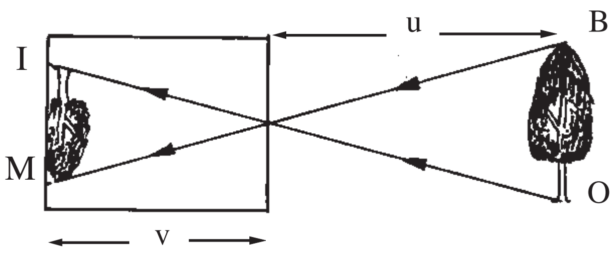
$$\text{Magnification (m)} = \frac{\text{height of the image (IM)}}{\text{height of the object (OB)}}$$

$$m = \frac{IM}{OB}$$

Sometimes it becomes difficult to measure the height of the image or the height of the object accurately. In such cases, magnification can be calculated in terms of object and image distances. For example, consider a pinhole camera far from a tree and another one near a tree (Fig. 13.16).



(a) Pinhole camera far from a tree



(b) Pinhole camera near a tree

Fig. 13.16: Image formed on a pinhole camera

The height of the image in Fig. 13.16(a) is smaller compared to the height of the image in Fig. 13.16(b). This is because the distance of the tree from the camera in (a) is more than the distance from the camera in (b). When the object distance is decreased, magnification increases.

Using the symbols, u, for the object distance (distance between the object and the pinhole) and, v, for the image distance (distance between the image and the pinhole), magnification is defined as *the ratio of the distance of the image from the pinhole to the distance of the object from the pinhole* i.e

$$\text{Magnification (m)} = \frac{\text{distance of the image from the pinhole (v)}}{\text{distance of the object from the pinhole (u)}}$$

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

Combining the two equations, we can write the formula for magnification as

$$m = \frac{IM}{OB} = \frac{v}{u}$$

Example 13.1

A pinhole camera of length 20 cm is used to view the image of a tree of height 12 m which is 40 m away from the pinhole. Calculate the height of the image of the tree obtained on the screen.

Solution

$$\text{Magnification, m} = \frac{\text{height of the image}}{\text{height of the object}} = \frac{\text{image distance}}{\text{object distance}}$$

$$\therefore\ m = \frac{IM}{OB} = \frac{0.20\ m}{40\ m}$$

$$\therefore\ \frac{IM}{12\ m} = \frac{0.20\ m}{40\ m}$$

$$IM = 12\ m \times \frac{0.20\ m}{40\ m} = 0.06\ m = 6\ cm$$

$\therefore$ The height of the image of the tree is 6 cm.

Example 13.2

If the pinhole camera, in Example 13.1 is moved by 10 m towards the tree, what will be the height of the tree on the screen?

Solution

Now the object distance has decreased by 10 m. Therefore the new object distance, u = 30 m

$$\text{Magnification m} = \frac{IM}{OB} = \frac{v}{u}$$

$$\therefore\ \frac{IM}{12\ m} = \frac{0.20m}{30m}$$

$$IM = 12\text{ m} \times \frac{0.20\text{ m}}{30\text{ m}}$$

$$IM = 0.08\text{ m} = 8\text{ cm}$$

$\therefore$ The height of the image is 8 cm.

Exercise 13.2

1. What is a pinhole camera?
2. Explain with a well labelled diagram how a simple pinhole camera works. Describe the nature of the image formed.
3. The distance of the object from the pinhole is increased. Discuss how this change affects the brightness, sharpness and the size of the image formed.
4. State and explain the effect on the image formed in a pinhole camera if:
   - **(a)** the hole is made larger.
   - **(b)** the length of the box is increased.
5. A pinhole camera is used to take the photograph of a person who is 4 m away from the pinhole. If the length of the box used is 18 cm and the height of the image of the person is 9 cm, calculate the:
   - **(a)** magnification produced by the pinhole camera.
   - **(b)** height of the person.
6. A tree 18 m high is observed with a pinhole camera that is placed 40 m away. If the camera is 20 cm long, find the height of the image formed.
7. The length of a pinhole camera is 10 cm. It forms an image of linear magnification of 0.2. Find the position of the object.
8. State three characteristics of the image formed by a pinhole camera.

13.7 Reflection of light at plane surfaces

Activity 13.9 To demonstrate reflection of light at plane mirror

Materials: Plane mirror, iron sheets

1. Let your partner hold a plane mirror facing the sun. Stand infront of the mirror and look at it from a distance. What do you observe? Explain.
2. Now, look towards new iron sheet erected on the roof of a building. What do you see? Explain.
3. Use your experience in steps 1 and 2 to describe what reflection of light is.

Your eyes must have at one time been overwhelmed by the bright sunlight reflected by a mirror or very new iron sheets on a roof.

Reflection is the *bouncing off of light as it strikes a surface*. The ray coming from the source is called incident ray. The ray moving away from the reflecting surface is called reflected ray. (Fig. 13.17)

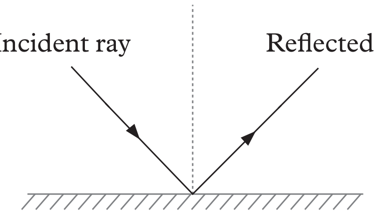


Fig 13.17: A reflection of light

Types of reflections

Activity 13.10 **To differentiate between types of reflection**

Materials

- Mirror and a paper

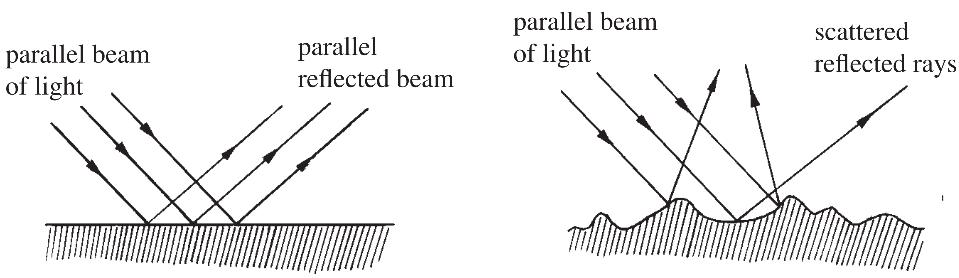
Steps

1. Look through the mirror , what do you observe? Do you see your image?
2. Look through the paper, what do you observe? Do you see your image?

In Step 1 in Activity 13.10, you saw your image because the mirror is smooth hence regular reflection takes place. You did not see your image in a paper because rays of light are scattered by the paper because it is rough

There are two types of reflection; regular and diffuse (irregular) reflections.

When light is reflected by a plane or a smooth surface, the reflection is regular i.e parallel incident rays are reflected parallel to each other. When reflection occurs at a rough surface, it is called diffuse reflection i.e incident parallel rays are reflected in random directions. Fig 13.18 shows the two types of reflections.



(a) A regular reflection (b) A diffuse reflection

Fig. 13.18 : Reflection of light on different surfaces

Terms used to describe reflection of light on plane mirrors

Activity 13.11 **To observe and describe rays on a plane mirror**

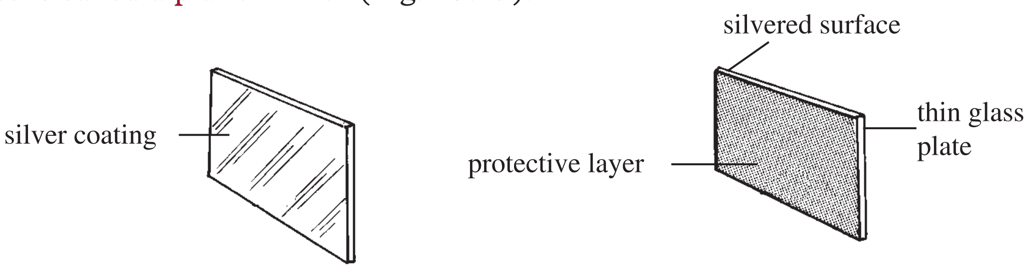
Materials

- Plane mirror
- Cardboard
- Ray box

Steps

1. Take a plane mirror provided to you, and observe its parts.
2. Now, place the plane mirror vertically on a cardboard and illuminate the shinny surface with a ray box. What do you observe? Explain your observation?
3. Sketch the diagram and identify; angle of incident, the normal, reflected ray and angle of reflection.
4. Discuss your findings with others in class.

A thin glass plate coated with silver on one side and a protective layer on the other side is called a plane mirror (Fig. 13.19).



(a) Front view **(b)** Rear view

Fig. 13.19: A plane mirror

Fig. 13.20 shows a ray of light AB striking the plane mirror at B and bouncing off to C. The ray AB is called incident ray and the ray BC is called reflected ray. A line drawn perpendicular to the surface of the mirror at the point where the incident ray and the reflected ray meet is called the normal (BN). The angle between the incident ray and the normal (∠ABN) is called the angle of incidence (∠i). The angle between the reflected ray and the normal (∠CBN) is called the angle of reflection (∠r).

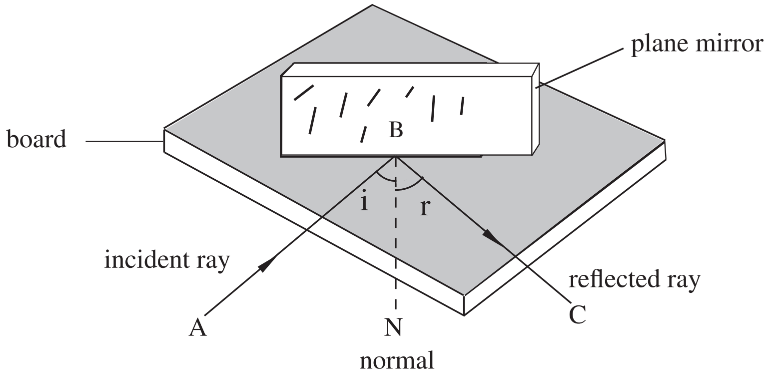


Fig. 13.20: Reflection on a mirror

To verify the laws of reflection using optical pins

Activity 13.12 **To verify the laws of reflection using optical pins**

Materials

- A soft board
- A plane mirror
- Plasticine
- Protractor
- White sheet of paper
- Drawing pin
- 4 optical pins
- A ray box

Steps

1. Draw a line PM on a white sheet of paper. Fix the white sheet on a soft-board with drawing pins.
2. Using some plasticine, set up a plane mirror vertically with its plane perpendicular to the plane of the paper and the silvered surface on the line PM (Fig. 13.21(a)).
3. Stick two optical pins O_1 and O_2, called the object pins, vertically into the softboard, about 6 or 7 cm apart.
4. Keeping the eye along the plane of the paper and in a convenient position, look into the mirror. The images of the two pins are seen. These images appear to be at the rear of the mirror (Fig. 13.21(a)).
5. Move your head to and fro slowly until in one particular position, the images of the two pins lie in a straight line.
6. Fix a third pin, I_1, called the image pin, such that this pin and the images of the first two pins lie along the same straight line.

7. Repeat the procedure with the fourth pin I_2, so that the image pins I_1 and I_2 and the images of O_1 and O_2 lie along the same straight line.
8. Using a sharp pencil, mark the positions of the four pins with a small circle and remove the pins and the mirror.
9. Join the points O_2 and O_1 to meet the line PM. Similarly join the points I_2 and I_1 to meet the line PM. These lines meet at a point B on the line PM.
10. At B, draw a line BN perpendicular to PM. Measure the angle of incidence ($\angle i$) and the angle of reflection ($\angle r$) (Fig. 13.21(b)).

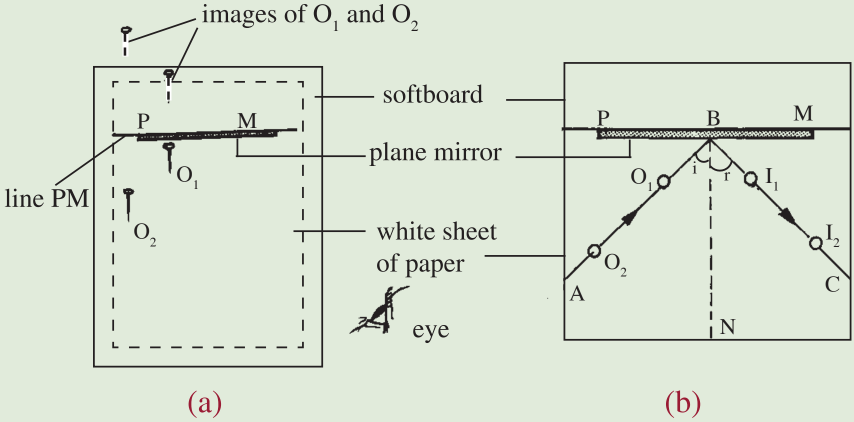


Fig. 13.21: Laws of reflection of light using optical pins

11. Repeat the experiment for three different angles of incidence and record the four readings in a table as shown in Table 13.1. What is the relationship between these two angles?

Angle of incidence, i (°)	Angle of reflection, r (°)

Table 13.1: Angle of incidence and reflection

To verify the laws of reflection using a ray box

Activity 13.13 **To demonstrate and verify the law of reflection using a ray box**

(Group work)

Steps

1. Using the same materials used in Activity 13.8, direct light from a narrow opening of a ray box on a plane mirror placed over a white sheet of paper in a semi-dark room. What do you see?

2. Mark two points, O_1 and O_2, one near the plane mirror and the other very close to the opening in the light box. Observe the path of the reflected ray and mark the points I_1 and I_2, as shown.
3. Remove the ray box and join the points O_2 and O_1 to the line PM. Similarly join points I_2 and I_1, to meet line PM. These lines meet at point B on line PM. At B draw a line BN perpendicular to line PM.
4. Measure the angle of incidence ($\angle$ i) and the angle of reflection($\angle$ r).
5. Repeat the experiment for three different angles of incidence and record your readings in a table similar to Table 8.1. What is the relationship between these two angles?

In Activities 13.12 and 13.13, you must have observe that the light is reflected as a thin beam as shown in Fig. 13.22.

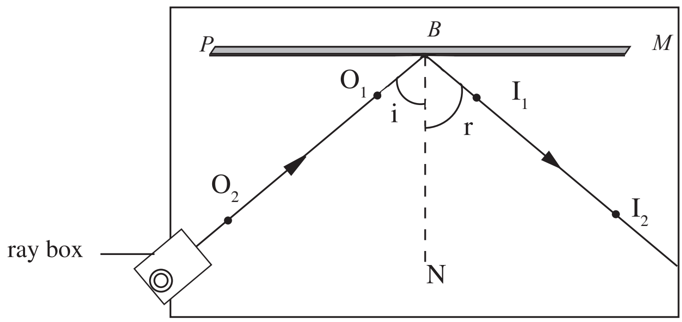


Fig. 13.22: Laws of reflection of light using a ray box

The angle **i** is equal to angle **r**, Q_2 Q_1 joined to the mirror meets lines I_1I_2 at B. Line NB represents the normal ray to the mirror at B.

The observations also show that the incident ray, the reflected ray and the normal, all lie in the plane of the paper.

The observations are in Activity 13.12 and 13.13 summed up into laws of reflection as follows.

Laws of reflection

The laws of reflection of light state that:

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

13.6 Image formation by a plane mirror

Activity 13.14 **To observe the characteristics of images formed by a plane mirror**

Material

- Plane mirror (Big size)

Steps

1. Stand infront of a plane mirror from its reflecting surface. What do you observe? Discuss.
2. List the characteristics of your image formed by the mirror, guided by the following questions:
   (a) How does your distance from the mirror compare to that of your image from the mirror?
   (b) How does your size compare to that of your image?
   (c) Swing your right hand. Which hand does your image appear to swing? Repeat with your left hand.
   (d) Can you put a screen behind the mirror for your image to be formed there?
   (e) Is your image upright or upside down?
3. Now place different objects infront of the plane mirror and analyse their images guided by the questions in step 2.
4. Sketch a diagram to show image formation by a plane mirror.
5. Deduce the general characteristics of images formed by a plane mirror.

Image formation for a point object

We need a minimum of two incident rays from a point object to the mirror in order to locate the position of the image using a plane mirror. The reflected rays from the plane mirror, when produced backwards appear to meet at a point. This is the position of the image. The image is virtual as it only appears to be there and it cannot be projected on a screen (Fig. 13.23).

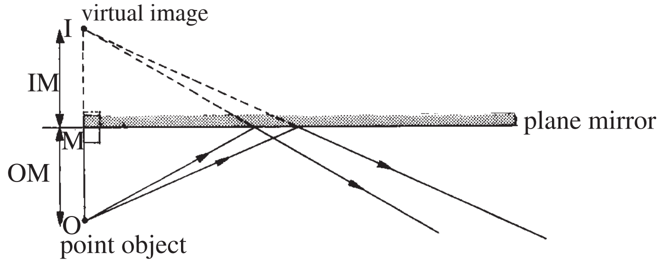


Fig. 13.23: Image of a point object

Measure the perpendicular distance (OM) from the point object O to the mirror and the perpendicular distance (IM) from the position of the virtual image I to the mirror. *The image distance from the mirror is equal to the object distance from the mirror*, OM = IM

Image formation for an extended object

Place an extended object in front of a vertical plane mirror and observe the image formed (Fig. 13.24). Is the image upright or inverted? What is the size of the image?

The image is erect and the size of the image is the same as the size of the object.

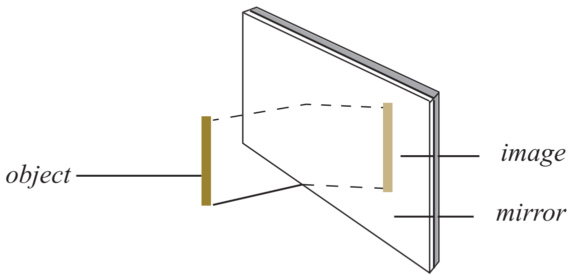


Fig. 13.24: Image of an extended object

Fig. 13.25 shows a ray diagram showing the image of an extended object.

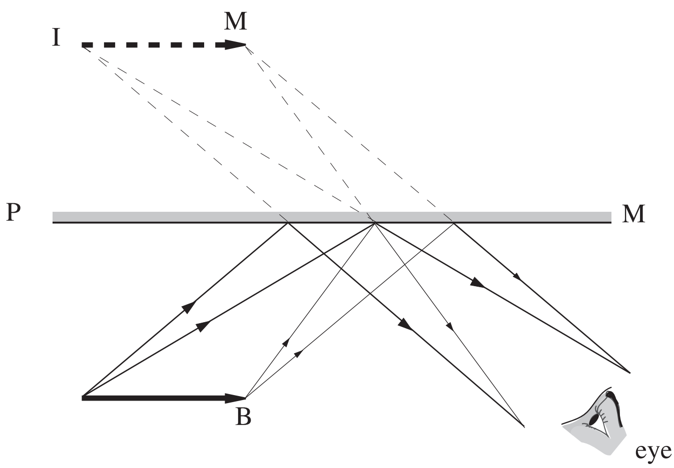


Fig. 13.25: Image formed on a plane mirror

Lateral inversion

Fig. 13.26 shows the image of a sign board in a mirror as seen by a person keeping the eye at E. The eye sees the letter P in the signboard on the left hand side, but the image of the letter P in the mirror is on the right hand side.

The left hand side of the object becomes the right hand side of the image. We say the image is laterally inverted.

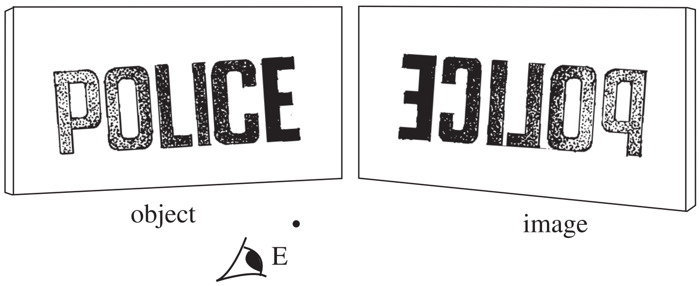


Fig. 13.26: Lateral inversion

Look at yourself in a plane mirror. If your shirt or blouse pocket is on the left side, your image appears to have a pocket on the right hand side. However, the image is upright and of the same size.

From the above observations, we can summarise the characteristics of images formed by plane mirrors as follows:

1. The size of the image is equal to the size of the object.
2. The image is erect or upright.
3. The image is virtual i.e cannot be focused on the screen.
4. The distance of the image behind the mirror is equal to the distance of the object in front of the mirror.
5. The image is laterally inverted.

Example 13.3

What is the angle of reflection in each of the following figures (Fig. 13.27(a) and (b))?

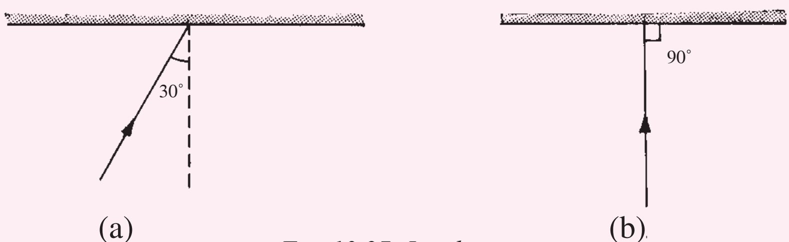


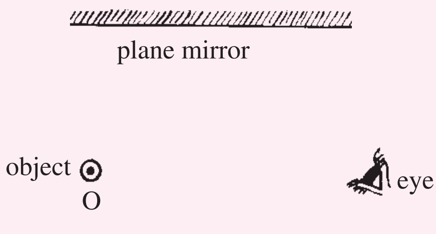
Fig. 13.27: Incident rays

Solution

In Fig. 13.27(a), the angle of reflection = 30°
In Fig. 13.27(b), the incident ray is along the normal. Therefore the angle of incidence = 0°. Hence the angle of reflection = 0°. The ray is bounced back along the normal.

Example 13.4

Explain with the aid of a ray diagram, how the image of a point object O is seen by the eye (Fig. 13.28(a)).



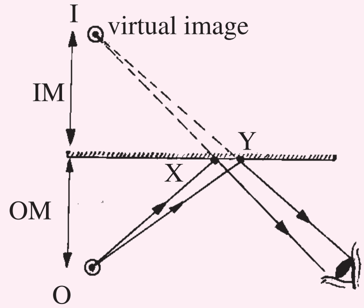


Fig 13.28: Observing how object is reflected by a plane mirror

Solution

In order to see the image, the reflected rays must reach the eye. The image distance behind the mirror is equal to the object distance from the mirror (IM = OM). Hence fix the position of the image first and then draw the two reflected rays from I to reach the eye of the observer. Finally draw the two incident rays OX and OY (Fig. 13.28(b)). Produce the reflected rays back to meet at I.

Example 13.5

Gasore stood infront of a plane (Fig. 13.29). Use suitable rays to show how he may see his full image in the mirror.

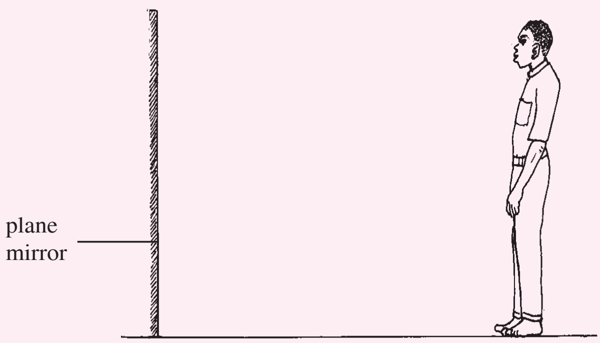


Fig. 13.29: A person standing infront of a plane mirror

Solution

First fix the images of the head and the toe, say M and I, at equal distances from the mirror. The reflected rays from M and I must reach the eyes of Gasore. Therefore, first draw the reflected rays from M and I to reach the eyes. Draw the incident rays HX and TY. Hence, he can see his full image, IM, in the portion of the mirror XY.

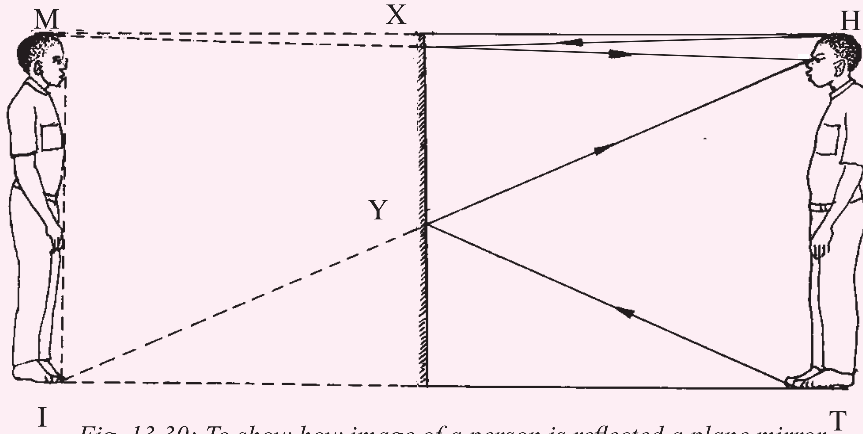


Fig. 13.30: To show how image of a person is reflected a plane mirror

Note

Measure XY and the length of the person TH in Fig. 13.30.

The height of the mirror needed XY is always half the height of a person.

Example 13.6

The ray OA is incident on mirror M_1 as shown in Fig. 13.31. Draw a second plane mirror M_2 positioned such that the ray OA reflected by mirror M_1 is again reflected by the second mirror M_2 so as to reach the eye of the observer.

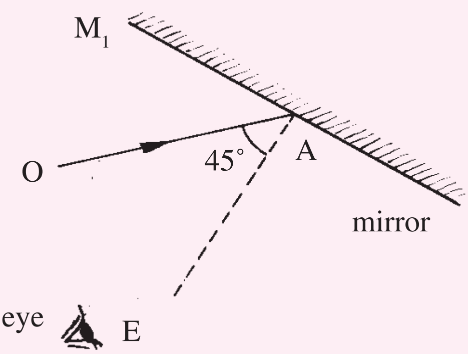


Fig. 13.31: An incident ray

Solution

$\angle i = 45^\circ$, hence $\angle r = 45^\circ$. AB is the reflected ray (Fig. 13.32(a)) and it has to be reflected by the second mirror in order to reach the eye. From the eye draw a line to meet the reflected ray AB at C (Fig. 13.32(b)). At C draw a line CN such that it divides $\angle ACE$ into 2 equal parts (Fig. 13.32(c)). Draw a line CM_2 at C such that it is perpendicular to the line CN (Fig. 13.32(d). This line M_2C represents the position of the second mirror M_2 so that the reflected ray can reach the eye.

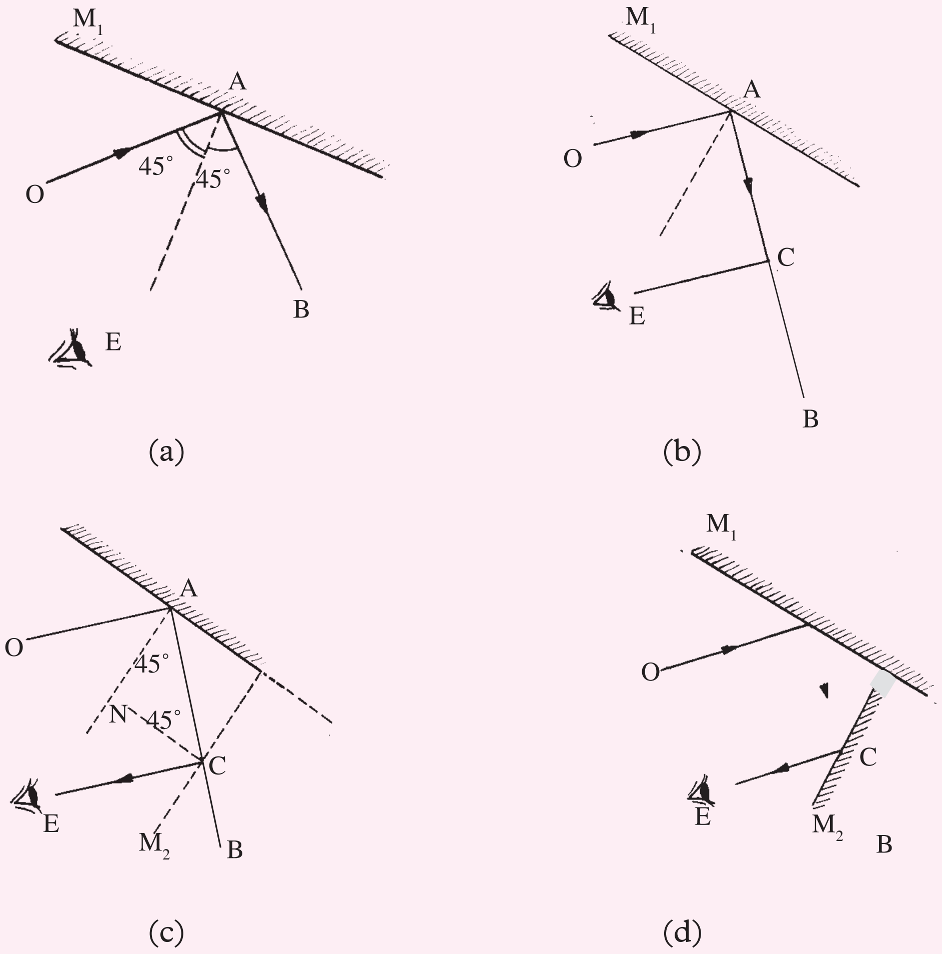


Fig. 13.32: A path taken by light rays when reflected

Exercise 13.3

1. **(a)** Define the terms: angle of incidence, angle of reflection, and the normal ray.
   (b) What is the relationship between the angle of incidence and the angle of reflection?
2. Fig. 13.33 shows a plane mirror on which the angle of incidence is 30°.

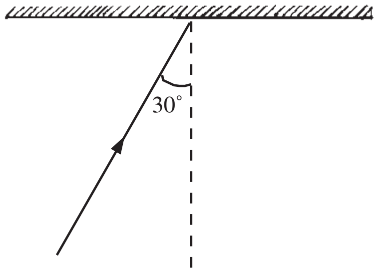


Fig. 13.33: An incident ray at an angle of 30°

(a) What is the angle of reflection?

(b) If the angle of incidence is increased to 40°, with the aid of a sketch diagram, show that the angle between the two reflected rays is 10°.

3. State the laws of reflection. Suggest a simple experiment to prove that the angle of incidence is equal to the angle of reflection.

4. Show the appearance of a print FG as seen in a plane mirror (Fig. 13.34).

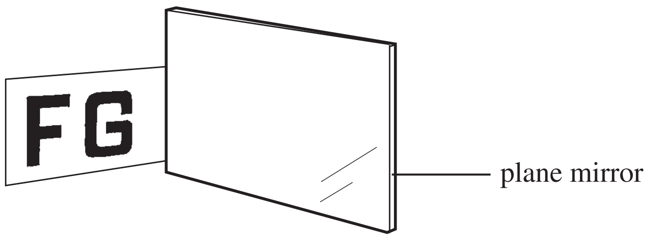


Fig. 13.34: A plane mirror

5. Draw a diagram to show how the eye of a person sees the image of a point object, formed by a plane mirror.

6. A ray of light AB is incident on a mirror M_1 at an angle of 30° as shown in Fig. 13.35. Copy and complete the diagram to show the path of ray AB after reflection from mirror M_2 and hence calculate the angle of reflection from the mirror M_2.

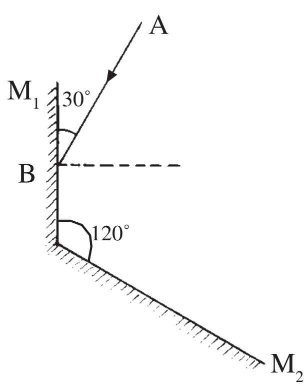


Fig. 13.35:A path taken by light rays when striking a mirror

7. The ray OA is incident on mirror M_1 as shown in Fig. 13.36. Draw a second mirror M_2 positioned such that the ray OA reflected by mirror M_1 is again reflected by the second mirror M_2 so as to reach the eye of the observer.

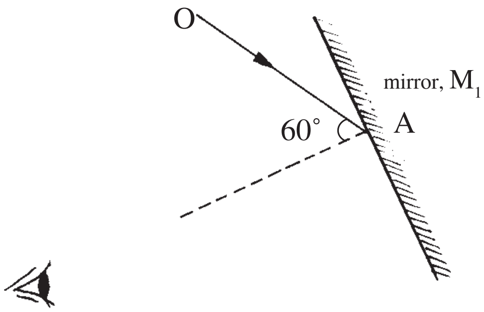


Fig. 13.36: An incident ray striking a mirror

Numbers of images formed by a plane mirrors at an angle

Parallel plane mirrors

Activity 13.15 **To investigate the images formed by parallel plane mirror**

Materials

- 2 plane mirrors
- Small object (e.g a small bulb)

Steps

1. Place two plane mirrors standing parallel to each other on a bench with the reflecting surfaces facing each other.
2. Place a small object on the bench between the two mirrors.
3. In turns, let each one of you in the group try to count the number of images formed for that object. What number do you get?
4. Try sketching how the images are formed by the two parallel mirrors.
5. Suggest where the concept being investigated in the activity is applied in real life.

From Activity 13.15, you should have noted that when a bright point object O (e.g. a small bulb of a torch light) is placed between two parallel mirrors M_1 and M_2 (Fig. 13.37), I_1 is the image formed by the mirror M_1 and I_2 is the image formed by the mirror M_2. I_1 (a virtual image) acts as an object in front of the mirror M_2 and an image $I_{1.2}$ is formed behind M_2. $I_{1.2}$ acts as an object in front of the mirror M_1 and an image $I_{1.2.1}$ is formed behind M_1.

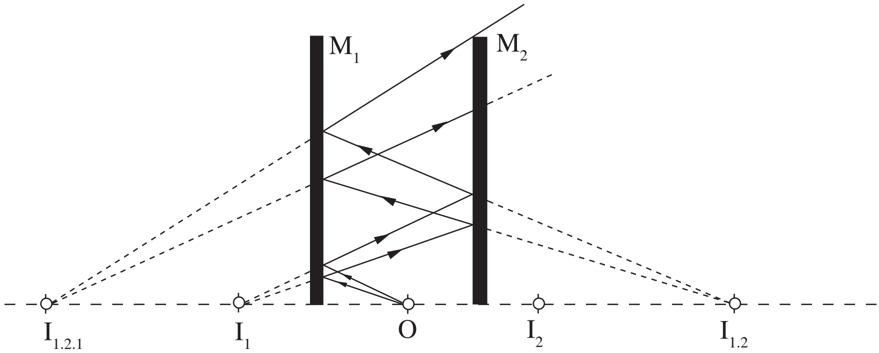


Fig. 13.37: Parallel mirrors

The image $I_{1.2.1}$ acts as an object in front of the mirror M_2 and forms another image and so on. In this way, the number of images formed is infinite (countless). But the images become dimmer as the distance travelled keep increasing with each reflection. It should be noted that the images of I_2 are not considered in the construction above.

This principle of multiple reflections is used in beauty parlours, tailor and barber shops, etc.

Plane mirrors inclined at an angle of 90°

Activity 13.16 **To find out the number of images formed by two plane mirror placed 90^0 to each other**

Materials

- 2 plane mirror
- An objects (e.g a stone)

Steps

1. Draw two lines which are perpendicular to each other i.e at 90°.
2. Place two mirrors along the two lines to touch each other at point of intersection of the lines.
3. Place an object between the two mirrors as shown in Fig 13.38.
4. Look through the two mirrors and count the number of images formed. What number do you see?

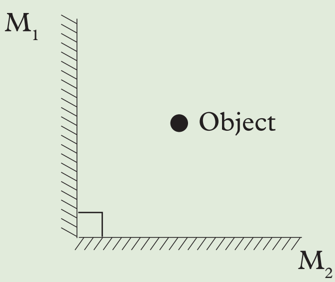


Fig. 13.38: Two perpendicular mirrors

O is a bright point object placed between two plane mirrors M_1 and M_2 as shown in Fig. 13.39. I_1 is the first image formed by M_1. I_2 is the second image formed by M_2.

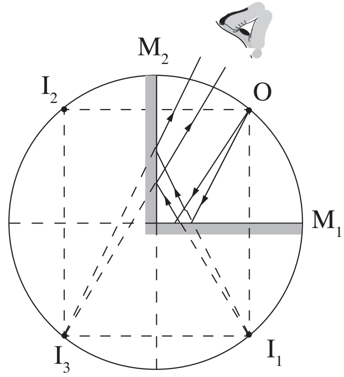


Fig. 13.39: Mirrors inclined at an angle of 90˚

The virtual image of I_1 in front of the image mirror M_2 forms an image I_3 behind the image of mirror M_2. Similarly the virtual image I_2 in front of the image of mirror M_1 forms an image behind the image mirror M_1, which coincides with the image I_3. Hence three images are formed.

Two plane mirrors inclined at an angle of 60˚

Activity 13.17 **To observe the images formation by two plane mirrors inclined at an angle of 60⁰**

Materials

- 2 plane mirrors
- An object (e.g a stone)

Steps

1. Draw two lines which are at angle of 60º to each other.
2. Place two mirrors along the two lines to touch one another at point of intersection of the line (Fig. 13.40).
3. Place an object between the two mirrors and count the numbers of images formed. What number do you get?

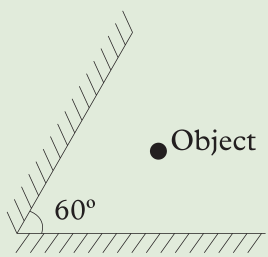


Fig. 13.40: Two mirrors inclined at an angle of 60º

4. Now, discuss with your partner Activities 13.17 and 13.18 and deduce a general formula for calculating the number of images formed when two plane mirrors are inclined at an angle.

O is a bright point object placed between the two plane mirrors M_1 and M_2 inclined at an angle of 60° as shown in fig. 13.41. Image I_1 is formed by M_1. Image I_2 is the second image formed by M_2.

The virtual image I_1 (in front of M_2) forms an image I_3 behind M_2. Similarly I_2 (in front of M_1) forms an image I_4 behind M_1. I_3 forms an image I_5 due to reflection at M_1 and I_4 forms an image due to reflection at M_2, which coincides with I5. Hence 5 images are formed.

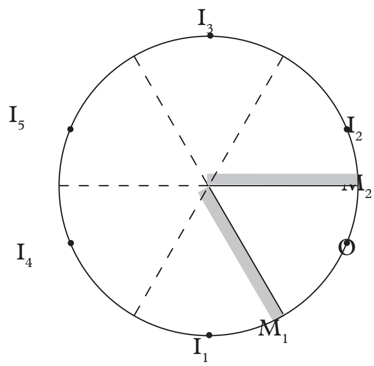


Fig. 13.41: Mirrors inclined at an angle of 60°

The formula to calculate the number of images formed, n, when two mirrors are inclined at an angle θ.

When angle θ is 90°, the number of images formed , n, is 3. i.e.

$$n = \frac{360^\circ}{90^\circ} - 1 = 3$$

When the angle θ is 60°, the number of images formed, n, is 5 i.e.

$$n = \frac{360^\circ}{60^\circ} - 1 = 5$$

In general if the angle between 2 mirrors is θ, the number of images formed is, n, is given by.

$$n = \frac{360^\circ}{\theta} - 1$$

13.9 Applications of reflection at plane surfaces

Activity 13.18 **To find out the applications of reflection at plane surfaces**

Materials

- Reference books
- Internet

Steps

1. Conduct a research from internet and reference books on the applications of reflection at plane surface.
2. In your research, identify the devices in which reflection is applied and how they work.
3. Note down the key points from your research.

From Activity 13.18, you may have established that reflection of light is applied in the working of a periscope among other devices:

Periscope

A periscope is a device which enables us to see over the top of an obstruction (e.g. a wall). As shown in Fig. 13.42, a periscope uses two plane mirrors kept parallel to each other and the polished surfaces facing each other. Each plane mirror makes an angle of 45° with the horizontal. Light from the object OB is turned through 90° at each mirror and reaches the eye.

The final image produced IM is virtual, erect and the same size as the object. The lateral inversion produced by the two plane mirrors cancel out each other.

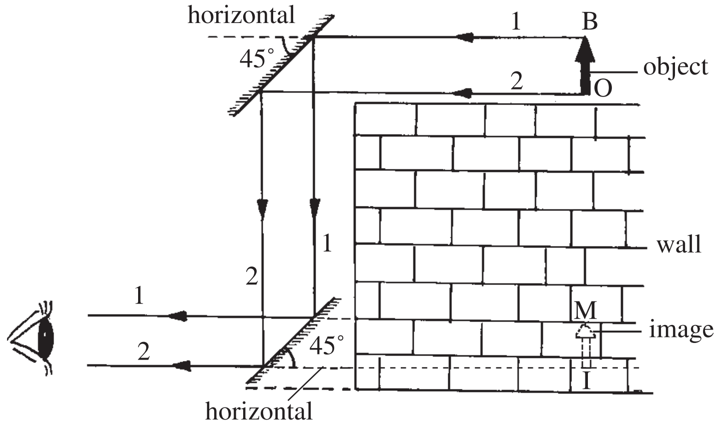


Fig. 13.42: A periscope

Exercise 13.4

1. **(a)** What is a periscope?
   (c) State the size and nature of the image formed by a periscope.
2. Draw a simple ray diagram to show the working of a periscope.

3. **(a)** Two plane mirrors are kept inclined to each other. Calculate the number of images formed for the following angles of inclination

(i) 120° **(ii)** 90°

(iii) 60° **(iv)** 30°

(b) Which of the above set up is used in the construction of a kaleidoscope?

4. A bright point object O is placed between two parallel plane mirrors M_1 and M_2 as shown in Fig. 13.43. (not drawn to scale).

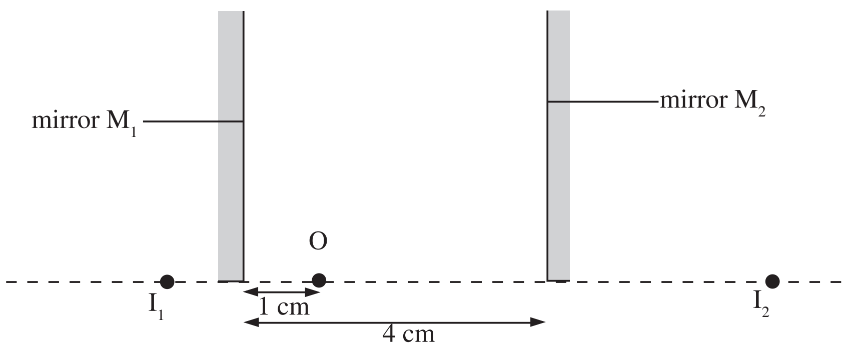


Fig. 13.43: Reflection of an object by parallel plane mirrors

For the object O, mirror M_1 forms a virtual image I_1 behind the mirror M_1. I_2 is the image of O in the mirror M_2. Show that the image of I_2 due to the mirror M_1 is 6 cm behind the image I_1.

13.10 Project work

Construction of pinhole camera

Suggested materials

An old cardboard shoe-box or a carton of size 40 cm × 15 cm × 12 cm, a sewing needle or a paper pin, grease proof paper, tracing paper or frosted glass, black paint and brush or black paper (optional), a black cloth big enough to cover the box and the head of the viewer (optional).

Assembly

- If black paint is available, paint the inside of the box black or stick black paper inside. Pierce a small hole with the tip of a needle or pin on one side. Cut a small opening on the opposite side and paste a grease proof paper or a tracing paper (any translucent material will be sufficient).

How to use the assembled model

- Place the box so that the pin hole faces a bright object, say a building on a sunny day (or a candle in a semi dark room) . View the translucent screen (Fig. 13.44).
- Cover the box and the head of the viewer with a black cloth to cut off any stray light entering the box or falling on the translucent screen.

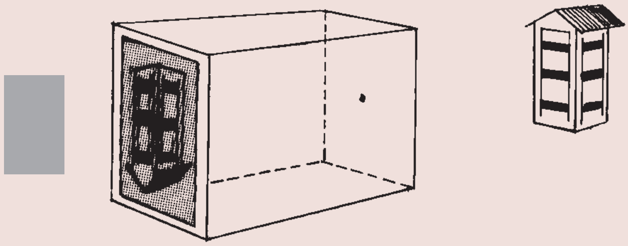


Fig. 13.44: A pinhole camera

Construction of a periscope

Working model

Materials needed

Retort stands, boss and clamp, small pieces of wood or old erasers to hold the mirrors firmly without breaking, candle.

Assembly

- Set up the two mirrors at an angle of 45˚, with the horizontal and the silvered surfaces facing each other as shown and look for the image (Fig. 13.45).

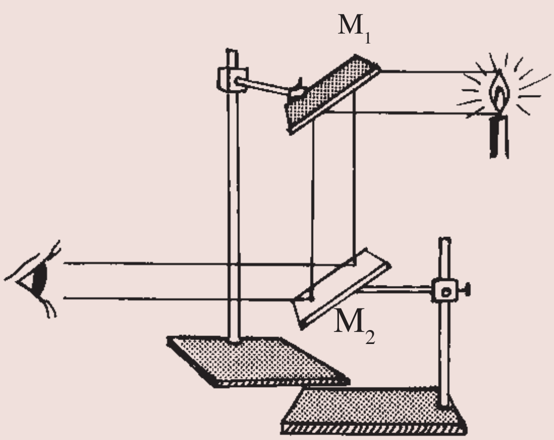


Fig. 13.45: A model periscope

Project: Construction of a periscope

Suggested materials

A narrow long cardboard box (e.g. tennis ball/ shuttle cock containers) or a carton of cardboard of size 40 cm × 5 cm × 5 cm, two plane mirrors (5 cm × 5 cm), adhesive tapes, a razor blade or a pair of scissors.

Assembly

- Insert the two mirrors, one at the top and the other at the bottom at an angle of 45° to the line joining the mirrors (mirror adjustments can be made later when the image is viewed). Cut suitable openings near each mirror (Fig. 13.46).

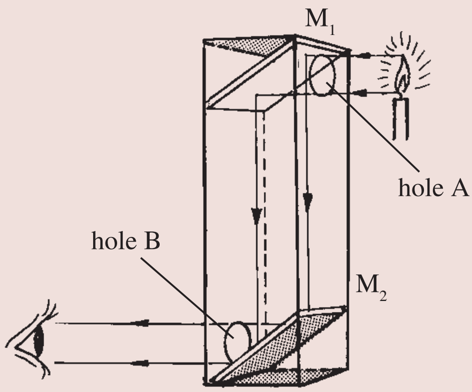


Fig. 13.46: A periscope

How to use the constructed periscope

A candle is held near the opening A and the image is seen through the opening B.

Unit summary and new words

- Light is a form of energy in wave form.
- Light helps us to see objects.
- Light travels in a straight line. This property of light is called the rectilinear propagation of light.
- A substance through which light can pass through is a medium.
- A shadow is a region where light does not reach.
- Formation of shadows and pinhole cameras are direct evidences for the rectilinear propagation of light.
- Magnification (m) $= \dfrac{\text{height of the image}}{\text{height of the object}} = \dfrac{\text{image distance}}{\text{object distance}}$

- A plane mirror bounces light back into the same medium. The angle of incidence is equal to the angle of reflection.
- A plane mirror forms an image of the same size as the object. The image is erect and laterally inverted. The distance of the image from the mirror is the same as the distance of the object from the mirror.
- Periscopes use the properties of light reflected in plane mirrors.

Unit Test 13

1. Uwamahoro stood before a plane mirror in their house. Her image was upright. Which row shows the correct characteristics of the image formed by the plane mirror?

	Laterally inverted	Magnified	Virtual
1.	No	Yes	Yes
2.	Yes	Yes	Yes
3.	Yes	No	Yes
4.	Yes	No	No

Table 13.2

2. What is meant by reflection of light?

3. State the laws of reflection.

4. The diagram in Fig. 13.47 shows a ray of light reflected from a plane mirror. What is the angle of reflection?

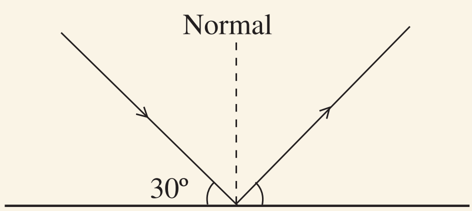


Fig. 13.47: A reflected ray

5. Calculate the number of images formed when two plane mirrors are inclined at:

(a) 30º **(b)** 150º

(c) 75º **(d)** 45º

6. A ray of light strikes a plane mirror as shown in Fig. 13.48. Copy the diagram and draw the path of the reflected ray. Mark clearly any two angles which are equal.

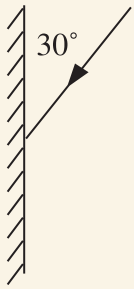


Fig. 13.48: A ray striking a mirror at 30°

7. Draw the reflected ray of light for the incident ray shown in Fig. 13.49. Now draw a second mirror like the first mirror arranged so that the reflected ray is again reflected. The reflected ray should be parallel to the original path but in the opposite direction.

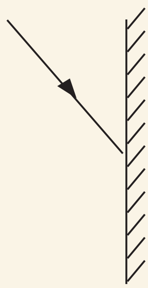


Fig. 13.49: A ray striking a mirror

8. A triangular object ABC is on one side of a vertical mirror (Fig. 13.50). Draw the image formed by the mirror.

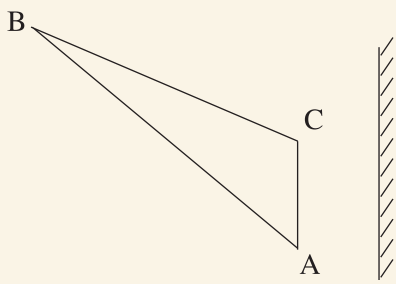


Fig. 13.50: A triangular object infront of a mirror

9. Fig. 13.51 shows the path of light PQRS in a simple optical fibre which undergoes reflection. Calculate the angle between the rays PQ and RS.

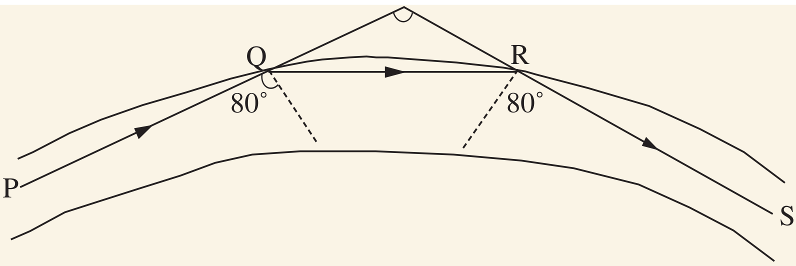


Fig. 13.51: A path taken by a light ray

10. Distinguish between solar and lunar eclipses.

11. **(a)** Describe a project on how to make a periscope.

(b) Explain how a captain uses a periscope to see oncoming ship.

12. Draw rays from the object OB to show the image formed by a pinhole camera on a screen (Fig. 13.52). Is the image upright or inverted? Is the image real or virtual?

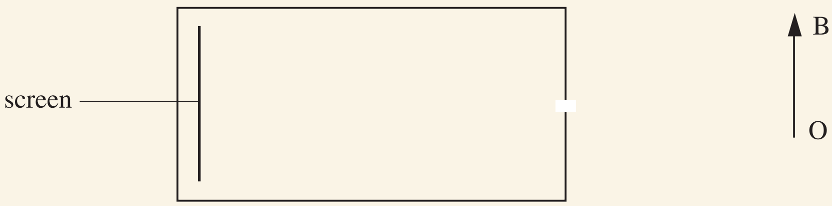


Fig. 13.52: Object infront of a pinhole camera

13. State and explain the effect on the image formed in a pinhole camera if:

(a) The object distance is decreased.

(b) The length of the box used is decreased.

14. A pinhole camera forms an image of size 10 cm. The object is 5 m tall and 10 m away from the pinhole. Calculate the length of the pinhole camera.

15. Describe how a kaleidoscope works.

GLOSSARY

- Derived quantities –are quantities that are expressed in terms of fundamental quantities.
- Instantaneous speed –is the speed at any given instant in a body' motion.
- Average speed – is the total distance covered by a body over the total time.
- Upthrust- the upward force that a liquid or gas exerts on a body immersed in it.
- Inertia –is the state of reluctance of a body a change to its state of motion.
- State of equilibrium- is the state of balance of a body.
- Centre of gravity - is the point where the whole weight of a body appear to act from.
- An element - is a substance which cannot be split into a simpler substance.
- Ductility -the ability of a substance to be drawn into the wire (stretched into a wire).
- Elasticity-is the tendency of a material to return to its original size and shape after a tensional or compressional force acting on it is withdrawn.
- Kinetic theory of matter - is the theory that states that matter is made up of tiny discrete individual particles that are continuously in random motion.
- Melting - is the process by which a solid is changes to a liquid at a constant temperature.
- Viscosity - is a measure of how much a fluid resists movement of an object through it.
- A magnet - is piece of metal with either natural or induced properties of attracting another metal objects or another magnet.
- Magnetic poles - the points in a magnet where the force attraction or repulsion is strongest.
- A magnetic field - is the region around the magnet where magnetic effect is experienced.
- Electrostatic- study of static charges.
- A charge - a characteristic of matter that expresses the extent to which it has more or fewer electrons than protons and vice versa.
- Electric field strength - the force per unit charge.
- Electric potential -is the work done in bringing a unit positive charge from infinity to that point.

- Charge density is the quantity of charge per unit area of a surface of a conductor.
- Earthing- is the process of connecting a charged body to the ground in order to channel the negative charges to/from the ground.
- Conductors- materials that allow charges (electrons) to pass through them.
- Insulators- materials that do not allow the charges (electrons) to pass through them easily.
- Electrodes-aconductor through which electricity enters or leaves an object, substance, or region.
- Electrolytes - are solutions that are good conductors of electric current charge.
- Electric current. The rate of flow of charges from one point to the other in an electric circuit.
- Electrolysis - is the process through which chemical changes takes place in a liquid due to the flow of electric current is through them
- A beam of light - a collection or group of light rays.
- Translucent materials–These are materials that partially allow the light falling on them to pass through them.
- Magnification - is how big or how small the image is compared to the object.
- Umbra- is the region of complete darkness.
- Penumbra- is the region of partial darkness.