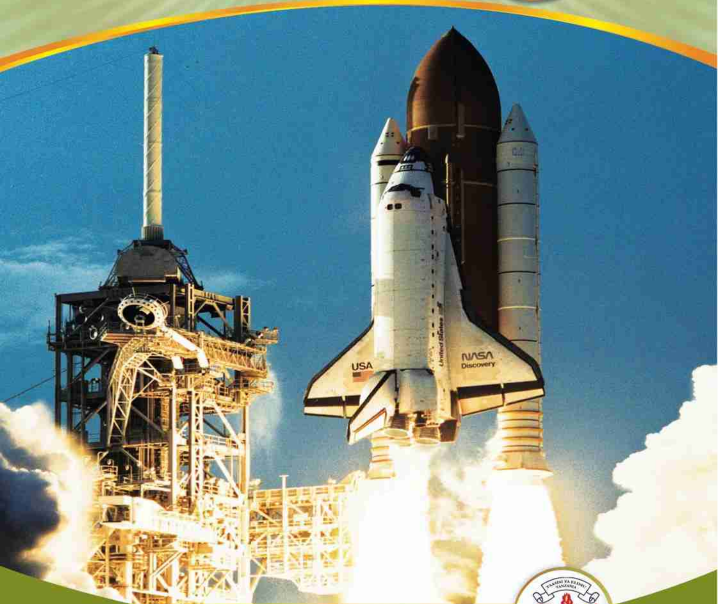
Physics

for Secondary Schools

Student's Book Form One



Tanzania Institute of Education

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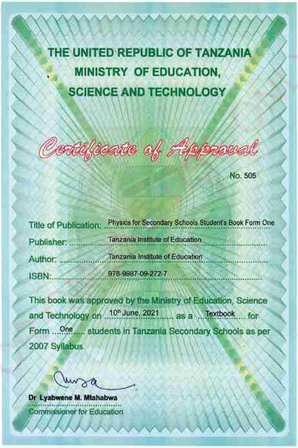
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Dr Aneth A. Komba
Director General
Tanzania Institute of Education

Preface

This textbook, *Physics For Secondary Schools* is written specifically for Form One students in the United Republic of Tanzania. This book prepared in accordance with the 2007 Physics Syllabus for Secondary Schools, Form I-IV, issued by the then Ministry of Education and Vocational Training.

The book consists of ten chapters, namely: Introduction to Physics, Introduction to laboratory practice, Measurements, Force, Density and relative density, Archimedes' principle and law of floatation, Structure and properties of matter, Pressure, Work, energy, and power as well as Introduction to light.

Each chapter contains illustrations, activities and exercises. Your are encouraged to do all the activities and exercises together with other assignments that will be provided by the teacher. Doing so will enhance your understanding and promote the development of the intended competencies.

Tanzania Institute of Education

Chapter One

Introduction to Physics

Introduction

Physics as a subject deals with the study of matter, energy, and the interaction between them. Physics deals with both very large objects like planets and very small ones such as atoms. In this chapter, you will learn concepts and applications of physics in daily life. The competencies developed through learning physics will enable you to apply physics principles and skills to solve daily life problems. You will also be able to relate physics to other branches of natural sciences.

Concepts of physics

The universe is a totality of matter, energy, space, and time. The word universe originates from a Latin word 'universus' which means 'all or everything'. It can therefore be literally referred to as everything surrounding us, within, near, far and beyond our planet, solar system, and galaxy in which our solar system belongs (the Milky Way Galaxy). We are part of the universe. Science is the major tool of studying and exploring the universe. Science begins with inquiries such as what is the universe? What is its origin? What makes up the universe? How does it change with time? Why does the sky look blue? And why does iron turn red when heated? In order to answer such questions, the applications of theories, principles and laws of science are required.

Physics falls under a broad category of natural science, which is divided into three main branches, namely physics, chemistry, and biology. Physics is the branch of science which deals with the study of matter, energy and their mutual interactions.

The word physics originated from a Greek word 'Physikos' which means 'nature'. Physics involves the study of physical and natural phenomena around us. Examples of these phenomena are occurrence of eclipse, causes of sunset and sunrise, the formation of rainbow, and volcanic erruption, as shown in Figure 1.1 and many more.

(a) Eclipse

(b) Sunrise and sunset

(c) Formation of rainbow

(d) Volcanic eruption

Figure 1.1: *Natural phenomena*

Physics is the branch of science that deals with the study of matter, energy and the mutual interactions between them. A person who studies physics is known as Physicist.

In physics, matter is studied in relation to its motion, as well as space and time. Matter is defined as any substance which has mass and occupies space. Physics as a subject uses concepts like force, energy, and mass to explain different phenomena. In doing so, students of physics get to learn more about matter, energy and how they interact with each other. Energy, for example, may take the form of heat, light, or electricity. Among the most important forms of energy today is electricity which can be generated in many ways including water falls and combustion of natural gas. Figure 1.2 shows the power generation station at Kinyerezi, Dar es Salaam.

Figure 1.2: *Kinyerezi power generation station*

Task 1.1

Identify ten (10) items around your school and home environment which use the concepts of physics in their operation. Present your results in class.

Physics is known to be a fundamental subject among all branches of science. The content of physics is very broad and wide in such a way that it cannot be covered within a single domain. Therefore, for the aims of physics to be attained, physicists have divided physics into a number of branches. The following are some of the branches of physics:

Mechanics

Mechanics is the branch of physics that deals with objects are either stationary or in motion, the influence of forces acting on them and their impacts. Under this branch, aspects like linear, circular, and oscillatory motions of objects as well as fluids and their impacts are studied.

Heat

Heat is one among the forms of energy. Heat can be transferred from one point to another by conduction, convection or radiation. This branch of physics describes the phenomena of matter when heat energy is supplied to it. These properties include the expansion of matter, changes of states of matter, and the anomalous expansion of water.

Light

Light is a form of energy. The sun is the main source of light. Light travels in a straight line. We see objects like mountains or water bodies with the aid of light. Our eyes enable us to see objects when light falls on them.

Electromagnetism

Electromagnetism is the branch of physics which deals with the interaction between electric and magnetic fields. It has a wide range of applications in our daily life, including generation of electricity and fabrication of motors. Life could be difficult without electricity.

Astronomy

Astronomy deals with the study of the universe (cosmos) and everything contained in it. The word astronomy originates from two Greek words, 'astron' which means 'star' and 'nomos' which means 'laws'. The Greeks referred to it as the study of laws of stars. Astronomy seeks to answer inquiries such as how celestial objects such as moons, planets, stars, and galaxies originate and change with time.

Geophysics

Geophysics is the branch of physics which deals with physical processes and physical properties of the Earth and its surroundings. It speculates the interior and exterior structure of the earth in terms of physical and chemical properties.

Electronics

Electronics is the basis of modern technology. It involves the study of circuits that are made of semiconductor components like, diode, transistor, and integrated circuits. Most of communication devices are made of semiconductor materials. Examples of devices that use the principles of electronics are television, radio, Light Emitting Diode (LED) lamps, mobile phones, cameras, printers, and computers.

Physics of the atom

This is a branch of phyics which deals with the behaviour of particles that make up the atom and accompanying energy. We learn about radiation which is emitted by the atom during disintegration and how we can protect ourselves from harmful radiation.

Relationship between physics and other subjects

Physics relates with many subjects in terms of either direct applications or the principles governing the working of instruments used in a given subject. Physics is closely related to chemistry, biology and mathematics. Physics is also related to earth sciences such as geology and meteorology. The relationships between physics and other subjects are discussed below.

Physics and chemistry

Chemistry principles are used to produce pesticides, insecticides, (see Figure 1.3) perfumes, and fertilizers. Then, physics principles are applied in packaging them so that they can be released in a controlled manner from compressed cylinders or sprays. Also, chemists use equipment designed and constructed using physics principles to achieve extraction of chemicals.

Figure 1.3: *Pesticide and insecticide*

Physics and biology

A number of instruments such as microscopes used in biology are designed and constructed using physics principles. Processes such as photosynthesis, conversion of matter into energy, and even the transfer of heat used in biology can be well explained by using laws of physics.

Physics and mathematics

Mathematics is a working tool of almost all disciplines. All branches of mathematics for instance, algebra, trigonometry, and vectors are applied to study physics. More often mathematical relations are used in expressing physics concepts. For instance, force, F is directly proportional to extension, e. This concept can be expressed mathematically as:

$$F \propto e$$

$$F = ke$$

where k is a constant of proportionality. A graph of force, F against extension, e is shown in Figure 1.4.

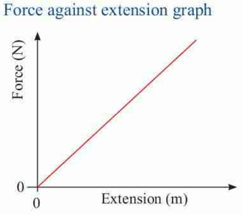
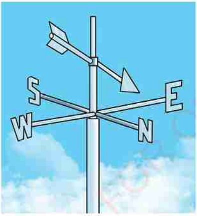


Figure 1.4: *Graph of force against extension*

Physics and meteorology

Meteorology deals with the study of weather and climate. Meteorologists use an instrument like rain gauge in Figure 1.5 (a) which is designed and constructed using the principles of physics to measure rainfall. A wind vane in Figure 1.5 (b) uses phyics principles to measure direction of the wind.

(a) Rain gauge



(b) Wind vane

Figure 1.5: *Instruments used in meteorology*

Physics and astronomy

Astronomy, which is the scientific study of, for example, the moon, sun, stars, and the planets in the solar system, involves the concepts of physics as shown in Figure 1.6. The physical laws can be applied when studying the size, position, and motion of planets and stars. Space objects are governed by the laws of physics. In addition, properties of the bodies of space objects are determined by the principles of physics.

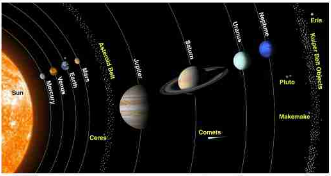


Figure 1.6: *Solar system*

Task 1.2

In a group of four students, discuss the relationship between physics and other natural science subjects. Present your findings in class.

Importance of studying physics

Generally, physics helps us to understand nature. The following are examples of its importance.

(a) The study of physics enables a person to answer questions about physical properties of matter.

(b) Physics helps to answer questions like why some materials are attracted by magnets while others are not, why the sky looks blue, and why clouds look white?

(c) The study of physics enables us to acquire skills that are required in different professions such as engineering, technology, teaching, and architecture.

(d) The study of physics enables us to acquire knowledge and skills that are applied in designing and constructing different items which are useful in our daily life. These include, simple machines such as pulleys inclined planes, and complex ones like bicycles, escalators, and bulldozers.

(e) Physics is fun. It helps to understand the applications of physics principles in sports and games.

(f) Physics helps to understand the working principles of home appliances such as electric iron, grinder, vacuum flask, thermos flask, cooking stoves, television, and radios.

Application of physics in daily life

Discoveries in physics have led to various inventions that influence our lives. Electricity, motor vehicles, and electronics in general, are results of scientific and technological advancement. The study of how to control tiny particles like electrons and protons led to the discovery of electronics which in turn led to the production of items like calculators and computers, as shown in Figure 1.7. By so doing, physicists have been able to give the products of their acquired knowledge and skills back to the society.

(a) Calculator

(b) Computer

Figure 1.7: *Electronic equipment*

Other applications of physics which can be evidenced in daily life situations include the following:

At home

All tools and machinery that we use in our homes to simplify work are made by applying the laws of physics. These include crowbars, hammers, door handles, cutlery, hinges, car jack, and pulley. For example, a sprayer and a garden shear is used when working on a home garden as shown in Figure 1.8.

(a) Garden shear

(b) Garden sprayer

Figure 1.8: *Tools used for working on a home garden*

Similarly, it would be difficult to get underground water to the surface without a pulley system and water pumps. Pulleys are used for drawing water from wells by applying small force as shown in Figure 1.9.

Figure 1.9: *Drawing water from a deep well*

The physicists have reduced the cost of electricity by applying physics principles in designing and constructing energy saving bulbs such as Compact Fluorescent Lamp (CFL) and Light Emitting Diodes (LED) as shown in Figure 1.10.

(a) Compact fluorescent lamp (CFL)

(b) Light emitting diode (LED) lamp

Figure 1.10: *Energy saving lamps*

In medical field

Machines are used in hospitals for diagnosis and treatment of various diseases. These machines are designed and constructed using physics principles. They include, X-ray and ultrasound machine. Figure 1.11 shows an ultrasound machine. The knowledge used in handling and even using these machines is based on the knowledge and skills acquired in physics. This means that those who operate these machines must have knowledge of physics.

Figure 1.11: *Ultrasound machine*

In addition, premature babies are nursed in incubators, as shown in Figure 1.12(a), until they attain a safe weight and physical condition for them to survive on their own. The conditions in incubators are modified to an extent that they almost resemble a mother's womb in order to support the survival of the babies. Syringes and needles for administering injections, warm clothing, feeding tubes and bottles are all applications of physics in the medical field.

Figure 1.12(b) shows various tools used in medical field.

(a) Infant incubator

(b) Syringe and injectable medicine

Figure 1.12: *Medical equipment*

Sources of energy

Some processes and machines help us to obtain energy for our daily use. These machines make use of various laws of physics to give us different forms of energy. For example, batteries, generators and solar cells, shown in Figure 1.13, provide electrical energy. This energy is used in charging mobile phones, powering radios, and televisions. A car battery provides the energy needed in a car. When devices like bulbs are connected to these sources, they provide light energy for our daily use.

(a) Battery

(b) Generator

(c) Solar cell

Figure 1.13: *Sources of energy*

Transport

Application of the laws of physics such as motion and frictional forces ensure vessels used in transportation like aeroplanes, trains, ships, cars and bicycle, are able to move, brake and stop when necessary. Figure 1.14 shows transport vessels which operate because the laws related to friction, flotation, and balance are observed and applied accordingly.

(a) Aeroplane

(b) Train

(c) A cargo ship

Figure 1.14: *Transport vessels*

When these laws are disobeyed, ships sink and trains derail. Ships and boats have refrigerators and air conditioners that function through the application of the laws of physics. Heat is removed from the fridge by the refridgerant and prevented from entering into the fridge by using insulating materials such as a rubber strip attached to the fridge door.

Communication

Communication is important to human life as it keeps us informed of day-to-day happenings. Devices used in communication systems such as a mast, telephones, satellite dish, antenna, and modems, as shown in Figure 1.15, are used for accessing the internet, television, and radio signals using physics principles. Telecommunication transmitters and receivers relay information. The knowledge of physics is essential in constructing these instruments.

(a) A communication mast

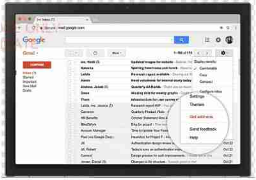
(b) A telephone set

(c) A satellite dish

Figure 1.15: *Communication equipment*

Short messages (SMS) through mobile phones, electronic mails (emails), and fax messages from fax machines as shown in Figure 1.16 are all reliable means of communication. All these are results of the application of the knowledge acquired from the study of physics.

(a) A mobile phone displaying sms



(b) A computer displaying emails

(c) Fax machine

Figure 1.16: *Communication devices*

Entertainment

Physics has enabled people to enjoy a variety of leisure activities as it is evident in camera, exercise machines, inflated balloons, and bouncing castles, as shown in Figure 1.17, and other sports equipment. Inflated balloons and bouncing castles are used to entertain children.

(a) Camera

(b) Exercise machine

(c) Bouncing castles

Figure 1.17: *Equipment used for recreation*

Music and pictures are recorded on tapes or compact disk commonly referred to as CD. They are then listened or watched on televisions using Visual Compact Disk (VCD) player, Digital Video Disk (DVD) or USB drive. The recording process utilises physics principles. Figure 1.18 shows DVD player and other accessories, and Compact Disk, respectively.

(a) Digital Video Disk (DVD) player

(b) Compact disk (CD)

Figure 1.18: *Musical equipment*

Industry

Physics principles and laws have enabled industries to assemble, calibrate, and use highly accurate instruments. Physics can be applied in various industries such as construction, manufacturing, and automobile industries. Many instruments used in different industries use the laws and principles of physics in their operation. Examples are, sawmills used for cutting wood, crane used for lifting heavy loads, and spanner used in tightening and loosening nuts and bolts.

In schools

In schools, equipment such as computers, photocopy machines, printers, projectors, language translating devices, telescopes, cameras, and binoculars, use the knowledge of physics.

In addition, instruments and apparatus used in school laboratories are made using the knowledge and skills acquired in physics. Examples of such apparatus and instruments are shown in Figure 1.19. Instruments should meet certain specifications or standards that are universally accepted. This is to enable the instrument to give the same standard or common measured value when used throughout the world.

(a) Voltmeter

(b) Tongs

(c) Tripod stand and wire gauze

Figure 1.19: *Laboratory apparatus*

Generally, physics is applied in many fields. Laws of physics determine how structures like bridges, roads, and railways are built for the safety of passengers.

Activity

Aim: To demonstrate applications of physics.

Materials: A plane mirror, a scale balance, different masses (5 g, 10 g, 15 g), flagpole

Procedure

Part I:

1. Look at your image in a plane mirror.
2. Observe how your face looks like.

Part II:

1. Prepare a beam balance.
2. Place a 10 g mass on one side and a 15 g mass on the other side of the scale balance.
3. Record your observations.
4. Now add a 5 g mass on the side with 10 g and observe what happens.

Part III:

1. Go out of the classroom and observe the top of the flagpole.
2. Look at the full length of the string used to host the flag and record your observations.

Questions

(a) How did your face look like? Explain.

(b) From your results, explain what happened in step 4.

(c) How are the scouts in your school able to raise the flag to the top of the pole? Explain.

Plane mirrors always form images of their observers. Therefore, a person looking at a mirror will obviously see an image of himself or herself. A scale balance leans on the side that has more mass than the other. This is useful when measuring some items such as sugar and flour. A flag is raised to the top of a flagpole using a string that is rotated on a pulley. The string is then fastened at the bottom. All of these are applications of physics in daily life.

Chapter summary

1. Physics is the study of the relationship between matter and energy.
2. People who study and work professionally in the field of physics are known as physicists.
3. Physicists use results from experiments to develop scientific laws that are normally expressed in the language of mathematics.
4. Physics is regarded as the 'fundamental' of natural sciences and it is related to other subjects. These subjects include, chemistry, biology, and mathematics.
5. Physics is applied in many areas of our lives. Some of the areas where it is evident are homes, hospitals, schools, communication, transport, industry.
6. Physics is important since it explains the behaviour of the universe while answering many questions. It is also important in:
   (a) career development;
   (b) manufacturing industries; and
   (c) physics practicals.

Revision exercise 1

Section A

Choose the most correct answer

1. People who study physics are known as
   (a) physikos.
   (b) scientists.
   (c) physicists.
   (d) philosophers.
2. Physics is ________
   (a) a quantitative science.
   (b) an experimental science.
   (c) the most basic science.
   (d) analytical science.
3. Which of the following best describes why the knowledge of physics is necessary to understand all other sciences?
   (a) Physics explains how energy passes from one object to another.
   (b) Physics explains how gravity works.
   (c) Physics explains the motion of objects that can be seen with the naked eye.
   (d) Physics explains the fundamental aspects of the universe.
4. The following represents a set of branches of physics except:
   (a) agrobusiness, mechanics, and molecules.
   (b) heat, optics, mechanics, and electricity.
   (c) biophysics, geophysics, chemophysics, and astrophysics.
   (d) wave, physics of the atom, and radionuclides.

5. Match the correct statement from Column B that corresponds to the item in Column A, then write the letter in the table provided.

Column A	Answers	Column B
1. Physics 2. Chemistry 3. Biology 4. Geography		A. deals with the study of living things B. deals with the behaviour of matter C. deals with the study of man and his environment D. deals with the study of matter in relation to energy

6. Write **TRUE** for correct statements and **FALSE** for incorrect statements in the space provided.
   (a) Physics is expressed in Mathematics. ________
   (b) Astronomy is not a branch of Physics. ________
   (c) Scientific laws are obtained from observations made during experiments. ________

Section B

7. Explain the meaning of the following terms:
   (a) Physics.
   (b) Physicist.
   (c) Matter.
8. State the importance of physics in your daily life.
9. Describe four areas where physics is applied.
10. What is the importance of mathematics in physics?
11. Some of the transport vessels that rely on the laws of physics are:
    (a) ________ (b) ________
    (c) ________ (d) ________ .
12. Your classmate has an urgent message to relay to his parents. If the message were to appear in writing, which methods would you advise him to use? Name four.
    (a) ________ (b) ________
    (c) ________ (d) ________ .
13. Explain how you will apply physics in your daily life.
14. Describe any four branches of physics.
15. Write any four applications of physics in the following areas: Hospital, transport, aviation, meteorological agencies.
16. Name any four common musical instruments that are used at your surroundings.
17. Name any six celestial objects you can observe in a clear night sky.
18. 'Physics is a fun subject'. What does the statement mean?

Chapter Two

Introduction to laboratory practice

Introduction

Physics as an experimental subject; it requires a laboratory and different apparatus or equipment that need to be handled with great care. Therefore, good laboratory practices in physics laboratory must be implemented to ensure safety among teachers, students, laboratory technicians, and other laboratory users. In this chapter, you will learn about laboratory rules, safety, and basic principles of scientific investigation. The competencies developed will enable you to identify different safety signs and apply the best ways of handling different laboratory apparatus and equipment as well as home electrical appliances. Moreover, you will acquire skills in providing First Aid to victims of accident that may occur in the laboratory, in public places, and at home.

Concept of laboratory

A laboratory is a special room that is designed and equipped for carrying out scientific experiments for the purpose of study or research. More specifically, physicists perform experiments in the physics laboratory which is designed for this purpose. Thus, a physics laboratory has special tools and instruments commonly known as apparatus (equipment), which are used in carrying out experiments. Figure 2.1 shows a physics laboratory with several equipment used in conducting physics experiments.

Figure 2.1: *Physics laboratory with several apparatus*

A school laboratory differs from other school facilities such as classrooms, library and staffroom in design and use. A laboratory is usually supplied with water, sources of heat, electricity, and drainage system. It must also be well ventilated and with enough light, as in Figure 2.2.

Figure 2.2: *Laboratory room*

Applications of physics laboratories

A physics laboratory is essential in the development of skills in physics. The following are some of the benefits of physics laboratory activities.

1. To provide an experimental foundation for the theoretical concepts introduced in lessons. This will help students to verify and prove theoretical concepts. For example, the verification of Hooke's Law.
2. To familiarise students with experimental apparatus/equipment and scientific methods of data collection and analysis.
3. To teach how to make careful experimental observation and how to draw final conclusion from the data.
4. To learn how to write a good scientific report which communicates scientific information in a clear and concise manner.
5. To introduce new concepts of physics which have a wide application in daily life. An example of such concepts is the Mpemba effect, 'Hot water freezes faster than cold water'.

Laboratory rules and safety

A standard list of basic laboratory safety rules is given under this section. These rules must always be followed in every laboratory that uses dangerous and hazardous materials. That is, the rules must be observed before, during and after experiment. These basic rules control the behaviour, hygiene and safety in order to avoid accidents in the laboratory. Note that, sometimes there are specific safety rules for particular equipment, experimental processes, and materials.

Rules in a physics laboratory

The following are rules to be observed while using the physics laboratory.

1. Do not enter the physics laboratory without permission from your teacher or laboratory technician.
2. Do not do any experiment unless your teacher or technician permits you to do so.
3. Do not start an experiment before you get information about the proper procedure to be followed.
4. Follow instructions carefully in all experiments to avoid damaging the apparatus or getting wrong results.
5. Handle all the apparatus with care to avoid damage.
6. Avoid handling apparatus and chemicals in the laboratory until you are asked to do so by your teacher or laboratory technician.
7. Avoid running, screaming, or playing in the laboratory.
8. Avoid tasting, eating, or drinking anything in the laboratory.

9. While you are in the laboratory, keep the windows open for ventilation.
10. Do not touch any electrical equipment with wet hands.
11. Before leaving the laboratory make sure that all gas and water taps are well closed.
12. All exits in the laboratory must be cleared of any obstruction.
13. In case of an emergency, walk out quickly in a calm and orderly manner through recommended exits.
14. Arrange the materials you need to use in an orderly way.
15. Keep the laboratory apparatus or equipment away from the edges of the working benches.
16. Never use an open flame to heat inflammable materials.
17. Never attempt to blow out a fire even a small one.
18. Report all accidents and injuries to the teacher or laboratory technician.
19. Never use bare hands to handle hot objects.
20. Never use your bare hands to pick up pieces of broken glass.
21. Dress appropriately for the laboratory practical. Wear shoes with hard soles and good treads to protect your feet against sharp objects and to avoid slipping. Always wear a laboratory coat when conducting experiments.
22. Do not use dirty or broken apparatus.
23. Solid wastes should not be disposed off in the sinks.
24. Clean the working areas before leaving the laboratory.
25. Wash your hands with water and soap after performing an experiment.

Safety measures in a physics laboratory

In addition to laboratory rules, all those involved in performing physics experiments in the laboratory must be aware of some safety measures. These measures will reduce risks in the laboratory to manageable levels. The following is a list of vital safety measures or features of a good laboratory.

(a) A physics laboratory should be well ventilated and its doors should be open outwards.

(b) Fire extinguishers should be fitted in accessible positions as shown in Figure 2.3. They should also be in good working condition including clear instructions for use.

Figure 2.3: *Proper position of fire extinguisher*

(c) Laboratory floors should not be polished as this will make them slippery.

(d) An adequately equipped First Aid kit should be placed in every laboratory.

(e) Cabinets and drawers should be included in the design of a laboratory so as to be used for storing apparatus as in Figure 2.4.

Figure 2.4: *Laboratory fixtures and fittings*

Task 2.1

In groups of four students,

(a) Identify and list ten rules to be observed while using a physics laboratory (Use Manila paper and marker pen, hang the list in the laboratory).

(b) Discuss the importance of safety measures in a physics laboratory. Ask your teacher for further advice.

First Aid

Though we always try to avoid accidents in a science laboratory, sometimes they do occur. When an accident occurs, we have a duty of taking immediate actions to assist the victims. First Aid is first and immediate assistance or care given to a sick or injured person before getting professional medical help. First Aid is important due to the following reasons:

(a) it helps to save life;

(b) it prevents the victim's condition from becoming worse;

(c) it promotes recovery by bringing hope and encouragement to the victim;

(d) it helps to reduce pain and suffering; and

(e) it prevents infection.

A person who gives First Aid to the victim is called First Aider.

First Aid kit

The First Aid kit is a small box containing items that are used to give help to a sick or injured person. The box is usually labelled "FIRST AID KIT" as shown in Figure 2.5 and stored in a safe place where it can be easily accessed.

(a) First Aid kit

(b) Items in the First Aid kit

Figure 2.5: *First Aid kit*

The First Aid kit contains a number of items. Table 2.1 shows some of the items found in the First Aid kit and their uses.

Table 2.1: Items in the First Aid Kit

Item	Picture	Use
Disposable sterile gloves		Prevent direct contact with victim's body fluids
Liniment		Reduce muscular pain
Adhesive bandage (plasters)		Cover minor wounds
Safety pins, clips and tape		Secure bandages or dressings
Sterile gauze		Protect wounds from dirt and germs

Clinical thermometer		Measure body temperature
Pain killers		Relieve pain
Assorted bandages and cotton wool		Clean, cover and dry wounds
Petroleum jelly		Smooth and sooth skin
Scissors and razor blade	 	Cut dressing materials
Antiseptic solution		Clean fresh cuts and bruises
Antiseptic soap		Wash hands, wounds and equipment

Other items such as torch, a whistle, blankets, materials for improvised splints and a polythene survival bag are also useful to be added to the First Aid kit for camping or outdoor activities.

First Aid procedures

It is common for accidents or injuries to occur while in the laboratory. The following are common causes of accident in the laboratory:

(a) Slippery floors;

(b) Incorrect use and handling of apparatus;

(c) Gas leakages from faulty gas taps;

(d) Fires; and

(e) Failure to follow the right experimental procedures or safety rules.

Some of the accidents or injuries that are likely to occur in a physics laboratory are falls, cuts, burns, electric shock, and fire. First Aid is needed in times of such unpredictable situations. It is therefore the responsibility of every individual to give First Aid services to accident victims. Hence, there is a need to learn how to administer the First Aid. Note that First Aid is not a treatment. The following are some of the common accidents in the physics laboratory and their First Aid procedures.

Electric shock

Electricity is the energy that has several uses in our daily life. We use electricity for lighting, heating, cooling, refrigeration and for operating electrical and electronic appliances. In physics laboratory, electricity is used to conduct several experiments. Thus, the presence of electricity is an important feature of a physics laboratory. However, when an electric current passes through a human body it causes an electric shock. The electric shock can cause serious injuries and even death. The electric shock can be caused by faulty switches, defective electric appliances, or handling electrical appliances with wet hands. Standing on a wet floor can also cause electric shock. In an event of an electric shock, the First Aider should follow the following guidelines to help the victim.

(a) Do not touch the victim who is still in contact with electric current.

(b) Break the contact by switching off the current at the switch or the main switch if it can be reached easily.

(c) If it is not possible to switch off the current, move the person from his or her position by using a dry non-conducting material, for instance a piece of dry wooden plank or a broom, as shown in Figure 2.6.

Figure 2.6: *Rescuing electric shock victim*

(d) If you suspect that the area has high voltage, call for professional help immediately.

(e) If the victim is unconscious, check the breathing and pulse rate. If he or she has breathing problems, try to revive his or her breathing rate to normal.

(f) Administer First Aid for shock, burns or other injuries sustained by the victim.

(g) Take the victim to the nearest health facility.

Cuts or wounds

A wound is any abnormal break in the skin or different parts of a body. When there is a cut, blood may come out from the body. This is called bleeding. Germs may enter the body through wounds or cuts and cause infection. A small cut causes a person to lose a small amount of blood. A person who has a big cut loses a lot of blood. This is the reason for quick First Aid action.

The following actions are to be taken when dealing with a wounded person:

For a small cut or wound

(a) Wash your hands using soap and clean water.

(b) Wear hand gloves.

(c) Wash the wound or cut using spirit or salty water and a clean cloth as shown in Figure 2.7.

Figure 2.7: *Cleaning of wound*

(d) Cover the wound or cut with an adhesive bandage or plaster as in Figure 2.8.

Figure 2.8: *Covering wound*

For a large cut or wound

(a) Let the victim lie under a shade or allow her/ him to sit comfortably.

(b) Wash your hands using soap and clean water.

(c) Wear hand gloves.

(d) Prevent further blood loss by applying pressure over the wound using a folded but clean handkerchief or cloth as shown in Figure 2.9. Dressing or sterile gauze can also be used.

Figure 2.9: *Covering a wound with a folded piece of cloth*

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(e) Use adhesive bandage or plaster to wrap the first cloth or dressing or sterile gauze. Don't wrap the first cloth too tight to avoid interfering with the blood flow of the other tissues.

Figure 2.10: *Wrapping the cloth*

(f) Take the victim to the nearest health facility.

Fainting

Fainting happens when a person loses conciousness for a shot period of time because his or her brain does not get enough oxygen. A fainted person is weak and unable to stand on his or her own. A fainted person can be assisted as follows.

(a) Take a person to a cool place or under the shade.
(b) Let the victim lie on his or her back with his or her legs raised higher than his or her head to allow more blood to flow to the brain, as in Figure 2.11.

Figure 2.11: *Fainted person lie on his back with his legs raised high*

(c) Loosen his or her clothes and belt to ensure sufficient supply of air.
(d) Dip a clean handkerchief in water and press it on his or her forehead.
(e) Give the victim clean water to drink when he or she regains consciousness.
(f) If the victim does not regain consciousness, take the victim to the nearest health facility.

Fire

Perhaps this is one of the most highly destructive accidents in the laboratory. Fire is a complete combustion. It is a chemical reaction that involves heat, fuel, and oxygen that combine together in suitable proportions and producing a fire flame, smoke and heat. This process can be illustrated using a fire triangle shown in Figure 2.12.

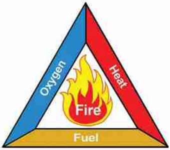

Figure 2.12: *Fire triangle*

Figure 2.12 indicates the fire triangle which is a simple model for understanding the necessary ingredients for most fires. The following are

necessary components for a fire to occur.
(a) Fuel: There must be fuel to burn.
(b) Oxygen: There must be air to supply oxygen.
(c) Heat: There must be heat to start and support fire.

In a physics laboratory, fire may be caused by:
(a) electrical faults;
(b) flammable materials;
(c) carelessness in using gas lighter or match box; and
(d) ignorance and negligence of smoldering materials.

Basic principles for fire prevention

The following are basic principles for fire prevention.
(a) Do not start open fires near buildings.
(b) No smoking in prohibited areas.
(c) Do not interfere with electrical installations.
(d) All electrical appliances must be turned off immediately after use or before leaving the laboratory.
(e) All sources of heat should not be kept near the bench edges to prevent them from falling down easily.
(f) All flammable substances should be locked up in drawers or cabinets.

However, in the event of a fire, fire extinguishers are used. These are special equipment for preventing flames of fire from blowing up and spreading.

Fire extinguishers

Fire can be classified according to the type of medium that is burning. Moreover, fire extinguishers are designed to handle specific types of fire. There are six different classes of fire and several types of fire extinguishers. Table 2.2 shows the classes of fire and their appropriate fire extinguisher.

Table 2.2: Classes of fire, materials involved and the most appropriate fire extinguishers

Fire class	Burning medium	Most appropriate extinguisher	Device
CLASS A	Fire involves solid materials (wood, paper, or textiles)	Water (Air-pressurised water) Foam spray, ABC powder, Wet chemical	

Fire class	Burning medium	Most appropriate extinguisher	Device
CLASS B	Flammable liquids and greases e.g. (petrol, diesel or oils)	Dry powder, Foam spray, Carbon dioxide	
CLASS C	Flammable gases e.g. (methane, LPG)	Dry powder	
CLASS D	Combustible metals e.g. (magnesium or sodium)	Dry powder	
CLASS F	Cooking appliances which use oil or fats as a fuel at high temperature	Wet chemicals	

Other equipment for extinguishing fire are fire blankets, pressurised water in hose reels, and sand. Fire blankets are suitable for rescuing individuals whose clothes have caught fire. The blankets are usually wrapped around the victim. Hose reels help by providing a continuous flow of water. Sand or blanket can be used to cut off the supply of oxygen, thus extinguishing the fire. Figure 2.13 shows the fire blanket, hose reel, and bucket of sand.

(a) Fire blanket (b) Hose reel (c) Bucket of sand

Figure 2.13: *Fire fighting equipment*

How to operate a portable fire extinguisher

(a) Remove the fire extinguisher from the wall.
(b) Hold the extinguisher upright and then remove the safety pin.
(c) Direct the jet nozzle of the extinguisher at the base of the fire.
(d) Squeeze the handle so as to release the extinguishing agent.
(e) Sweep from side to side at the base of the fire until the fire is out.

Note: To avoid being choked by smoke, stand in an opposite direction with the smoke.

Fire fighting procedure

In the event of fire, the following steps are necessary.

(a) If the laboratory is equipped with fire alarm, press it to alert the occupants. Figure 2.14 shows types of fire alarms.

(a) Electric alarm

(b) Button alarm

Figure 2.14: *Types of fire alarms*

(b) Do not panic.
(c) Attack the fire using an appropriate fire fighting equipment if you can.
(d) Ensure that everybody has been taken to a safe place.
(e) Exist the laboratory by following the fire exit signs, as shown in Figure 2.15 to the recommended exits doors. Lifts must not be used during fire outbreak.
(f) Close all doors and windows. Do not lock them.

Figure 2.15: *Fire exit sign*

Task 2.2

How to give First Aid

In pairs, practice how to give First Aid to a victim of:

(a) electric shock;
(b) cuts; and
(c) burns.

Each member of the group should get a chance to be the victim and the First Aider.

Ask for help when you encounter difficulties.

What was your experience? Discuss it in class.

Safety symbols or signs

Laboratory apparatus and chemical containers are labelled with safety symbols or signs in order to ensure that all activities are carried out safely in the laboratory. Some signs may be found in or on the boxes used to hold either apparatus or chemicals. These signs must be obeyed in order to avoid accidents. Safety symbols show that a substance is either toxic, irritant, flammable, oxidizing, or corrosive.

Toxic

Toxic symbol means that a substance is dangerous and can cause death. These substances contain poisonous ingredients. They can enter the body through:

(a) ingestion – by eating and drinking;

(b) inhalation – by breathing through the nose; and

(c) by injection – from a syringe or an insect bite or a snake bite. In case of contact with the skin, wash the skin with plenty of water. An example of signs on toxic substances such as hydrogen sulphide or chlorine is shown in Figure 2.16.

Figure 2.16: *Toxic substance sign*

Health hazard sign

Any substance that is a cancer-causing agent (carcinogen) or substance with respiratory, reproductive or organ toxicity that causes damage over time (a chronic, or long-term, health hazard) is a health hazard. Though their effect is slow, they ought not to be ignored. Health hazard sign is shown in Figure 2.17.

Figure 2.17: *Health hazard substance sign*

Flammable

All chemicals and other substances that can easily catch fire are called flammable materials. They should be kept away from open flames. All sources of fires should be put off when dealing with flammable substances. Since flammable substances are often volatile (produce fumes) and evaporate quickly, they should be kept in stoppered containers. Vapours from the flammable substances ignite and burn in the presence of an ignition source like a cigarette or a spark. Substances that are flammable include gasoline, kerosene, butane, nail polish remover, and turpentine. The sign of flammable substance is shown in Figure 2.18.

Figure 2.18: *Flammable substance sign*

Oxidising agent

An oxidising agent speeds up the rate of burning. Sometimes it is called oxidant or oxidizer. An oxidising agent should never be burnt together with an organic material such as sawdust as an explosion can occur. Oxidants include oxygen, chlorine, fluorine and hydrogen peroxide. The sign of an oxidant is shown in Figure 2.19.

Figure 2.19: *Oxidant substance sign*

Corrosive

Corrosive substances have the ability to cause gradual damage whenever they come into contact with other materials. For example, they can corrode floors, metals, and skin. Substances that are corrosive include concentrated sulphuric acid, hydrochloric acid, nitric acid, and concentrated alkalis such as sodium hydroxide and ammonia. The sign on corrosive substance is shown in Figure 2.20.

Figure 2.20: *Corrosive substance sign*

Radioactive

Radioactive substances emit harmful radiation that has the ability to penetrate human bodies and cause damage. They should be avoided at all times. Radioactive substances include uranium and plutonium isotopes and their compounds. The sign of radioactive materials is shown in Figure 2.21.

Figure 2.21: S*ign of a Radioactive material*

Danger of electric shock

A safety sign for a danger of an electric shock is shown in Figure 2.22. The equipment which gives electric shock is labeled with this sign. Equipment having this label should not be touched when it is in operation.

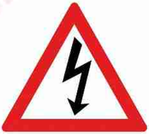

Figure 2.22: *Danger of an electric shock sign*

Explosive

Explosive substances are stored in special containers and kept away from anything that can facilitate their explosion. This means that these substances cannot explode unless detonated. However, there are some

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explosive substances that could explode without being externally detonated. These substances are much more dangerous. Explosive substances should never be stored in glass containers; in case of an explosion, pieces of glass would fly all over and injure people. The symbol of a substance that can easily explode is shown in Figure 2.23.

Figure 2.23: *Explosive substance sign*

Fragile

Fragile materials should be handled with care to prevent them from breaking. A safety sign of a fragile substance is shown in Figure 2.24. This symbol is normally found on boxes or containers containing fragile materials like glass.

Figure 2.24: *Fragile material sign*

Danger/caution mark

Exclamation sign shown in Figure 2.25 is used to mark a substance which is hazardous and can cause damage to organs from a single short-term exposure.

Figure 2.25: *Danger/Caution mark*

Task 2.3

(a) With the guidance of your teacher, identify warning signs that are found within your school environment, on the road and at home.

(b) In groups of five students, use Manila papers and marker pen to make wall charts for warning signs. State where they are mostly found. Use appropriate colours to make your work as attractive as possible. The best wall chart will be pinned on the school's notice board.

Laboratory apparatus

An apparatus is a tool or an equipment that is required in order to perform a particular activity or task effectively during the teaching or learning process. Each apparatus in a laboratory is specifically designed for a specific use which includes heating, measuring and storage while others act as containers. Tables 2.3 and 2.8 show the classification of laboratory apparatus according to their application.

Table 2.3: Instruments/Apparatus for measuring length and time

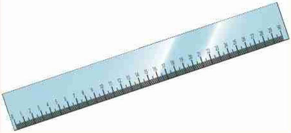
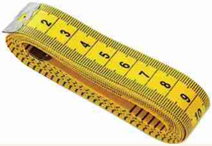
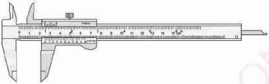
Apparatus	Picture	Uses
Metre rule		Measure length up to 100 cm
Tape measure		Measure length or distance of 1 m and above
Vernier caliper		Measure length, depth, internal, and external diameters of cylindrical objects more accurately
Micrometer screw gauge		Measure the diameter of a wire, hair, and very small objects more accurately
Stopwatch	 	Measure time

Table 2.4: Instruments/Apparatus for measuring mass and weight

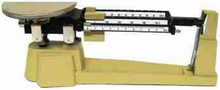
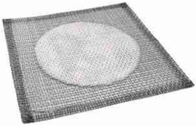
Apparatus	Picture	Uses
Spring balance		Measure force/weight in Newtons
Triple beam balance		Measure mass of a substance
Digital balance		Measure mass of a substance more accurately
Triple lever arm balance		Measure mass of a substance

Table 2.5: Instruments/Apparatus for measuring volume of liquids

Apparatus	Picture	Uses
Beaker		Measure volume and heating liquids
Measuring cylinder		Measure volume of liquids
Burette		Dispense and measure volume of liquid more accurately
Pipette		Transfer specific but small volumes of liquids

Table 2.6: Instruments/Apparatus for heating purposes in the laboratory

Apparatus	Picture	Uses
Bunsen burner		Source of heat
Wire gauze		Support beaker or flasks during heating
Tripod stand		Provide stability and support for glassware such as beaker and flask
Calorimeter		Measure amount of heat of a liquid

Test tube		Hold and heat chemicals and liquids
Kerosene stove		Source of heat
Gas container		Hold a gas which is used as the source of heat in the laboratory
Test tube holder		Hold a test tube during heating

Table 2.7: Instruments/Apparatus for electrical measument

Apparatus	Picture	Uses
Ammeter		Measure electric current
Voltmeter		Measure voltage
Galvanometer		Detect and indicate the direction of an electric current
Electric cell/ battery		Source of electromotive force (emf)

Rheostat		Vary resistance in electric circuit
Battery holder		Hold battery
Bulb		Source of light
Plug key		Turn ON and OFF electricity in a circuit
Connecting wires		Connect electrical devices in a circuit

Metre bridge	 	Determine unknown resistance of a resistor or a conductor.
Resistance box		Estimat and compare resistances.

Table 2.8: Instruments/Apparatus for light experiment

Apparatus	Picture	Uses
Plane mirrors		Looking glasses
Lenses		Magnify and diminish images of objects
Curved mirror		Concave for shaving; in torches. Convex for vehicle side mirrors

Drawing boards		Draw the path of rays of light
Optical pins		Used as object in light experiments
Triangular glass prism		Show the minimum angle of deviation and separate white light into its constituent colours (recall rainbow)
Rectangular glass block		Used to demonstrate the concept of refraction of light rays

Task 2.4

Visit the following school premises; and then, answer questions (i) - (iii)
(a) Physics laboratory.
(b) Chemistry laboratory.
(c) Biology laboratory.
   (i) List the items you see in each room and their uses.
   (ii) List the items that are commonly found in all laboratories.
   (iii) Discuss these items in groups.

Basic principles of scientific investigation

Scientific method is an experimental procedure used in constructing and testing a scientific hypothesis or law. A scientific method consists of the collection of data through observation and experimentation, data analysis, drawing conclusion, and writing scientific report.

The concept of scientific investigation

The scientific method is the basic skill needed in the world of science. Always humans are curious on why and how things happen in the world around. The scientific method provides scientists with a well-structured scientific platform to help find the answers to their questions.

Commonly, a scientific method is a set of techniques used by scientists to investigate a problem or answer questions.

Basic steps of scientific investigation

Scientists including physicists are always looking for scientific evidence. A systematic search for evidence is recommended during and after experiments. The following are steps followed when carrying out a scientific investigation.

1. Problem identification

This is the first step in the scientific method. It is when one makes a puzzling observation. An example of such an observation would be 'What is the relationship between the length of the string to which the pendulum bob is attached to the time taken by the pendulum to complete a given number of oscillations'?

2. Formulating a testable hypothesis

A hypothesis is a scientific assumption or prediction of the outcome. It is a suggestion of the answer to the question asked. For example, 'Length of the string to which the pendulum bob is attached affects the time taken by a pendulum to complete a given number of oscillations'.

FACT: In science we never prove an hypothesis through a single experiment because there is a chance that you made an error somewhere along the way. What you can say is that, your results support or do not support the original hypothesis.

3. Performing an experiment

An experiment is a test under controlled conditions. In this case, the aim of the experiment is to determine whether the formulated hypothesis is true or false. In an experiment, variables are used to test the hypothesis. Variables are those conditions in an experiment that can change or be changed, so as to obtain a set of values. There are three different types of variables, namely; dependent, independent, and controlled variables.

(a) **Dependent variable**: A variable which changes if the experimental condition changes. For example, the dependent variable is the time it takes for the pendulum bob to complete a given number of oscillations.

(b) **Independent variable**: A variable which does not change even when the experimental condition is changed. For example, length of the pendulum bob is independent variable.

(c) **Controlled variable**: This is a variable that is kept constant during an experiment. For example, the number of oscillations is a controlled variable.

4. Data collection and analysis

Data collection involves recording what has been observed during the experiments. The observed results are tabulated (recorded in a table form) and ready for analysis. This involves ploting graphs, calculating mean, standard deviation, and errors. The results of the experiment can be recorded as shown in Table 2.9.

Table 2.9: Length of the string to which the pendulum bob is attached and time taken to complete number (n) of oscillations.

Number of observations	Length, l (m)	Time to complete (n) oscillations, t (s)	Periodic, T (s) $T = \frac{t}{n}$ (s)	T^2 (s^2)

5. Data presentation and interpretation

Data presentation involves the use of charts, graphs and mathematical formulae.

Drawing graphs in science

For all graphs plotted from experimental data, it is important to remember that you should not connect the dots. Data will not always follow a line or curve perfectly. By obtaining several experimental data points any discrepancies in each data point can be removed. The data points plotted should be fitted by drawing a best line that passes through most of the points.

The graphs you plot must have the following features:

(a) An appropriate scale is used for each axis so that the plotted points must occupy enough axis/space (work out the range of the data and the highest and lowest points).

(b) The scale must remain the same along the entire axis and should use easy intervals such as 10 s, 20 s, 50 s. Use graph paper for accuracy.

(c) Each axis must be labelled with what is shown on the axis and must include the appropriate units in brackets, e.g. Temperature (°C), time (s), height (cm).

(d) The independent variable is generally plotted along the *x*-axis, while the dependent variable is generally plotted along the *y*-axis.

(e) Each point has an *x* and *y* co-ordinate and should be plotted with a symbol which can be easily seen, e.g., a cross or circle.

(f) A best fit line should be drawn to the graph.

(g) Do not start the graph at the origin unless there is a data point for (0,0), or if the best fit line runs through the origin.

(h) The graph must have a clear, descriptive title which outlines the relationship between the dependent and independent variable.

(i) If there is more than one set of data drawn on a graph, a different symbol (and/or colour) must be used for each set and a key or legend must be included to define the symbols.

(j) Use line graphs when the relationship between the dependent and independent variables is continuous.

(k) For a line graph, you can draw a line of best fit with a ruler. Make sure the number of points are distributed fairly and evenly on each side of the line.

Example of a graph of period, T^2 (s^2) against length l (m) is shown in Figure 2.26.

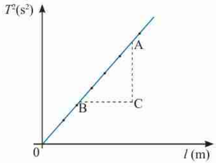


Figure 2.26: *Graph of period, $T^2(s^2)$ against length, l (m)*

(l) In an exponential graph a best fit line should be drawn by using freehand.

After recording and analyzing the data, you may look for possible trends or patterns and explain why they occur that way. For instance, physicist may notice that as the length of the string to which the bob is attached increases, the time to complete a given number of oscillation also increases. This pattern forms the basis on which evidence can be obtained.

6. Drawing a conclusion

A conclusion is a summary of the result of the experiment. It includes a statement that either proves or disapproves the hypothesis. For instence, *'Length of the string to which the pendulum bob is attached affects the time taken by a pendulum to complete a given number of oscillations'* proves our hypothesis. The experiment may be repeated to make sure the results obtained are reliable.

7. Reporting results

Scientists communicate their results to others in a final scientific report. It is very important to communicate scientific findings to the public in the form of scientific publications, at scientific conferences, in articles, TV or radio programmes. The experimental results are presented in a specific format, so that others can read your work, understand it, and repeat the experiment. The structure of a good scientific report includes:

(a) **Aim** - a brief sentence describing the purpose of the experiment;
(b) **Apparatus** - a list of the apparatus or equipment;
(c) **Method** - a list of the steps followed to carry out the experiment;
(d) **Results** - tables, graphs and observations about the experiment;
(e) **Discussion** - what your results mean; and
(f) **Conclusion** - a brief sentence concluding whether or not the aim was achieved.

Note: If your results do not support the hypothesis:
(a) do not leave out the experimental results;
(b) suggest possible reasons for the difference between your hypothesis and the experimental results; and
(c) suggest ideas for further investigations so as to find answer to the problem.

Scientific method flow chart

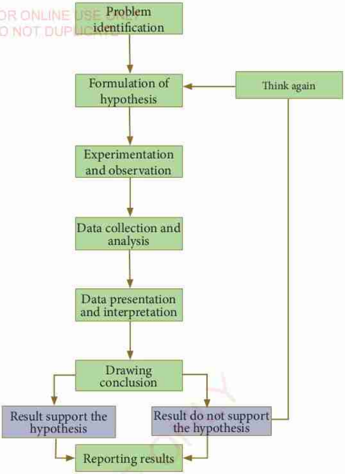


Figure 2.27: *Scientific method flow chart*

Task 2.5

In a group of 3 or 4 students study the flow chat provided in Figure 2.27, then discuss the following questions:

1. Once you formulate a research problem explain, why is it important to conduct background research before doing anything else?
2. What is the difference between a dependent, independent, and controlled variable and why is it important to identify them?
3. What is the difference between identifying a problem, a hypothesis, and a scientific theory?
4. Why is it important to repeat your experiment if the data fits the hypothesis?

Activity 2.1

In this activity you are required to design your own experiment. Use the information provided below and the scientic method flow chart outlined previously to design your scientific experiment. The experiment should be handed in 1 - 2 page report. Below are basic steps to follow when designing your own experiment.

1. Ask a question which you want to find an answer.
2. Perform background research on your topic of choice.
3. Write down your hypothesis.
4. Identify important variables of your investigation; those that are relevant and you can measure or observe.
5. Decide on the independent and dependent variables in your experiment and variables that must be kept constant.
6. Design the experiment that you will use to test your hypothesis:
   (a) State the aim of the experiment.
   (b) List all the apparatus (equipment) that will be used in your experiment.
   (c) Write the method that will be used to test your hypothesis
   – in the correct sequence, with each step of the experiment numbered.
   (d) Indicate how the results should be presented and what data are required.

Activity 2.2

Aim: To apply the scientific investigation method in order to test the accuracy of stopwatches.

Materials: Sellotape, table, pendulum bob, string, retort stand, analogue, and digital stopwatches

Procedure

1. Arrange a simple pendulum system as shown in Figure 2.28.

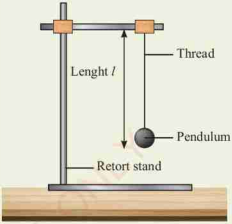


Figure 2.28: *Simple pendulum*

2. Pull the bob slightly to one side then release it so that it swings back and forth.
3. Using analogue stopwatch, measure the time the pendulum takes to swing back and forth.
4. Record your observation for one complete oscillation.
5. Repeat steps 3 and 4 using the digital stopwatch instead of the analogue one.

Questions

With reference to the pendulum bob, use the scientific method outlined previously to investigate whether the digital stopwatch is more accurate than the analogue stopwatch in measuring the time taken to complete one oscillation. Briefly address the following:

(a) Develop a hypothesis;
(b) Design and conduct an experiment to test the hypothesis;
(c) Draw a conclusion from the experiment;
(d) After comparing the measurements, which stopwatch do you think is more accurate than the other? And
(e) Write a report explaining your experiment and conclusions.

The measurement from a digital stopwatch is more accurate than the one from an analogue stopwatch. The digital stopwatch therefore, gives a more precise measurement of time than the analogue one.

Task 2.6

1. Discuss with your teacher the steps for carrying out experiments using the scientific method.
2. In groups of five students, discuss the application of the scientific investigation method for a simple pendulum.
3. Briefly explain the importance of forming hypothesis before doing an experiment.

Chapter summary

1. A laboratory is a special room that has been designed and equipped for carrying out scientific experiments for the purpose of study or research.
2. Laboratory rules and safety measures should be observed while carrying out experiments in the laboratory. This is to ensure your safety and that of the other laboratory users.
3. First Aid is the immediate assistance or care given to a sick or injured person before getting a professional medical help.
4. Items for rendering First Aid are contained in the First Aid kit.
5. First Aid helps to save life; it prevents the victim's condition from becoming worse, promotes recovery by bringing hope and encouragement, helps to reduce pain and suffering and also prevents infection.
6. First Aid can be given to victims of: electric shock, cuts or wounds and fainting.
7. Warning signs show whether a substance is harmful, toxic, irritant, flammable, oxidant, corrosive, explosive or can easily break.
8. Warning signs must be read and understood so as to avoid accidents in the laboratory.
9. Apparatus used in a Physics laboratory are tools and instruments required for effective learning and teaching of Physics.
10. The scientific method is a procedure used by scientists to investigate a problem or answer questions.
11. The scientific investigation method is divided into several steps, namely: problem identification, asking questions, formulating a testable hypothesis, performing an experiment, data collection and analysis, data presentation, data interpretation, and drawing a conclusion.

Revision exercise 2

Section A

Choose the most correct answer

1. When a large body of experimental evidence supports or does not support a hypothesis, what may the hypothesis eventually be considered?
   (a) Observation.
   (b) Insight.
   (c) Conclusion.
   (d) Law.
2. Which of the following best describes a variable?
   (a) A trend that shows an exponential relationship.
   (b) Something whose value can change over multiple measurements.
   (c) A measure of how much a plot line changes along the *y*-axis.
   (d) Something that remains constant over multiple measurements.
3. Write **TRUE** for correct and **FALSE** for incorrect statements for each of the following:
   (a) You should move a victim of electric shock using a metallic object. ________
   (b) First aid helps to save life. ____
   (c) Eating in the laboratory is prohibited. _________
4. Fill in the blanks.
   (a) ________ is an immediate assistance given to a _______ before getting professional medical care.
   (b) Take the victim to_______ if he or she does not regain consciousness.

Section B

5. Briefly answer the following questions.
   (a) What is a physics laboratory?
   (b) List ten laboratory rules.
   (c) Name five items found in a First Aid kit and state their uses.
   (d) Why it is necessary to wear gloves when giving First Aid to a bleeding person?
6. Outline four features of a good laboratory.
7. What should you do in the laboratory in the event of the following situations?
   (a) You need to carry out an experiment but there is nobody in the laboratory.
   (b) You have just finished your physics experiments for a day.
   (c) Your partner is cut by glass during the experiment.
   (d) You want to burn waste papers.
   (e) Your partner breaks a beaker.
   (f) You have water and you want to drink it.
   (g) One of your partners suggests that you take the apparatus out of the laboratory in order to finish the experiment at home.
   (h) Your partner wants to insert a bare wire in an electric plug.
8. State six classes of fire and their most appropriate fire extinguishers.
9. What are warning signs?
10. What do the following warning signs mean?

(a)

(b)

(c)

11. Draw the following apparatus and state its uses:
    (a) Beaker.
    (b) Thermometer.
    (c) Micrometer screw gauge.
    (d) Spring balance.
    (e) Measuring cylinder.
12. Why is it important for all apparatus used in electrical experiments to be thoroughly dried? Explain.
13. (a) What is a scientific method?
    (b) Use a diagram to name all the steps involved in a scientific investigation.
    (c) As part of their study, Form 2 students were asked to find out whether girls in their class perform better than boys in physics. If you were one of them:
        (i) ask the questions;
        (ii) propose the hypothesis;
        (iii) carry out an experiment to test your hypothesis; and
        (iv) draw a conclusion from your experiment.
14. A student investigated the strength of different fridge magnets by putting small sheets of paper between each magnet and the fridge door. The student measured the maximum number of sheets of paper that each magnet was able to hold in place. Why was it important that each small sheet of paper had the same thickness?
    Before starting the investigation, the student wrote the following hypothesis, 'The bigger the area of a fridge magnet the stronger the magnet will be'. The student's results are given in Table 2.10.

Table 2.10: Shows the fridge magnet, area, and number of sheets of paper.

Fridge magnet	Area of magnet in mm^2	Number of sheets of paper
A	40	20
B	110	16
C	250	6
D	340	8
E	1350	4

Give one reason why the results from the investigation do not support the student's hypothesis.

Chapter Three

Measurement

Introduction

Measurement is a word used in everyday life. We measure a piece of land in hectares or acres, and the circumference of a playground using a tape measure. In physics, accurate and precise measurements enable the collection of useful experimental data that can be tested against theoretical predictions to enhance the development of physical theories. In this chapter, you will learn about the concept of measurement of physical quantities, the basic apparatus/equipment used in measurement and how to use them. The competencies developed will enable you to deal with different situations involving measurements.

Concept of measurement

The word 'measurement' comes from the Greek word 'metron' which means 'limited proportion'. It is our common experience that, if you want to buy a trouser, the information that a shopkeeper first wants to know is the size of the trouser that fits your waist. If it happens that you do not know your size, he or she will take a tape and measure the size of your waist. The act of finding the size of a given quantity is referred to as measurement.

Measurement is defined as the process of assigning a number and a unit to an observation or event. Measurement is done through comparing the known and unknown quantity. For example, in measuring the length of a table, we have to compare a table with a ruler or a tape measure.

Every measurement has two parts which are:

1. a number or numerical part that gives the result of the comparison; and

2. A unit part which identifies the particular unit used to make the measurement.

In the unit part, the focus is on the standard unit (International System Units-SI units) though, other units may also be used. For example, if the length of a playground is 100 m, '100' is the number part while 'm' is the unit part. Therefore, a meaningful measurement must have both a number and a unit.

A complete measurement which includes both number and unit part is called measurement of a physical quantity. For example, the measurement of 100 km, 2 kg or 10 s.

Physical quantity

A physical quantity is any measurable quantity. Physical quantities are divided into two categories, namely fundamental physical quantities and derived physical quantities.

Fundamental physical quantities

Fundamental physical quantities are quantities of measurement which cannot be expressed in terms of other quantities. These include; length, mass, time, temperature, amount of substance, electric current and luminous intensity. Among the measured fundamental physical quantities mass, length and time are the most common. Table 3.1 shows the fundamental physical quantities and their respective SI units of measurement.

Table 3.1: The fundamental physical quantities and their SI units

Quantity	SI unit	Unit symbol
Length	Metre	m
Mass	Kilogramme	kg
Time	Second	s
Electric current	Ampere	A
Temperature	Kelvin	K
Amount of substance	Mole	mol
Luminous intensity	Candela	cd

Vector and scalar quantities

The pysical quantities can further be classified into either vector or scalar quantities.

Vector quantities

Vector quantities are those quantities that have both magnitude and direction. Examples of vector quantities are force, displacement, velocity and momentum.

Scalar quantities

Scalar quantities are those quanties that have magnitude but have no direction. Examples of scalar quantities are mass, distance, time, density, volume, pressure, speed, electric current, work, energy, and power.

For example, consider a car travelling at 100 kilometres per hour North. This describes the velocity of the car which is 100 kilometres per hour in the North direction. Velocity is a vector quantity. However, if the intention is to describe only the speed of the car and not the direction, the statement could be simply that the car is travelling at 100 kilometres per hour. Speed is a scalar quantity.

Table 3.2 gives some of the vector and scalar quantities.

Table 3.2: Some of the vector and scalar quantities

Vector quantities	Scalar quantities
Force	Mass
Displacement	Distance
Acceleration	Time
Velocity	Electric current
Momentum	Density
Magnetic field	Pressure
Electric field	Work
	energy
	power
	Volume
	Area

Measurement of length

Length is the most commonly measured quantity in daily life. Length is used to give the dimensions of an object or the distance between two points. Hence, distance is defined as the path taken by a particle in space between two points or objects. The distance around the surface of an object is called perimeter. You can measure the distance ranging from very small to a very large distance such as the distance from the earth to the sun. To cope with this large difference, there are several other units obtained from the metre, namely, kilometre (km), centimetre (cm), millimetre (mm), micrometre (μm), nanometre (nm), picometer (pm) and femtometre (fm). Their equivalence is as follows:

1 km = 1 000 m.
1 m = 100 cm.
1 cm = 10 mm.
1 mm = 1 000 μm.
1 μm = 1 000 nm.
1 nm = 1 000 pm.
1 pm = 1 000 fm.

Table 3.3 gives some of the units in comparison to the metre. Very small lengths are measured and expressed in mm, μm, nm, pm or fm.

The length of an object is measured using specific instruments. The choice of an instrument to be used is determined by the following factors.

1. The desired degree of precision.
2. The size of the physical quantity to be measured.
3. The shape of the object.

Table 3.3: Gives some of the units in comparison to the metre.

Distance	Comparison with SI unit
1 kilometre (km)	1 000 m
1 centimetre (cm)	$\frac{1}{100}$ m
1 millimetre (mm)	$\frac{1}{1\,000}$ m
1 micrometre (µm)	$\frac{1}{1\,000\,000}$ m
1 nanometre (nm)	$\frac{1}{1\,000\,000\,000}$ m

Basic equipment / apparatus and their uses

Before you perform an experiment, you should be comfortable with equipment or apparatus that you will use. The following section describes some of the common ones and how to use them.

Equipment that are commonly used in a laboratory to measure length are a metre rule, tape measure, vernier caliper and micrometer screw gauge.

Metre rule

In an elementary physics laboratory, the metre rule, half-metre rule, and 30 cm rule as shown in Figure 3.1, are recommended to be used. These rulers are mainly wooden or plastic and are graduated in centimetres and millimetres. A typical metre rule has markings for 1 cm and 1mm intervals.

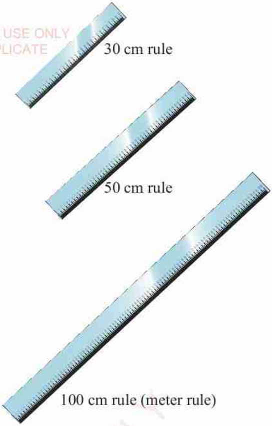


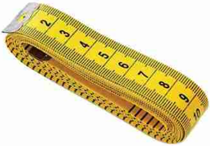
Figure 3.1: *Classification of rulers.*

Task 3.1

1. If you have to measure the length of a field, which type of instrument will you use?
2. Place the following objects on the paper. Mark the end points of each. Draw the line-segment for the length of each object and find the measure of length.
   (a) A pencil
   (b) A book
   (c) A match stick

Tape measure

A tap measure, as shown in Figure 3.2, is a flexible ruler used to measure long distances and lengths of objects which are not straight. It is commonly used in civil work, for example in construction sites for houses, roads and bridges. It has the accuracy similar to the metre rule, with the minimum distance to be measured as 1 mm. Two basic types of tape measures are shown in Figure 3.2.



(a) Plastic tape measure

(b) Metal tape measure

Figure 3.2: *Tape measures*

When taking a measurement, always ensure that your eye is perpendicular to the mark on the scale of the metre rule, as demonstrated in Figure 3.3, otherwise the value will have an error. An error caused by wrong positioning of the eye is known as parallax error. Such an error occurs when the measurement of an object's length is more or less than the true length, because of the eye being positioned at an angle to the measurement mark. Therefore, the eye should be perpendicular to the point you are reading, as shown in Figure 3.3.

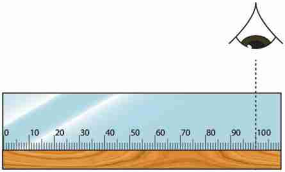


Figure 3.3: *Reading from a metre rule*

Care should be taken while using a metre rule so as to avoid damaging the ends. This is because the rule does not have an allowance (a short ungraduated portion) for wear at both ends. Suppose, you wish to measure the length of a table. The zero (0 cm) mark of the metre rule is aligned with one end of the table, as shown in Figure 3.4.

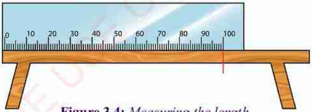


Figure 3.4: *Measuring the length*

Since the metre rule does not extend beyond the end of the table, we carefully mark the point on the table that corresponds to the end of the metre and then continue, as shown in Figure 3.5.

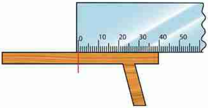


Figure 3.5: *Reading to complete length*

The actual length of the table is then given as: 100 cm + 40 cm = 140 cm. Therefore, the table has a length of 140 cm or 1.4 m. In case the edge of a ruler is worn out, which is almost inevitable, it is advised to:

(i) always start measuring from the mark more than zero; and

(ii) subtract the mark from the final reading.

Figure 3.6 illustrates the use of a ruler with worn-out edges.

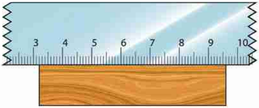


Figure 3.6: *Using a ruler with a worn-out edge*

The length of the object = (9.6 – 3.2) cm = 6.4 cm.

Task 3.2

The following task should be carried out in groups of three students. Use a metre rule to measure the length and width of the cover of your physics textbook to the nearest tenth of a centimetre. Record your results. Calculate the perimeter of the cover. Perimeter = 2 times the length + 2 times the width = 2 (l + w). Present your results in the class.

A vernier caliper

A vernier caliper is an instrument used to measure small lengths with a greater degree of accuracy than a metre rule.

Measurement by use of a vernier caliper is obtained to the nearest hundredth of a centimetre, which means to the accuracy of 0.01 cm. A vernier caliper has a fixed scale and a vernier scale. The fixed scale is also known as the main scale. The vernier scale slides along the fixed scale hence readings are taken from both scales. The fixed scale gives readings in centimetres and millimetres while the vernier scale gives readings in the hundredth of a centimetre. This explains the second decimal place. Figures 3.7 and 3.8 show a vernier caliper and a vernier scale for taking measurement.

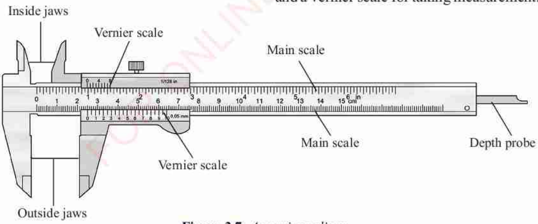


Figure 3.7: *A vernier caliper*

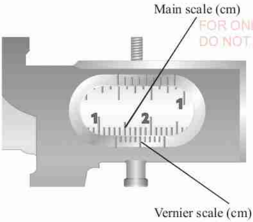


Figure 3.8: *A vernier scale*

The vernier scale is a short scale. 10 vernier divisions cover 9 main scale divisions. This is a length of 0.9 cm. When this is divided into 10 equal intervals, the result is the difference between the main scale division and the vernier scale division. This is known as Least Count.

$$\text{Main scale division} = \frac{1\ \text{cm}}{10} = 0.1\ \text{cm.}$$

$$\text{Vernier scale division} = \frac{9\ \text{cm}}{0.1} = 0.09\ \text{cm.}$$

Therefore,
least count of a vernier caliper

$$= (0.1 - 0.09)\ \text{cm} = 0.01\ \text{cm.}$$

The vernier caliper has a set of 'jaws' that can be used to measure the lengths of some objects or the thickness of other objects. They can also be used to measure the external diameters of objects using outside (outer) jaws, as shown in Figure 3.9.

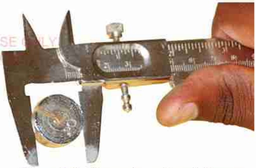


Figure 3.9: *Measuring external diameter using the outside (lower) jaws*

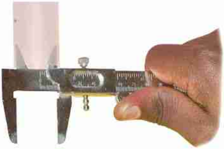


Figure 3.10: *Measuring inner diameter using inside jaws*

At the top of a vernier caliper are two inner (upper) jaws that can be used to measure the internal diameter of a hollow objects, as shown in Figure 3.10. A stem sticks out from the right side of the caliper is called a depth gauge or a depth probe. It can be adjusted to measure a depth of an object, as shown in Figure 3.11.

Figure 3.11: *Measuring depth using the vernier caliper*

The screw clamp visible on top of the caliper is tightened to secure the objects being measured, so that the reading does not change while measuring.

How to read a vernier caliper

The following steps are taken when measuring length using a vernier caliper.

1. Close the jaws of the vernier caliper and look out for the zero cm (0 cm) mark differences.
2. Place the object to be measured between the jaws.
3. Slide the vernier along the main scale until it just touches the end of the object. Use the screw clamp to secure the object in position, as shown in Figure 3.12.

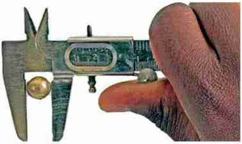


Figure 3.12: *Measuring the diameter of a steel ball bearing*

4. Read and record the reading on the main scale which is to the left of the zero cm mark of the vernier scale. This value is to the nearest tenth of a centimetre.
5. Observe along the vernier scale and record the mark which coincides with a mark on the main scale.
6. Read and note down the value on the vernier scale. This gives the digit in the hundredth place of the measurement.
7. Add the values in steps 4 and 6 to get your correct reading. Therefore, length of object = main scale reading + vernier scale reading.

Example 3.1

Using Figure 3.13, determine the diameter of the object that is placed between the jaws of the vernier caliper.

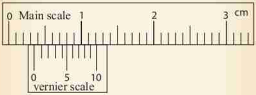


Figure 3.13: *Vernier caliper*

Solution

From Figure 3.13,

Main scale reading = 0.3 cm = 3.0 mm

Vernier scale reading = 5 divisions x 0.1 mm = 0.5 mm

Total reading = Main scale reading + Vernier scale reading

= 3.0 mm + 0.5 mm = 3.5 mm

Therefore, the total reading = 3.5 mm

The diameter of the object = 0.35 cm.

Example 3.2

The jaws of a vernier calliper touch the inner wall of calorimeter without pressure. The position of zero of vernier scale on the main scale reads 3.4 cm. The 6th of vernier scale division coincides with the main scale division. Vernier constant of callipers is 0.01 cm. Find actual internal diameter of calorimeter, when it is observed that the vernier scale has a zero error of – 0.03 cm.

Solution

Main scale reading = 3.4 cm

Least count (L.C) = 0.01 cm

Vernier coincidence = 6

Reading

= Main scale reading + Vernier coincidence × LC

= 3.4 + 6 × 0.01

= 3.4 + 0.06

= 3.46 cm.

Corrected reading

= reading – zero error

= 3.46 – (-0.03)

= 3.54 + 0.03

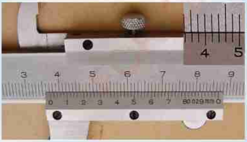
= 3.49 cm.

Exercise 3.1

Answer all questions

1. Draw both the main and vernier scales of a vernier caliper to show a reading of 0.36 cm.
2. What is the reading in Figure 3.14 (a) and 3.14 (b)?

(a)



(b)

Figure 3.14: *Vernier calipers*

3. The thin metallic strip of vernier caliper moves downward from top to bottom in such a way that it just touches the surface of a beaker. Main scale reading of calliper is 6.4 cm whereas its vernier constant is 0.1 mm. The 4th vernier scale division coincides with main scale division. Calculate the actual depth of beaker. (Assume zero end error).

Activity 3.1

Aim: To measure the external diameter of a test tube using a vernier caliper.

Materials: Test tube, vernier caliper

Procedure:

1. Close the jaws of the vernier caliper and observe the zero cm marks of the main and vernier scales. Record your observations.
2. Open the jaws and place the test tube between them.
3. Close the jaws gently until the test tube is held firmly. Record your observations.
4. Repeat steps 1 to 3 using other parts along the test tube.
5. Obtain three readings. Record your observations.

Questions

(a) Calculate the average of the readings obtained.
(b) Were the four obtained readings equal?
(c) Explain why three readings were taken and not one.

A test tube is cylindrical in shape. This means that its diameter is the same throughout. The readings obtained using the outside caliper jaws are equal in magnitude since the test tube is almost uniform in shape.

In an experiment, it is always best to obtain many readings so as to obtain an average result. Two or more readings offer an opportunity for the experimenter to compare and identify any pattern.

Task 3.3

Collect a variety of objects such as books, pencils and other writing materials. In your collection, include cylindrical objects. Use a vernier caliper to measure the thicknesses of the collected objects. The depth, internal and external diameters of the hollow objects should also be measured. Record your measurements in the following table:

Object	Dimension (cm)	Main scale reading (cm)	Vernier scale reading (cm)	Actual reading (cm)

A micrometer screw gauge

A micrometer screw gauge gives readings with better precision than the vernier caliper. Measurement can be obtained to the nearest thousandth of a centmetre. This is an accuracy of 0.001 cm. For this reason, it is usually used to measure the diameters of thin objects like wires and ball bearings. The micrometer screw gauge has different parts, as shown in Figure 3.15.

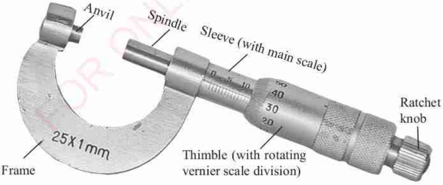


Figure 3.15: *Parts of the micrometer screw gauge*

A micrometer screw gauge consists of main scale (sleeve) and thimble scale. The main scale is marked in millimetres. The thimble scale is divided depending on the distance between two consecutive threads of the screw. This is called the pitch of the screw. If the pitch of the screw of the micrometer is 0.5 mm, then the thimble scale has 50 equal divisions. Otherwise, it has 100 divisions when the pitch is 1.0 mm. This means that when the thimble makes a complete turn, the spindle moves either forward or backward a distance of 0.5 mm or 1.0 mm respectively along the sleeve. When the spindle is completely closed onto the anvil, the thimble edge aligns with the zero mark on the sleeve scale. The thimble also has its zero-mark lying on the central line of the sleeve scale. Therefore, the gap between the spindle and the anvil equals the distance between the edge of the thimble and the zero mark on the main scale.

To measure the diameter, an object is placed between the anvil and the spindle. The thimble is then rotated using the ratchet knob until the object is secured firmly between the anvil and the spindle. This in turn moves the spindle forward. The ratchet knob must be used to secure the object firmly, otherwise the instrument will be damaged or give a wrong reading. It is recommended that three clicks of the ratchet should be obtained before taking the reading. Note that as the thimble turns, it slides over the sleeve. The sleeve has a linear scale while the thimble bears a circular one. Care has to be taken to ensure that the thimble does not rotate while the reading is being taken.

Measuring the diameter of a wire by micrometer screw gauge

The following is the procedure for measuring the diameter of a wire using micrometer screw gauge.

1. Unscrew the thimble to create enough space to accommodate the wire between the spindle and the anvil.
2. Close the gap by rotating the thimble clockwise. Screw the ratchet knob until it clicks so as to show the correct setting.
3. Read and note down the value on the sleeve; that is the last mark must be visible to the left of the thimble. This value is to the nearest tenth of a millimetre. The value is 7.5 mm as shown in Figure 3.16.

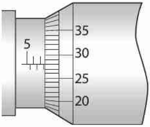


Figure 3.16: *Reading a micrometer screw gauge*

4. Read and note down the value on the thimble that is just below the reference line on the sleeve. This value is to the nearest hundredth of a millimetre (0.28 mm for Figure 3.16).

5. Add the values in steps 3 - 5. Therefore, for Figure 3.16,

Reading = Sleeve Scale Reading (SSR) + Thimble Scale Reading (TSR)

Observed reading = *SSR* + *TSR*

= 7.00 mm + 0.28 mm = 7.28 mm

Task 3.4

Diameter of a steel ball is measured using a vernier callipers which has divisions of 0.1cm on its main scale (MS) and 10 divisions of its vernier scale (VS) match 9 divisions on the main scale. Three such measurements for a ball are given as:

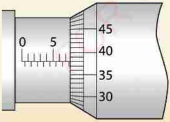
S. No.	MS (cm)	VS division
1.	0.5	8
2.	0.5	4
3.	0.5	6

If the zero error is – 0.03 cm, calculate the average corrected diameter is:

Example 3.4

What is the correct reading for the micrometer screw gauges shown in Figure 3.17?

(a)



(b)

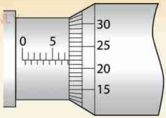


Figure 3.17: *Micrometer screw gauge readings*

Solution

From Figure 3.17 (a)

(a) Main scale reading = 7.50 mm
Thimble scale reading = 0.38 mm
Reading = 7.88 mm.

From Figure 3.17 (b)

(b) Main scale reading = 7.50 mm
Thimble scale reading = 0.22 mm
Reading = 7.72 mm.

Example 3.3

When a screw gauge with a least count of 0.01 mm is used to measure the diameter of a rod, the reading on the sleeve is found to be 1.6 cm and the reading on the thimble is found to be 48 divisions. What is the correct diameter of the rod, if the zero error for the gauge is − 0 003 cm?

Solution

Least count (LC) of a micrometer screw gauge given = 0.01 mm.

Main scale reading (*MSR*) = 1.6 cm or 16 mm .

Circular scale reading (*CSR*) = 48 divisions.

The reading $= MSR + CSR \times LC$

The reading
= 16 mm + 48 × 0.01 mm = 16.48 mm

Correct reading
= 16.48 + 0.03 = 16.51 mm.

Exercise 3.2

Answer all questions

1. What is the reading of the micrometre screw gauge in Figure 3.18?

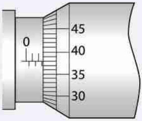


Figure 3.18: *Micrometer screw gauge readings*

2. What is the difference between a micrometer having 100 divisions and one with 50 divisions?
3. State one limitation of using a micrometer screw gauge to measure length.
4. The actual diameter of a lead ball is 3.21 mm. Determine the reading that would have been obtained if:
   (a) a micrometer screw gauge was used.
   (b) a vernier caliper was used.
5. When a screw gauge with a least count 0.01 mm is used to measure the diameter of a wire, the reading on the sleeve is found to be 0.5 mm and the reading on the thimble is found to be 27 divisions. What is the correct diameter of the wire, if the zero error for the gauge is - 0 005 cm?

Activity 3.2

Aim: To measure the diameter of a steel ball using a micrometer screw gauge.

Materials: Micrometer screw gauge, steel ball

Procedure

1. Unscrew the thimble anticlockwise to create a gap between the anvil and the spindle.
2. Hold the steel ball in the gap while rotating the thimble clockwise until it gently grips the ball.
3. Turn the ratchet knob until it clicks.
4. Record your observations.
5. Unscrew the thimble slightly. Free the ball and turn it through a certain angle. Then repeat step 3.
6. Record your second observation.
7. Repeat step 5 and note the third observation.

Questions

(a) Calculate the average of the obtained readings.

(b) Why would you prefer a micrometer screw gauge to a vernier caliper in measuring this diameter?

A micrometer screw gauge is more accurate than a vernier caliper. It measures up to three decimal places in the unit of mm. This means that its degree of precision is to the nearest thousandth of a centimetre. Unlike a micrometer screw gauge, a vernier caliper can only measure to a hundredth of a centimetre.

Task 3.5

Collect a variety of pieces of wire of different diameters, lead pencils and steel balls. In your groups:

1. Find out the smallest division on the main scale of your micrometer screw gauge and the number of divisions on the thimble.
2. Measure the diameters of the different objects. Each person in the group should measure at least one object. Record your findings in the following table.

Object	Sleeve reading (mm)	Thimble reading (mm)	Vernier reading (mm)	Actual diameter (mm)
Wire 1				
Wire 2				
Steel ball				
Lead pencil				

Measurement of time

Time is a measure of the interval between two events, or the period within which an event takes place. It is the precise moment as determined by a clock or a watch. The SI unit of time is second (s). There are smaller units of time that are based on the second. These are the millisecond (ms), the microsecond (μs), and the nanosecond (ns) as shown in Table 3.4.

Large units of time are minutes, hours, days, weeks, months and years as shown in Table 3.5.

Table 3.4: Small units of time

Time	Comparison with SI unit
1 millisecond (ms)	$\frac{1}{1\,000}$ s
1 microsecond (μs)	$\frac{1}{1\,000\,000}$ s
1 nanosecond (ns)	$\frac{1}{1\,000\,000\,000}$ s

Table 3.5: Large units of time

Time	Comparison with SI unit
1 day	$(24 \times 60 \times 60)$ s
1 hour (hr)	(60×60) s
1 minute (min)	60 s

Reading time using stopwatch

Time is used to indicate when an event occurs, the order in which several events occurs or the rate at which an event happens. Under normal circumstances, time is usually measured using a clock or a wristwatch as shown in Figures 3.19(a) and (b), respectively.

(a) Clock

(b) Wristwatch

Figure 3.19: *A clock and wristwatch*

For those experiments that require measurement of time in the laboratory, stopwatches are used. At this level, we shall concentrate on measuring time by means of a stopwatch.

A stopwatch is a device that is held in the hand and is used to show the time elapsed. Thus, the time interval is obtained from the time it is started to the time it is stopped. It is used when time must be measured precisely and with a minimum error. Stopwatches are used for timing laboratory experiments or sporting events like athletics.

There are two types of stopwatches, namely analogue stopwatch and digital stopwatch, as shown in Figure 3.20.

An analogue stopwatch has two scales, the minute scale and second scale. The pointer on each scale enables the time that has elapsed to be read, see Figure 3.20 (a).

(a) Analogue stopwatch (b) Digital stopwatch

Figure 3.20: *Stopwatches*

A digital stopwatch shown in Figure 3.20 (b) displays the actual time in hours, minutes, and seconds. Digital stopwatches are more accurate than analogue stopwatches. A large digital version of a stopwatch is called a stop clock. Stop clocks are designed for viewing at a distance, such as in sports stadia.

How to operate a stopwatch

The timing functions of a stopwatch are controlled by two buttons, one at the top of the watch and the other to the side of the watch. Pressing the top button starts the timer and pressing it again stops the timer. The elapsed time is then displayed on the screen. The side button usually has two functions, first, to reset the stopwatch to zero and second to record the split times or lap times. When it is pressed while the stopwatch is running, the elapsed time is displayed, with the watch mechanism continuing to run to record the total time elapsed.

Activity 3.3

Aim: To determine the period of a simple pendulum.

Materials: String, retort stand, analogue or digital stopwatch, object (200 g)

Procedure

1. With the guidance of your teacher, construct a simple pendulum by tying one end of the string to the retort stand.
2. Tie the 200 g object on the other end of the string.
3. Pull the object slightly to one side and release so that it swings back and forth.

4. Using a stopwatch, measure the time for the pendulum to swing back and forth ten times.
5. Record your observations.
6. Calculate the period (time for one complete oscillation).
7. Record your results.
8. Repeat steps 4-7 four times.

Question

Explain how you obtained the period (*T*) of the simple pendulum.

Measurement of mass

Mass is among the fundamental physical quantities of measurement. It is defined as the quantity of matter in an object. It measures the amount of matter in an object. The SI unit of mass is the kilogramme, written as kg. Other units of mass based on kilogramme are tonne (t), gramme (g) and milligramme (mg). Their equivalences are as given below. See also Table 3.6.

1 tonne = 1 000 kg.

1 kilogramme = 1 000 g.

1 gramme = 1 000 mg.

Table 3.6: A comparison of the units of mass

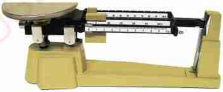
Mass	Comparison with SI unit
1 tonne (t)	1 000 kg
1 gramme (g)	$\frac{1}{1\,000}$ kg
1 milligramme (mg)	$\frac{1}{1\,000\,000}$ kg

Mass should not be confused with weight as is evidenced in day-to-day discussions and conversations. Weight is defined as a measure of the gravitational force acting on an object, or is the measure of how heavy an object is.

Measurement of mass using different instruments

The equipment commonly used to measure the mass of an objects in the laboratory is digital (electronic) balance, shown in Figure 3.21 (a), or triple beam balance shown in Figure 3.21 (b).

(a) Digital balance



(b) Triple beam balance

Figure 3.21: *Balances to measure mass*

A triple beam balance

A triple beam balance shown in Figure 3.21 (b) is used to measure the mass of an object. Its unit of measurement is the gramme. It is called triple beam balance because it contains three beams, each with specified standard mass graduations or markings. The first beam has 100 g graduations, the second has 10 g graduations while the third beam has 1 g graduations with 0.1 g graduations in between. To measure the mass of an object, the weights which are normally attached to each beam, are moved along the beams.

How to use a triple beam balance (Depends on the mass)

1. With the pan empty, move the three weights to the left of the beams, so that the balance reads zero, as shown in Figure 3.22. The balance pointer should be straight and aligned with the fixed mark at the right of the balance. If the pointer is not straight, use the counter weight to adjust as needed.

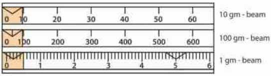


Figure 3.22: *A set triple balance*

2. Once the balance has been adjusted, place the object to be measured on the pan.
3. Move the 100-gram weight to the right along its beam until the indicator just drops below the fixed mark. The mark to the immediate left of this point indicates the number of hundreds of grams. Note down this value which is 0 for the case of Figure 3.23.
4. Move the 10 gram weight to the right along its beam until the indicator drops below the fixed mark. The mark immediately to the left of this point indicates the number of tens of grams. Note down this value, 20 for the case of Figure 3.23.
5. Move the 1 gram weight to the right along its beam until the pointer coincides directly with the fixed mark on the right, as shown in Figure 3.23. Note down this value which is 5 and given to the nearest tenth of a gram.

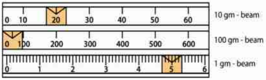


Figure 3.23: *The three weights showing the mass of the object*

6. To find the mass of the object on the pan, add the numbers from the three beams.

   That is, = 0 g + 20 g + 5 g = 25 g

Example 3.5

The diagram in Figure 3.24 shows the position of the three weights on the beams of a triple beam balance. Determine the mass of the object.

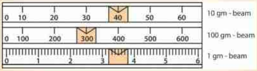


Figure 3.24: *Reading the triple beam balance*

Solution

We start with 100 g, 10 g, then 1 g. That is, 300 g + 40 g + 3.5 g = 343.5 g.

A digital balance

A digital balance shown in Figure 3.21 (a) is a very sensitive weighing balance. It can measure masses to an accuracy of one thousandth of a gram (0.001 g). The object whose mass is to be measured is placed on the pan on top of the balance and the mass read from the digital display.

Task 3.6

In your regular discussion groups, carry out the following:

1. Use a triple beam balance to measure the mass of your physics textbook, exercise book and your pen.
2. Use a digital balance to measure the mass of the same materials.
3. Compare the two measurements and discuss any differences.

Exercise 3.3

Answer all questions

1. Differentiate between estimated length and measured length.
2. State three basic fundamental quantities of measurement and their SI units.
3. Explain how the following fundamental physical quantities can be measured:
   (a) Length.
   (b) Mass.
   (c) Time.
4. Differentiate between the following items:
   (a) A stopwatch from a stopclock.
   (b) An analogue from a digital stopwatch.
   (c) Mass from weight.

Derived quantities

Derived quantities are obtained by combining the fundamental quantities through the application of basic arithmetic operations, namely multiplication and/or division. Their units are called derived units and the same method is used in deriving them. Examples of derived quantities are area, volume, density, velocity and acceleration. Their derived units are m^2, m^3, kg/m^3, m/s and m/s^2, respectively, as shown in Table 3.7.

Table 3.7: Derived quantities and their SI units

Physical quantity	SI unit	Unit symbol
Area	Square metre	m^2
Volume	Cubic metre	m^3
Weight	Newton	N
Density	Kilogram per cubic metre	kg/m^3
Pressure	Newton per square metre	N/m^2

These quantities are calculated using certain formulae or they are determined experimentally. For example, Area (A) of a square = length (l) × length (l) = $l \times l = l^2$. The SI unit of area is the square metre, m^2. However, areas of other regular shapes are calculated using their respective formulae depending on the shape of the object. This will be learnt more in mathematics lessons, though a few of them will be discussed in this textbook.

Measurement of volume

Volume is the quantity of space that an object occupies. The SI unit of volume is cubic metre (m^3). One cubic metre is the volume of a cube with sides 1 m long. Other units of volume includes:

(a) cubic centimetre (cm^3);

(b) millilitre (ml); and

(c) litre (l).

The cubic metre is rather a large unit of volume for everyday school laboratory work. For convenience purposes, volumes are measured using the cubic centimetre (cm^3). One cubic centimetre is the volume of a cube with sides 1 cm long, as shown in Figure 3.25.

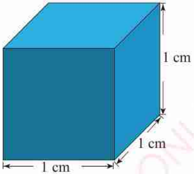


Figure 3.25: *A cube of 1 cm length*

Techniques for measuring volume

The techniques for measuring volume do vary depending on whether the sample is liquid, solid, or gas.

Liquids

Litre is another unit used for measuring the volume of liquids.

1 litre (l) = 1 000 cm^3 = 1 000 ml. This implies that 1 cm^3 = 1 ml. The volume of water in a 1- litre = $\frac{1}{1\ 000}$ m^3 as shown in Figure 3.26.

Figure 3.26: *One litre bottle of water*

Several graduated apparatus such as a graduated cylinder, burette or pipette are usually used to measure the volume of a liquid in the laboratory. Calibrated beakers and flasks can also be used. In rare cases, syringes are used for measuring the volume of liquids. A burette, a pipette or a volumetric flask gives accurate measurement of liquid volumes.

Measurement of volume using a measuring cylinder

Graduated measuring cylinders are used to measure the volume of a liquid, ranging from a few millilitres to hundreds of millilitres. They are of different sizes, made of glass or plastic. Measuring cylinders are graduated from the bottom upwards. They measure the volume of liquids that are poured into them. An example of a measuring cylinder is shown in Figure 3.27.

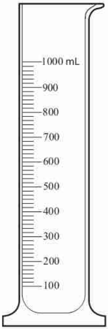


Figure 3.27: *Measuring cylinder*

When reading a measuring cylinder, the cylinder must be placed on a level surface. The curve in the upper surface of the liquid is called the meniscus. The meniscus can curve upward (concave) or downward (convex) depending on the liquid and the material of the cylinder. The volume of the liquid is read at the top of the meniscus or at the bottom of the meniscus, as illustrated in Figure 3.28 (a) and 3.28 (b), respectively. Note that the eye level should be in line with the meniscus of the liquid.

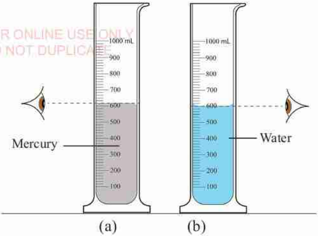


Figure 3.28: *Reading the volume of liquids in a graduated cylinder*
(a) top of meniscus (b) bottom of meniscus

Example

Figure 3.29, shows a 1 000-ml graduated cylinder containing a red-coloured water.

(a) What is the volume of water in ml?

(b) What is the volume of water in cm^3?

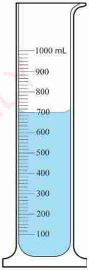


Figure 3.29: *A 1 000 ml graduated cylinder*

Task 3.7

Carry out the following task in groups of four students. Fill a drinking cup with water and then pour the water into a graduated measuring cylinder. Measure the volume of water and record. What is the reading on the cylinder?

Measurement of volume using a burette

A burette is a vertical cylindrical piece of laboratory glassware with a volumetric graduation on its full length and a precision tap, or stopcock on the bottom, as shown in Figure 3.30. It is used to dispense a required amount of a liquid reagent for which high precision is desired. A burette is graduated from the top downwards and measures the volume of a liquid that runs out from it. The use of a burette involves the following steps:

1. Pour the liquid into the burette and make sure that it does not pass the 0 mark at the top. Note down this volume, say V_1.
2. Note down the value of the amount of liquid you require to use, say V and add it to V_1 to get V_2.
3. Open the tap and let the liquid runs until the level of the liquid reaches V_2.
4. Subtracting V_1 from V_2 gives V.

Figure 3.30: *A burette*

Measurement of volume using a pipette

A pipette is a glass or plastic tube, usually open on both ends. A pipette is shown in Figure 3.31. It is used to transfer a known amount of a liquid from one container to another. The liquid is sucked into it until it reaches the level of the mark shown.

Figure 3.31: *A pipette*

Sometimes a flexible rubber bulb is placed at one end of the pipette to aid in sucking the liquid from a container, as shown in Figure 3.32.

Figure 3.32: *A rubber bulb with a pipette*

Common laboratory pipettes are calibrated with 20 cm^3, 25 cm^3 or 50 cm^3. The 20 cm^3 pipette is used to measure 20 ml of liquid while the 25 cm^3 and 50 cm^3 pipettes are used to measure 25 ml and 50 ml of liquid, respectively. This shows that pipettes are specifically made for transferring small amounts of liquids only from one container to another.

Activity 3.4

Aim: To measure volume of water using a pipette.

Materials: Pipette, beaker, graduated cylinder, water

Procedure

1. Pour 100 ml of water into a beaker.

2. Transfer 25 ml of water from the beaker to a graduated cylinder using a pipette.
3. Observe the meniscus of the water in the cylinder and record its reading.
4. Record the volume of water in the graduated cylinder.

Questions

(a) Compare the original volume of water in the pipette with the volume of water in the cylinder and state your observations.

(b) Is the volume of water transferred from the beaker equal to reading in the cylinder? Explain.

(c) Discuss your findings.

The volume of water transferred into the measuring cylinder equals the volume of the pipette. This is because the volume of a liquid does not change, irrespective of the apparatus used.

Measurements of a volume of a solid

(a) Determining the volume of regular objects

Dimensions of a solid with regular shape such as a cube, a cylinder or a sphere, can be measured and the appropriate formula is used to calculate its volume.

For example;

Volume (V) of a rectangular block = length (l) × height (h) × width (w). For a cube, $l = h = w$.

Volume of a cylinder

$$= \pi \times (radius, r)^2 \times (height,\ h) = \pi r^2 h$$

Volume of sphere $= \dfrac{4}{3}\pi r^3$

Example 3.6

Calculate the volume of a rectangular block, of sides 15 cm, 8 cm and 7 cm, as shown in Figure 3.33.

Solution

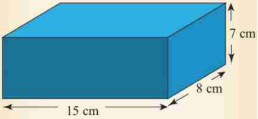


Figure 3.33: *Rectangular block*

Volume of the block = $l \times w \times h$

= 15 cm × 8 cm × 7 cm = 840 cm^3.

Example 3.7

Calculate the volume of the cylinder shown in Figure 3.34, given that $\pi = 3.14$.

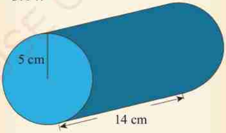


Figure 3.34: *Cylinder*

Solution

Given, $\pi = 3.14$, $r = 5$ cm and $l = 14$ cm

Formula for calculating volume of a cylinder $V = \pi r^2 l$

Substituting in the formula gives,

$V = 3.14 \times 5$ cm × 5 cm × 14 cm

= 1099 cm^3.

(a) Determining the volume of irregular solid objects

Measuring the volume of an irregular shaped solid object is based on the Archimedes' principle which states that 'when an object is completely submerged in water, it displaces a volume of water equal to its own volume'. The displacement or immersion method is used.

The volume of an irregular object can be measured using:

(a) a measuring cylinder; and
(b) eureka can or an overflow can.

Volume of irregular object by using a graduated cylinder

Suppose you want to measure the volume of a small stone.

The following steps are necessary.

1. Fill a graduated cylinder with about 300 ml of water as shown in Figure 3.35 (a).
2. Carefully measure the initial volume of water V_1.
3. Then gently lower the stone into the water as shown in Figure 3.35 (b).
4. Read the final volume of water V_2.
5. The difference between the final and the initial volume gives the volume of the stone.

$$\textit{Volume of the stone}(V_s) = \textit{final volume}(V_2) - \textit{initial volume}(V_1)$$

$$V_s = V_2 - V_1.$$

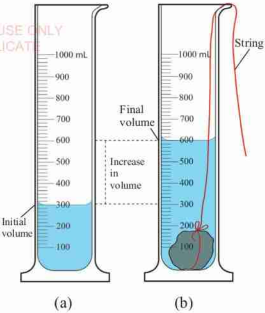


Figure 3.35: *Measuring the volume of an irregular object*

In the illustration,

$$V_s = 600 \text{ ml} - 300 \text{ ml} = 300 \text{ ml}.$$

Example 3.8

When an irregular solid object was immersed in 65 cm³ of water, the water level rose to 81 cm³. What was the volume of the irregular solid object?

Solution

Initial volume of water $V_1 = 65 \text{ cm}^3$

Final volume of water $V_2 = 81 \text{ cm}^3$

Using volume of solid, $V_s = V_2 - V_1$ gives

$$V_s = 81 \text{ cm}^3 - 65 \text{ cm}^3 = 16 \text{ cm}^3$$

Therefore, the volume of the irregular solid is 16 cm³.

Volume of an irregular objects by using eureka can

If the object is too large to fit into the graduated cylinder, an alternative method is to use an overflow can commonly known as a eureka can as shown in Figure 3.36. This is a large can with an overflow spout near the top. In practice, the following steps are involved when using an overflow can to measure the volume of an irregular object.

1. Fill the eureka can with water up to the level of the spout.

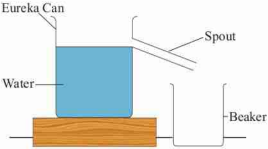


Figure 3.36: *Set up a Eureka Can*

2. Tie the irregular object with a string.
3. Gently lower the object into the water using the string.
4. The object will displace some water which will be collected in the beaker, as shown in Figure 3.37.

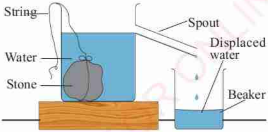


Figure 3.37: *Water displaced*

5. Transfer the displaced water into a graduated cylinder, as shown in Figure 3.38.
6. Measure the volume of the displaced water which is equal to the volume of the object.

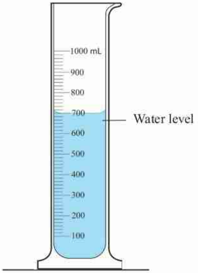


Figure 3.38: *Reading the volume of the stone*

Note: Hence, the volume of solid objects with irregular shape can be determined by using immersion methods.

Activity 3.5

Aim: To measure volume of an irregular object using a eureka can.

Materials: eureka can, stone, water, beaker, graduated cylinder, string

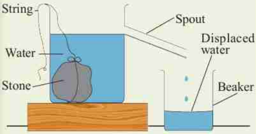


Figure 3.39: *Water displaced*

Physics Form 1 05/09/2021 Final.indd 70 05/09/2021 15:50

Procedure

1. Set up the apparatus as in Figure 3.39.
2. Tie the stone with a string and gently lower it into the water contained in the eureka can.
3. Collect the overflowing water in the beaker below the spout.
4. Measure and record the volume of the displaced water using a measuring cylinder.
5. This volume is equal to the volume of the stone.

Questions

(a) Why must the stone be tied and gently lowered into the water?

(b) Why is the water in the eurica can displaced when the stone is immersed?

The stone is tied before lowering it so as to prevent water from splashing. This would give wrong results as the remaining water level would be lower than the spout level. It would also interfere with the volume to be measured. The water is displaced so as to give room for the stone. The stone occupies a volume which is equal to the volume of water displaced.

If the solid has an irregular shape such as a stone, it is submerged in a measuring cylinder containing water and the volume of water displaced is taken as the volume of the solid.

Determination of volume of gases

A gas always fills any container into which it is placed. Therefore, the volume of a gas can be determined by measuring the volume of the container into which it is put. The volume of the container can be determined from its dimensions or by filling it with water and then pouring the water into a graduated cylinder.

Exercise 3.4

Answer all questions

1. Calculate the volume of a cube of sides 2 cm.
2. The volume of a brick is given as 60 cm^3. Given that its length and width are 6 cm and 4 cm respectively, calculate its height.
3. A cylindrical container has a diameter of 10 cm and a height of 12 cm. Calculate its volume, given that $\pi = 3.14$.
4. A beaker contains 100 cm^3 of liquid. A 25 cm^3 pipette is used twice to transfer the liquid to another beaker. What is the volume of the liquid left in the original beaker?
5. The initial volume in a burette was read as 80 cm^3. X cm^3 of the liquid was run out and the final volume was read as 57 cm^3. Calculate the value of X.
6. What is the volume of an irregular solid immersed in 50 cm^3 of water contained in a beaker if it raises the water level to 57 cm^3.

Sources of errors

While taking any measurement, there may be some error in the reading. An error is defined as a deviation from the actual reading. However, there is a more precise definition. An error is a measure of estimated difference between the measured value and the actual value of a physical quantity that is being measured or observed.

Errors usually arise due to several reasons:

1. Fault during manufacture – If a measuring instrument is not manufactured as per specification, then the accuracy is lowered.
2. Damage during use – Bad handling of instruments can lead to incorrect results. Each apparatus should be used properly and for the right purpose.
3. Poor storage – Apparatus should be well stored away from factors that affect their accuracy like dust and heat.
4. Human factors – Errors can arise when an experimenter does not take readings from an instrument properly. The three common errors due to improper reading of an instrument are:
   (i) Parallax error;
   (ii) Zero error; and
   (iii) Instrumental error.

Parallax error

Parallax error occurs when an observer takes measurement from wrong positions. Consider Figure 3.40.

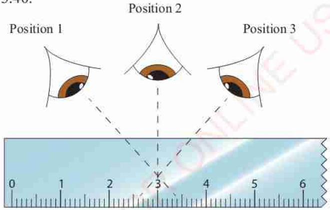


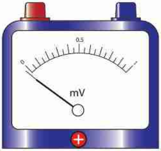
Figure 3.40: *Parallax error*

Positions 1 and 3 will give higher and lower readings than position 2. A reading taken at position 2 will be correct because the observer has positioned his/her eyes directly above the mark to be read.

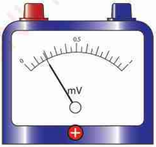
To minimize parallax error, the observer must position his/her eyes directly above the mark to be read.

Zero error

For a measurement to be considered accurate, the initial reading of a pointer should be at a zero mark.



(a) Pointer below zero mark



(b) Pointer after zero mark

Figure 3.41: *Zero errors of a voltmeter*

When a measurement is taken with an instrument with the pointer below or above the zero mark as shown in Figure 3.41 (a) and Figure 3.41 (b), zero error is said to occur. To minimise zero error, the instrument should be adjusted to read zero, as shown in Figure 3.42. A pointer can be adjusted to read zero.

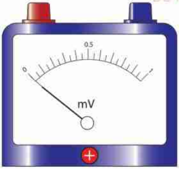


Figure 3.42: *Pointer at the zero mark*

For example, in a vernier caliper, zero error arises when the zero mark on the main and vernier scales do not coincide with each other when the jaws are closed. A micrometer screw gauge may also have zero error if the zero marks on the spindle and sleeve do not coincide after closing the gap between the spindle and the anvil.

Instrumental error

An instrumental error is caused by an instrument itself. The error occurs because of defects in the instrument used in taking a measurement. These defects can be from the manufacturer or they may result from poor handling of the instrument. Sometimes errors of this type may occur when the instrument used for measuring is overheated. Also, insensitivity of the instrument can result in this error. To minimise these errors, avoid overheating instruments, maintain them regularly and store all instruments in a safe place free from dust. Proper handling of instruments is also recommended.

Chapter summary

1. Initially, approximations were used as a form of measurement. Advancement in science has made it possible to have appropriate instruments for each type of measurement.
2. Every measurement has the number part and the unit part. This complete measurement is called measurement of a physical quantity.
3. Fundamental quantities are the physical quantities which cannot be obtained from any other quantities. These quantities include length, mass, time, temperature, amount of substance, electric current and luminous intensity.
4. The three fundamental quantities of measurement are mass, length and time. Their SI units are the kilogramme, metre and second, respectively.
5. The beam balance and digital balances are used to measure mass, while rulers, vernier calipers, micrometer screw gauges and tapes are used to measure length. On the other hand, time is measured using a stopwatch or a clock.
6. Derived quantities are obtained by dividing or multiplying two or more fundamental quantities. These quantities include weight, acceleration, velocity, volume and area. Their SI units are the Newton, metre per second square, metre per second, cubic metre, and square metre, respectively.
7. There are three types of errors that emerge during measurements, namely:
   (a) parallax error;
   (b) zero error; and
   (c) instrumental error.

Revision exercise 3

Section A

Choose the most correct answer

1. To measure the length using a metre rule, wrong position of the eye leads to:
   (a) parallax error.
   (b) eye error.
   (c) zero error.
   (d) metre error.
2. Which of the following instruments is most suitable for measuring the internal diameter of 100 ml beaker?
   (a) Metre rule.
   (b) Vernier caliper.
   (c) Measuring tape.
   (d) External caliper.
3. The mass of an object is reduced if its
   (a) state is changed.
   (b) amount of matter is reduced.
   (c) surface is reduced.
   (d) volume is reduced.
4. A cuboid with length 3 cm, width 4 cm and height 10 cm is made from wood. The actual volume of the cuboid is
   (a) 120 cm^3.
   (b) 240 ml.
   (c) 120 m^3.
   (d) 240 cm^3.
5. What is the zero error shown in the Figure 3.43?

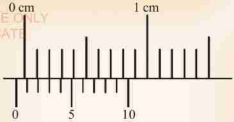


Figure 3.43

   (a) 0.3 mm.
   (b) 0.7 mm.
   (c) -0.3 mm.
   (d) -0.7 mm.

Section B

6. (a) From the list given below classify them in terms of regular or irregular shape.

   cube, orange, stone, banana, water pipe, a house, cuboid, chalkboard.

   (b) The internal and external radius of a hollow silver sphere are 7 cm and 14 cm, respectively. Find its volume.
7. (a) Write down the principal steps used in reading the vernier caliper.
   (b) In a vernier calliper, there are 10 divisions on the vernier scale and 1 cm on main scale is divided in 10 parts. While measuring a length, the zero of the vernier scale lies just ahead of 1.8 cm mark and 4th division of vernier scale coincides with a main scale division. Find the value of the length.

8. (a) Differentiate between the mass and the volume of a substance.

(b) Figure 3.44 shows a measuring cylinder containing water before and after a stone is immersed. What is the volume of the stone?

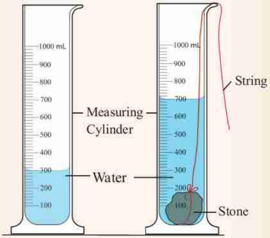


Figure 3.44

9. (a) Figure 3.45 shows a metre rule being used to measure the length of a textbook.

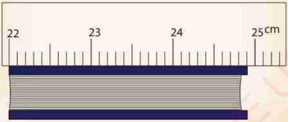


Figure 3.45

What is the approximate length of the book?

(b) Explain why it is advised to start at the mark beyond 1 cm when taking a measurement using a metre rule.

10. A physics student obtained the following results for the diameter of the same wire from an experiment: 0.35 mm, 0.36 mm and 0.34 mm. Calculate the diameter of the wire.

11. A rectangular block measures height 1.00 cm, width 2.50 cm, and length 4.00 cm.

(a) What instrument was used to measure the sides of the rectangular block?

(b) Calculate the volume of the rectangular block.

Chapter Four

Force

Introduction

The word force is often used in everyday situations. The interaction between two or more objects involves forces acting between them. Objects that are flying, hanging, balancing, moving, and spinning are all subjected to some kind of force. Almost every activity you do in daily life requires the application of force. This means, there are several types of forces and with different effects. In fact, it is hard to imagine a world without forces. In this chapter, you will be introduced to different types of forces and their effects. The competencies developed will enable you to classify forces as well as effectively interact with forces in your daily life.

Concept of force

If an object is at rest, it will remain in the state of rest unless some actions are performed to make it move. Similarly, if an object is in motion it will require some actions to make it stop unless otherwise it will keep moving. For example, in order for a cart at rest to move it needs to be pushed or pulled. Similarly, a stationary car should be pulled or pushed to make it move. The action of pushing or pulling objects in order to accomplish an intended task involves force. Figure 4.1 shows a cart being pulled and a car being pushed.

(a) A person pulling a cart

(b) A person pushing a stationary car

Figure 4.1: *Pulling and pushing actions*

A force can therefore be defined as a push or pull experienced by an object. It is usually described in terms of its magnitude and direction. The SI unit of force is Newton, N. One Newton is the amount of force required to give a mass of one kilogramme (1 kg) an acceleration of 1 m/s^2. Therefore, $1\ N = 1\ kg \times 1\ m/s^2$.

Effects of forces

An object is stationary when all forces acting on it are balanced. If a new force is applied to the object the forces become unbalanced. The result of unbalanced forces on an object can cause various effects on the object. These effects include:

(a) change in state of motion of an object;

(b) change in the way the object moves;

(c) change of shape or size of the object; and

(d) change of direction in which an object is moving.

Activity 4.1

Aim: To demonstrate force.

Materials: Carton of books, rubber bands, and coil spring

Procedure

1. Move the carton of books from one end of the class to another without lifting it.
2. Stretch a rubber band until it is close to its breaking point.
3. Compress a coil spring between your hands.
4. Stretch the coil spring until it extends in length.

Question

In each case, what action makes an object changes its shape or direction?

To move the carton of books, there is a need to either pull or push it. This means that a force has to be applied. The rubber band is pulled to stretch it while the spring is pushed to compress it. These activities demonstrate that force is needed to push or pull an object.

Determination of the magnitude of force

A spring balance can be used to estimate the magnitude of force. It consists of a coiled spring fixed to support at one end, with a hook at the other end as shown in Figure 4.2 (a).

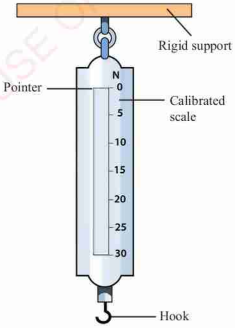
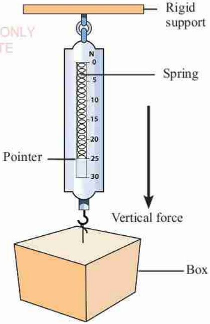


Figure 4.2: *A spring balance*

The body upon which the force acts is attached to the hook. The distance through which the spring is stretched is directly proportional to the magnitude of the force applied by the body. A pointer is attached to the spring and the magnitude of force is indicated on a calibrated scale. The larger the force, the more the spring is stretched and the higher the reading on the scale. The spring balance can be used to measure vertical and horizontal forces acting on a body, as shown in Figures 4.3 (a) and (b).

(a)



(b)

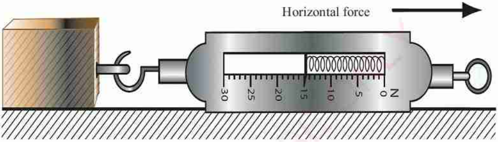


Figure 4.3: *Spring balance used to measure forces*

In Figure 4.3(a), the weight of the empty box is shown by the pointer on the spring balance. Similarly, if you the weigh the same box filled with sand the pointer will indicate the greater weight than that of the empty box. This is because the weight of the sand adds to the weight of the box. To get the weight of sand you need to subtract the weight of the box from the weight of the box filled with sand.

Types of forces

Some forces in the environment occur naturally while others are derived from natural forces. The naturally occurring forces are known as fundamental forces while the derived forces are referred to as non-fundamental forces. There are four types of fundamental forces: force of gravity, electromagnetic force, strong force, and weak force. All other types of forces are derived from these fundamental forces. Examples of derived forces are elastic and frictional forces. Depending on the interaction between objects, all forces can be classified as non-contact or action-at-a-distance force and contact force.

Non-contact (Action-at-a-distance) forces

These are forces which act on objects when the interacting objects are not in physical contact with each other, yet are able to exert a push or pull upon each other. All natural forces are classified as non-contact or field forces. Examples of non-contact forces are magnetic force and electric force.

Force of gravity

Force of gravity is the force of attraction between objects which have mass. All objects having mass are pulled towards the earth's centre by the earth's force of gravity. It is because of the earth's force of gravity that bodies in air move towards the earth's surface despite of their sizes. For example, some fruits fall from a tree because the earth exerts gravitational force on it. Human beings are able to walk properly because of the earth's forcegravity. The magnitude of the earth's force gravity on an object is referred to as the object's weight, which is equal to mass, m multiplied by the acceleration due to gravity, g. That is;

$$Force\ of\ gravity = weight\ of\ an\ object$$

But,

$$weight(w) = mass(m) \times (g)$$

Normally we write,

$$w = mg$$

Where, w - Weight of object

m - Mass of object

g - Acceleration due to gravity

> Weight is defined as the attractive force towards the earth's centre exerted by the earth on object.

The following are properties of gravity force:

(i) It is always attractive.

(ii) It is the weakest force among the four fundamental forces.

(iii) It is a central force (gravitational force between two objects act along the line joining the centres of the objects).

(iv) It operates over very long distances.

(v) It decreases as the distance between the mass and the earth increases.

Your weight is the gravitational force that the earth exerts on you. Remember that gravity is an action-at-a-distance force so even when you jump into the air, as shown in Figure 4.4, the earth still exerts its gravitational force on you. This is the force that prevents you from flying off on a spinning earth. The gravity force is also responsible for keeping a satellite in its orbit around the earth and planets in their orbits around the sun.

The difference between mass and weight is that mass is the quantity of matter in a body while weight is attractive force. Mass does not change while the weight of the body changes with position depending on accelleration due to gravity.

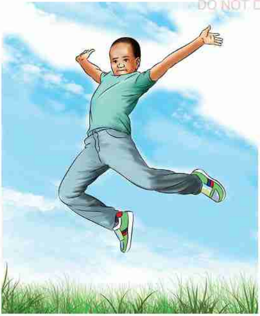


Figure 4.4: *Jumping up*

It should be understood that the weight of an object is related to its mass. For instance, on the earth's surface, an object with a weight of 1 N has also a mass of approximately 0.1 kg or 100 g. The ratio of weight (N) to mass (kg) gives approximately 10 N/kg which is always constant and is represented by "g".

So, g has two meanings:

(i) It is the gravitational field strength of the earth (10 N/kg); and

(ii) It is the acceleration due to gravity (10 m/s^2).

Near the earth's surface, there is a force of gravity of 10 Newtons for each kilogram of mass (see Figure 4.5). Thus, the earth's force of gravity is 10 Newtons per kilogram (10 N/kg).

Note that, the acceleration due to gravity varies depending on the reference body. For example, the acceleration due to gravity on the moon g_m is equal to one-sixth of the acceleration due to gravity on the earth, g_e.

That is, $g_m = \frac{1}{6} \times g_e$

If $g_e = 10$ N/kg,

then, $g_m = \frac{1}{6} \times 10 \text{ N/kg} = 1.67 \text{ N/kg}$.

Thus, you would weigh less on the moon than on the earth.

Figure 4.5: *Force of gravity acting on the bodies*

Example 4.1

Assume a fixed mass rocket in Figure 4.6, moves from the earth to a planet *X*. If it weighs 10 000 N on the earth and 300 N on planet *X*, determine the acceleration due to gravity on planet *X*.

Figure 4.6: *Launching a rocket*

Solution

Let the weight on the earth be w_e.

So, the weight of the rocket on earth is

$$w_e = m_e g_e$$

where m_e is the mass of the rocket on earth and g_e is the gravitational field strength on earth which is 10 N/kg

$$m_e = \frac{w_e}{g_e}$$

$$= \frac{10\ 000\ \text{N}}{10\ \text{N/kg}}$$

$$m_e = 1\ 000\ \text{kg}$$

Weight of rocket on planet X, w_X

Thus, $w_X = m_X g_X$

But, $m_X = m_e$

$$w_X = m_e g_X$$

$$g_X = \frac{w_X}{m_e} = \frac{300\ \text{N}}{1\ 000\ \text{kg}}$$

$$g_X = 0.3\ \text{N/kg}$$

Therefore, the acceleration due to gravity on planet X is 0.3 N/kg.

Activity 4.2

Aim: To measure force using a spring balance.

Materials: Spring balance, box, and sand

Procedure

1. Use a spring balance to measure the weight of an empty box. Record your readings.
2. Fill in the box with sand.
3. Measure the weight of the box containing sand. Record your reading.

Questions

(a) What is the weight of the empty box?

(b) What is the weight of the box when filled in with sand? Explain the difference.

Electromagnetic force

This is a force that includes both electric and magnetic forces. It is relatively stronger than the force of gravity.

The following are examples where electromagnetic forces are involved:

(a) In the formation of molecules of a substance. Atoms attract each other to form molecules. This is due to electromagnetic forces.

(b) If two parallel wires carrying current are placed near each other, the electromagnetic force acts on the wires.

Properties of electromagnetic force are:

(i) it is attractive or repulsive in nature;
(ii) it is a central force (originates from the centre or toward the centre);
(iii) it is stronger than gravitational force;
(iv) it is a long-range force (operates over a very long distance);
(v) its strength decreases as the distance between the objects increases; and
(vi) its direction depends on the charges of the objects involved.

Strong force

This is a nuclear force that binds protons and neutrons together to form atomic nuclei. The action of strong force results to binding energy which can be felt when splitting of a large nucleus into small fragments (fission) or combining two or more nuclei to form a bigger nucleus (fusion), as shown in Figure 4.7.

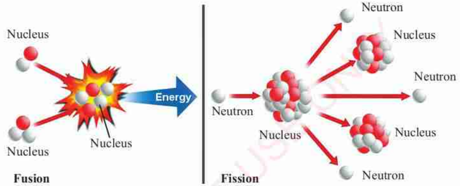


Figure 4.7: *Nuclear fusion and fission*

The strong force has the following properties:

(i) It is basically an attractive force.
(ii) It is a short-range force (operates in a distance ranging from 0.7 fm to 2.5 fm).
(iii) It is a non-central force (does not originate from the centre).
(iv) It is stronger than gravitational force.
(v) It does not depend on charges of objects.

Weak force

This is a nucleal force which appears only in a certain nuclear processes. The following are properties of the weak force:

(i) It is much stronger than the gravitational force but weaker than the strong and electromagnetic forces.
(ii) It acts on a small range of about 0.01 fm to 0.001 fm.

Exercise

1. Is an astronaut in space completely weightless? Explain your answer.
2. How much do you weigh on the earth? Would you weigh the same on the moon? Explain your answer.
3. Estimate your mass on the earth. If you are standing on the moon, do you think your mass on the moon will be the same? Discuss your answers.
4. Amina has a weight of 600 N. What is her mass?

Contact forces

These are forces which require physical contact to occur. They include: stretching, compression or restoring, attraction, repulsion, torsion, friction, viscous forces, and air resistance. These forces result from the interaction of fundamental forces. Hence, they are non-fundamental forces. Each force has particular effects on the objects to which it acts on. Hence, these forces are discussed based on their effects.

Frictional force

This is the force which opposes motion between two surfaces of objects in contact. Friction occurs when one surface of an object is resting or moving over another. Friction is a very common force. Whenever one object slides over another object, friction tries to stop the movement. For example, if a block is made to rest on a table top, its weight acts on the table. But if the block is tied with a string and made to slide (pulled) as shown in Figure 4.8, there is some kind of resistance to the movement of the block. This is the work of friction.

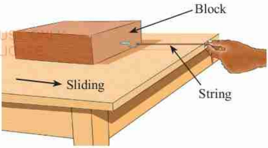


Figure 4.8: *Sliding a block on the table top*

Frictional force occurs depending on the nature of the surfaces of bodies in contact. Friction produces heat, as is the case in matchsticks. Wear and tear of car tyres and shoe soles are caused by friction. For example, Figure 4.9 (a) shows new tyres and Figure 4.9 (b) shows worn out tyres due to frictional force.

(a) New tyres

(b) Worn out tyres

Figure 4.9: *New and worn out car tyres showing the effects of friction*

Activity 4.3

Aim: To demonstrate frictional force.

Material: Pieces of wood

Procedure

1. Rub the palms of your hands against each other. What do you feel?
2. Rub them hard and record your observation.
3. Vigorously, rub the two blocks of wood against each other. What do you observe?
4. Record your observations.

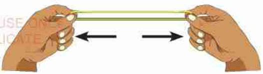
Questions

(a) Explain your observations.
(b) What is your conclusion?

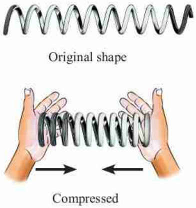
When two objects in contact rub against each other, heat is produced. Frictional force, unlike other forces, produces heat. Frictional force results to wastage of energy in the form of heat in engines. This heat can wear the moving parts of an engine and results to reduction in its performance.

Stretching and compressional forces

Stretching force is the force exerted on an object when its two ends are pulled apart. On the other hand, compressional force is the force which tends to reduce the size of an object. Stretching and compressional forces are important in dealing with elastic materials, such as a rubber bands, springs, wire and ropes. Figures 4.10 (a) and (b) show stretching forces on a rubber band and compressional force on a spring, respectively.



(a) Stretching force on the rubber band



(b) Compressional force on a spring

Figure 4.10: *Stretching and compressional forces*

Elastic (Restoring) force

Some materials tend to restore their original shapes and sizes when a force acting on them is removed. Such materials are said to be elastic materials. Examples of elastic materials are rubber bands and springs. As one stretches or compresses an elastic material, such as a spring, it resists the change in shape. The material exerts a counter force in the opposite direction to the stretching or compressing force. This force is called elastic force. As soon as the stretching or compressing force is removed, the elastic force causes the material to return to its original shape. Hence, the elastic force is also called a restoring force. Figure 4.11 illustrates the deformation and restoration of a spring.

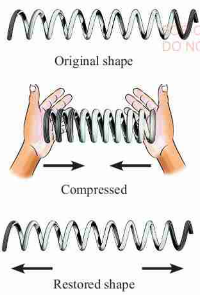


Figure 4.11: *Restoring force of a spring*

Air resistance

Air resistance is the force that resists the movement of an object through the air. Air resistance is an example of fluid resistance or fluid force. It is the force exerted on an object moving through a fluid (liquid or gas). This force depends on:

(a) the size and shape of the object;
(b) the speed of the object through the fluid; and
(c) the density of the fluid.

Air resistance is most noticeable in objects moving at high speeds or objects with large surface areas. For instance, a runner has to exert force so as to oppose the force of a blowing wind. On the contrary, if the runner moves along the direction of the wind, the wind provides the force that increases his or her speed. Air resistance slows down many moving objects such as a cars and even cyclists, as shown in Figure 4.12 (a). However, air resistance is advantageous to parachutists since it acts against the force of gravity on the parachute and slows its downward motion, as shown in Figure 4.12 (b). A submarine must overcome air resistance above the water surface and water resistance beneath it, as shown in Figure 4.13.

(a) A cyclist bends to reduce his air resistance

(b) A parachutist using air resistance to slow down a high speed falling down

Figure 4.12: *Effect of air resistance*

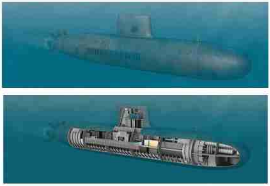


Figure 4.13: *Submarine overcomes air resistance beneath and above water surface*

Task 4.1

In groups of five students, discuss why engineers spend so much time trying to reduce fluid resistance in cars, ships, and planes.

Viscous force

Viscous force is the force between an object and a fluid moving past it. The force acts in a certain direction so as to oppose the flow of the fluid past the object. From day-to-day observations, water has a smaller viscous force than cooking oil. On the other hand, honey has a large viscous force than cooking oil. Figure 4.14 shows the visual identification of viscosity.

(a) Water viscosity

(b) Honey viscosity

Figure 4.14: *Comparison of water and honey viscosity*

Viscosity is the measure of a fluid's resistance to flow. When a highly viscous liquid runs off a surface, its inner layer sticks to the surface so that the other layers have to slide over each other. Friction between the layers stops them from sliding easily, thereby making the whole liquid to flow slowly. Another effect of viscosity is that a highly viscous liquid will resist the motion of objects through it. High viscosity is a necessity property in lubricants. Lubricants like oil and grease are meant to reduce friction in the moving parts of machinery. Grease has a higher viscosity than oil.

Activity 4.4

Aim: To demonstrate viscosity of substances.

Materials: Water, cooking oil, honey or lubricanting oil, beakers, stopwatch, plastic can, seal tape

Procedure

1. Clean a plastic can and drill a hole near the bottom.

2. Seal the hole using seal tape.
3. Fill in the can with water.
4. While starting the stop watch, unseal the hole on the can.
5. Allow all the water to flow out from the can into the beaker. Record the time taken.
6. Clean the can, dry and reseal the hole.
7. Repeat steps 3 to 6, using oil and honey one at a time.

Question

Which of the liquids has high viscosity or resistance to flow?

It takes longer for honey to flow into the beaker than it does for cooking oil. Honey has a higher resistance to flow. Therefore, we can say that honey is more viscous than cooking oil.

Tension force

The tension force is the force transmitted through a string, rope, cable, or wire when it is pulled tight by forces acting from opposite ends. The tension force is directed along the length of the wire and pulls outwards along the two ends of the rope. Figure 4.15 shows the tension force along the stretched cable wire.

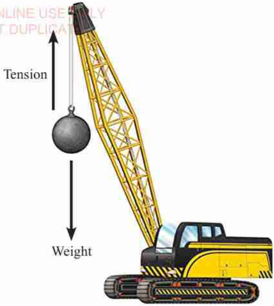


Figure 4.15: *Tenson force along the cable wire*

Buoyant force

Buoyant force is the force that causes objects to float. It is the force exerted on an object that is partly or totally immersed in a fluid. Buoyant force is caused by differences in pressure acting on opposite sides of an object immersed in a static fluid as shown in Figure 4.16. This is the reason why an object feels lighter when immersed in a fluid but heavier just above the surface of the fluid.

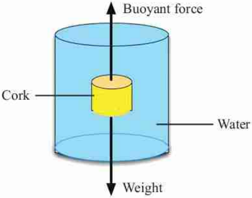


Figure 4.16: *Buoyant force*

Normal force

This is a support force exerted upon an object which is in contact with another stable object. The normal force is also called reaction force and it acts perpendicular (at right angle) to the surface in contact. For example, if a book is resting on a table, then the table is exerting an upward force on the book in order to support the weight of the book, as shown in Figure 4.17.

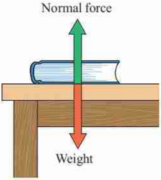
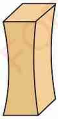


Figure 4.17: *A normal force*

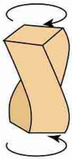
When a person leans against a wall, the wall supports the person by pushing him or her away perpendicular to the wall.

Torsional force

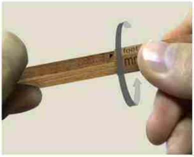
This is the force produced on a solid object when it is twisted. It is an elastic force as the object's shape returns to its original shape when the force is removed. An example of torsional force is in twisting a rubber or a ruler, as shown in Figures 4.18 (b) and (c). Figure 4.18 (a) shows untwisted rubber.



(a) Normal



(b) Twisted



(c) Twisting a ruler between the ends

Figure 4.18: *Illustration of tortional force*

Task 4.2

1. In a group of five students, state the four types of contact forces and discuss the properties of each type. State their uses in everyday life. Present your findings in class.
2. Hang two balloons on a wall side by side and allow them to touch each other. Rub each one of them with a dry cloth. What happens? Explain.
3. Place a bar magnet on a smooth table and then bring another bar magnet near it. What happens? Explain.
4. Starting with two bar magnet parallel to each other, rotate one bar magnet by 90° and bring it near the first magnet. What happens? Explain.

Chapter summary

1. A force is a push or pull experienced by an object. It results from the interaction between two objects.
2. Forces can cause a change;
   - in the speed or direction of an object's motion;
   - in the shape and size of an object; and
   - in the way an object moves.
3. Some forces act through physical contact between two objects while others can at a distance.
4. Force is measured in Newtons.
5. A spring balance, which is based on elastic force, can be used to measure various forces, including weight.
6. Weight is a measure of the gravitational force exerted on an object.
7. There are four fundamental forces, namely:
   - gravitational force;
   - electromagnetic force;
   - the strong force; and
   - the weak force.
8. Forces produce several effects when in action. These include stretching, compressing, bending and rotating or turning effects.
9. Friction is a resistance force that an object encounters when resting or moving over another object.
10. A compressional force is the force which when applied to an object results in a decrease of its volume.

Revision exercise 4

Section A

Choose the most correct answer

1. Which of the following is not a force at a distance?
   (a) Electrostatic force.
   (b) Force of gravity.
   (c) Frictional force.
   (d) Magnetic force.

2. Force of gravity is a
   (a) contact force.
   (b) consequential force.
   (c) action-at-a-distance force.
   (d) muscular force.

3. The force acting on a stone falling from the roof of a house is an example of
   (a) falling force.
   (b) magnetic force.
   (c) force of gravity.
   (d) electrostatic force.

4. What is the force acting on a book that is dropping in to the floor?
   (a) Gravity only.
   (b) Gravity and air resistance.
   (c) Air resistance.
   (d) Friction only.

5. The balls in Figure 4.19 have the same size. Which will hit the ground first if they are dropped at the same time and at the same height?

Wooden ball Plastic ball Metal ball

Figure 4.19

(a) metal first, then wood, then plastic last.
(b) wood first, then plastic, then metal last.
(c) they will all hit at the same time
(d) there is no way to tell.

6. A falling object is pulled down by the earth. The earth is pulled up towards the object. Why doesn't the earth move?
(a) Because the earth has only gravity.
(b) Because the earth has a very large mass and a small acceleration.
(c) Because the earth has a very small mass and a large acceleration.
(d) Because air resistance gets in the way.

7. Match item in column A with its corresponding item in column B. Then, write the letter of the correct response in the provided space.

Column A	Answer	Column B
1. Stretching		A. effect of magnet on iron material
2. Attraction		B. force in string
3. Friction		C. compression of rigid material such as spring
4. Viscosity		D. rough surface
5. Restoring		E. motion in fluid

8. Fill in the blanks in the following items.
(a) Force is an external agent which……. or tends to change the state of rest or uniform…… of a body.
(b) The force of ………. always attracts objects towards the earth.
(c) The force of ……...attracts tiny pieces of paper.
(d) …………. force can pull objects made of iron.
(e) …………… always oppose the motion of body.

Section B

9. From Figures 4.20 - 4.23 identify the force(s) that are acting.
(a) Force: __________________

Figure 4.20

(b) Forces are ______ and ______

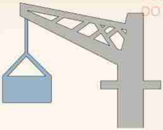


Figure 4.21

(c) Forces are______ and ______

Figure 4.22

(d) Forces are______ and ______

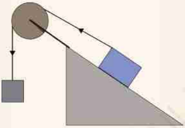


Figure 4.23

10. If an object weighs 30 N on the earth, what is its mass?
11. If an object has a mass of 200 g on the earth, how much would it weigh on the moon?
12. An object weighs 200 N on the earth. What would be its mass on the moon?
13. Suppose that the scale on a spring balance is unreadable. When a 150 g object is hung from the scale the pointer moves down a distance of 3 cm as shown in Figure 4.24.

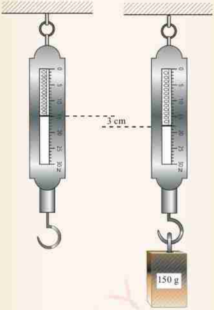


Figure 4.24 3 cm

The object is then placed on a table and reattached to the spring balance as shown in Figure 4.25.

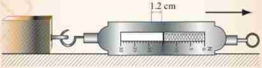


Figure 4.25

The scale is then pulled to the right and at the moment the object begins to move, the pointer is found to have moved 1.2 cm to the left. What is the force between the object and the table?

14. State the four fundamental forces.

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Chapter Five

Density and relative density

Introduction

Density is an important concept for scientists and engineers because it is useful in determining the characteristics of a material. Engineers must think of density of the materials before marine and air transport vessels can be designed and built so that they will float. For example, aircrafts are made of aluminium alloys and not steel since aluminium is less dense than steel. In this chapter, you will learn the concept of density, how to determine the densities of solids and liquids, the concept of relative density and determination of relative density of solids and liquids. The competencies developed are useful in designing and construction of models for marine and air transport vessels so that they will float. Moreover, you will acquire skills in identifying the purity of a substance and estimating the composition of different types of mixtures.

Concept of density

Suppose you measure the mass of three blocks of identical size, as shown in Figure 5.1. The blocks are made up of glass, iron, and wood. You will find that the masses of all blocks are different.

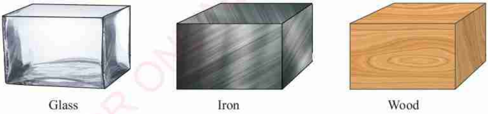
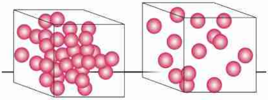


Figure 5.1 *Blocks of glass, iron, and wood*

Iron block will have a larger mass than the glass block which has a larger mass than the wooden block. The difference in mass arises from the way the particles of the blocks are packed together in equal volume. This suggests that a comparison of the mass of a substance and its volume leads to an important physical quantity called density.

If particles are closely packed in a small volume of a substance, the substance is said to have high density. Figure 5.2 shows a high and low density substances.



(a) High density (more packed)

(b) Low density (less packed)

Figure 5.2: *Concept of density*

The measure of how the constituent particles of a substance are packed in a unit volume is called density. Thus, density is the extent to which the particles of a susbstance are closely packed in a particular substance. Therefore, the more compact packing the particles are in a particular substance, the higher the density of the substance.

Thus, density is the mass of a substance divided by its volume. The symbol used for density is the Greek letter, ρ (rho).

Mathematically, density is expressed as:

$$Density, \rho = \frac{mass\ (m)\ of\ substance}{volume\ (V)\ of\ the\ same\ substance}$$

$$\rho = \frac{m}{v}.$$

The SI unit of density is kg/m^3. Another unit used for expressing density is g/cm^3. It is important to note that density is a scalar quantity.

The density, mass, and volume relationship of a substance can easily be remembered by the density-mass-volume triangle, as shown in Figure 5.3.

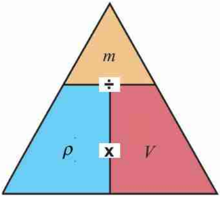


Figure 5.3: *The density-mass-volume triangle*

From the triangle, the horizontal line that separates mass (m) and the other variables represents division sign. So, whenever it is required to find density (ρ) or volume (V), mass (m) is divide by either volume (V) or density (ρ), respesctively.

That is, $\rho = \frac{m}{V}$ and $V = \frac{m}{\rho}$.

On the other hand, the vertical line that separates ρ and V represents the multiplication. Therefore, whenever it is required to find m, ρ and V are multiplied. Thus, $m = \rho \times V$. Density is an intrinsic property of matter since it is independent of the number of particles contained in the materials.

The densities of common substances are given in Table 5.1.

Table 5.1: Densities of common substances

Substance	Density (kg/ m^3)
Solids	
Aluminium	2 700
Copper	8 300
Gold	19 300
Iron	7 800
Lead	11 300
Glass	2 500
Ice $(0\ ^\circ C)$	920
Liquids	
Seawater	1 030
Water $(4\ ^\circ C)$	1 000
Water $(20\ ^\circ C)$	998
Gasoline/petrol	700
Gases (at standard conditions)	
Air	1.225
Carbon dioxide	1.98
Hydrogen	0.820
Helium	0.178

Activity 5.1

Aim: To determine the mass to volume ratio for given objects.

Materials: Vernier caliper, beam balance, three identical blocks of different materials (for instance, aluminium, copper, and iron, respectively) as shown in Figure 5.4

Figure 5.4: *Blocks of aluminium, copper, and iron*

Procedure

1. Measure the length, height and width of each object.
2. Measure the mass of each block.
3. Record all observations using the following table.

Substance	Length (cm)	Height (cm)	Width (cm)	Mass (g)	Volume (cm^3)	Mass-to-volume ratio (g/ cm^3)
Aluminium						
Copper						
Iron						

Questions

(a) Compare the mass to volume ratio of each substance.

(b) Are they different or the same? Why?

(c) What physical quantity does the ratio express?

Example 5.1

A glass block with dimensions of $0.12\ \text{m} \times 0.04\ \text{m} \times 0.10\ \text{m}$ has a mass of 1.2 kg. Calculate its density.

Solution

$$\textit{Volume of the block} = 0.12\ \text{m} \times 0.04\ \text{m} \times 0.10\ \text{m} = 0.00048\ \text{m}^3$$

$$\textit{Mass of the block} = 1.2\ \text{kg}$$

$$\textit{Density of block},\ \rho = \frac{m}{V}$$

$$\therefore\ \textit{Density of block} = \frac{1.2\ \text{kg}}{0.00048\ \text{m}^3} = 2\,500\ \text{kg/m}^3$$

Therefore, the density of the block is $2\,500\ \text{kg/m}^3$.

Example 5.2

Using the table of densities, calculate the mass of the glass that has the same volume as 5.4 g of aluminium.

Solution

Density of aluminium $= 2700\ \text{kg/m}^3$
$= 2.7\ \text{g/cm}^3$

Mass of aluminium $= 5.4$ g

Density of glass $= 2.5\ \text{g/cm}^3$

Required: Mas of the glass = ?

From the formula of density,

$$V = \frac{m}{\rho}$$

The volume of aluminium will be:

$$V = \frac{5.4\ \text{g/cm}^3}{2.7\ \text{g}} = 2\ \text{cm}^3$$

This volume is the same as that of glass,

Thus, $m_g = \rho_g \times V_g$

where m_g is the mass of glass, ρ_g is the density of the glass, and V_g is the volume of the glass.

Then,

$m_g = 2.5\ \text{g/cm}^3 \times 2\ \text{cm}^3$

$m_g = 5$ g

Therefore, the mass of glass is 5 g.

Determination of density of a substance

A technique used in the determination of density of a substance depends on the properties of the substance. For a given substance, the appropriate method for measuring its mass and volume must be used. Once the measured values of mass and volume are known, the density of a substance can be calculated.

It is important to note that different techniques are used to determine the density of solids, liquids and gases.

Determination of density of solid

The determination of density of a solid depends on the shape of the substance. The shape may either be regular or irregular.

Determination of density of solid with regular shape

The density of a regular shape object can be obtained by calculations once its mass and volume have been measured. The mass of the object can be measured using a beam balance. On the other hand, volume of a regular shape object can be calculated by the formula shown in Table 5.2.

The density can then be calculated by the shown formulas.

Table 5.2: Determination of density for regular shapes

Object	Volume	Mass	Density
	Base area × height = length × width × height $(l \times w \times h)$	Mass of a rectangular block, m_b	$\frac{m_b}{(l \times w \times h)}$
	Base area × height = $\pi r^2 h$	Mass of a cylinder, m_{cy}	$\frac{m_{cy}}{\pi r^2 h}$
	$\frac{4}{3}\pi r^3$	Mass of a sphere, m_s	$\frac{m_s}{\frac{4}{3}\pi r^3} = \frac{3m_s}{4\pi r^3}$
	Base area × height = $(\text{length of side})^3 = (l)^3$	Mass of a cube, m_{cube}	$\frac{m_{cube}}{l^3}$

Example 5.3

A block of mass with 150 g has dimensions of 3 cm × 4 cm × 5 cm. Determine the density of the block. What material is the block made of?

Solution

$$mass = 150\,\text{g}$$

$$Volume = 3\text{ cm} \times 4\text{ cm} \times 5\text{ cm}$$
$$= 60\text{ cm}^3$$

$$Density = \frac{mass}{Volume} = \frac{150\text{ g}}{60\text{ cm}^3}$$

$$= 2.5\text{ g/cm}^3 \text{ or } 2500\text{ kg/m}^3.$$

This value is the same as the density of glass (see Table 5.1). Therefore, the block is made of glass.

Task 5.1

In groups of four students, carry out the following task. You will be provided with wooden blocks. Measure the masses of the blocks using a beam balance. Measure the dimensions of each of the blocks using a vernier caliper and a metre rule. Determine their volumes. Calculate the density of the wooden blocks.

Determination of density of an irregular solid

The density of an irregular solid can be determined through the following procedure:

1. Measure its mass using a triple beam balance or digital balance.
2. Determine the volume through the displacement or immersion method involving the eureka can and measuring cylinder. The procedures are as follows:

   The eureka can is filled with water to the level of the overflow spout. A beaker is then placed under the spout. The object whose volume has to be determined is gently lowered into the eureka can using a string. The displaced water is collected in the beaker after which it is transferred to the measuring cylinder. The volume of the water is equivalent to the volume of the object.
3. Calculate the density, that is;

$$\rho = \frac{Mass\ of\ an\ irregular\ object}{Volume\ of\ water\ displaced}.$$

Figure 5.5: *Irregular solid (Stone)*

Activity 5.2

Aim: To determine the density of an irregular object.

Materials: Eureka can, stone, beaker, measuring cylinder, string, triple beam balance, or digital beam balance

Procedure

1. Measure the mass of an irregular stone using a beam balance and record your result.
2. Set the eureka can as shown in Figure 5.6.

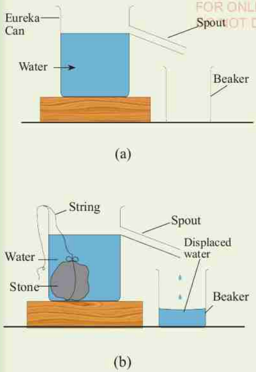


Figure 5.6: *Density of solid with irregular shape*

3. Tie the stone using a string and gently lower it into the water containing in the eureka can.
4. Collect all the overflowing water in the beaker below the spout.
5. Using a measuring cylinder measure and record the volume of the water displaced. This volume is equal to the volume of the stone.

Question

Calculate the density of the stone.

Example 5.4

An irregular solid X has a mass of 50 g. When it is totally immersed in the water of volume 60 cm^3, the final water volume is 70 cm^3. Calculate the density of the irregular solid X.

Solution

Mass of irregular solid, $m = 50$ g

Initial volume of water, $V_1 = 60\ cm^3$

Final volume of water, $V_2 = 70\ cm^3$

Volume of water displaced, $V = V_2 - V_1$

volume of the solid = volume of water displaced

$$\textit{Volume of a solid} = 70\ cm^3 - 60\ cm^3$$
$$= 10\ cm^3.$$

But, $\rho_s = \dfrac{m}{V}$

$$= \frac{50\ g}{10\ cm^3}$$

$$= 5 g/cm^3$$

Therefore, the density of the irregular solid X is 5 g/cm^3.

Task 5.2

In groups of four students, carry out the following task: Measure the mass of a stone using a triple beam or a digital balance. Measure the volume of the stone using a eureka can and a measuring cylinder. Calculate the density of the stone.

Density of insoluble granules

Determination of the density of small insoluble particles such as sand grains is also possible. Unlike other solids, granules must be held in some type of container while being measured. This could be realised by using a density bottle. A density bottle has a precisely measured volume, usually 25 ml, 50 ml, or 100 ml and a tight-fitting stopper with a small hole to allow excess liquid to escape. It is mostly used in studying and analysing the relative densities of two immiscible liquids. Figure 5.7 shows parts of a density bottle.

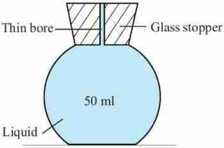


Figure 5.7: *Density bottle*

The following steps are to be followed when using a density bottle to measure the density of insoluble granules. For this explanation, sand will be used.

1. Measure the mass of the empty density bottle with its stopper; record as m_0.
2. Remove the stopper, add a small amount of sand to the bottle and replace the stopper. Measure the mass of the bottle containing sand and its stopper; record this mass as m_1.
3. The difference between m_1 and m_0 gives the mass of the sand. Mass of sand $= (m_1 - m_0)$.
4. Remove the stopper, add water into the bottle until the bottle is full, replace the stopper.
5. Measure the mass of the bottle containing water and sand as m_2.
6. The difference between m_2 and m_1 gives the mass of the water added to the bottle. Mass of water is $(m_2 - m_1)$.
7. Since the density of water is 1 g/cm^3, the volume added to the bottle is given in cm^3, which is numerically equal to the mass of the water in grammes.

$$volume\ of\ water(V_w) = \frac{mass\ of\ water(m_w)}{density\ of\ water(\rho_w)}$$

Thus, $V_w = \frac{m_w}{\rho_w}$

$$V_w = \frac{m_w}{1\ \text{g/cm}^3}$$

$$V_w = \frac{(m_3 - m_2)}{1\ \text{g/cm}^3} = (m_3 - m_2)\text{cm}^3.$$

Therefore, the volume of water is in cm^3.

8. Since the only materials in the bottle are water and sand, the sum of their volumes must be equal to the volume of the bottle.

That is,

$$volume\ of\ bottle = volume\ of\ sand + volume\ of\ water.$$

Then,

$$volume\ of\ sand = volume\ of\ bottle - volume\ of\ water$$

$$V_{sand} = V_{bottle} - V_{water}$$

9. Use the formula to calculate the density of sand. That is,

$$\rho_{sand} = \frac{m_2 - m_1}{V_{bottle} - V_{water}} = \frac{m_2 - m_1}{V_{bottle} - (m_3 - m_2)}.$$

Activity 5.3

Aim: To determine density of lead shots.

Materials: Density bottle, lead shots, water

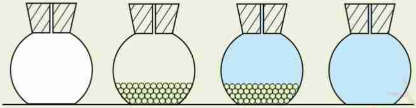


Figure 5.8: *Density bottles in use*

Procedure

1. Find the mass m_o of density bottle when empty.
2. Put some lead shots in the bottle, then find the mass, m_1 of a bottle and lead shot.
3. Pour water into the bottle until it is full. Find the mass, m_2 of a bottle, lead shot and water.
4. Finally, find the mass, m_3 when the bottle is filled with water only.

   Figure 5.8 illustrates the procedure.

Results

Mass of lead shots = $(m_1 - m_0)$ g

Mass of water on top of lead shots = $(m_2 - m_1)$ g

Mass of water filling the bottle = $(m_3 - m_0)$ g

Volume of lead shots if the density of water is $1.0\ \text{g/cm}^3$ will be

$$V = \frac{[(m_3 - m_0) - (m_2 - m_1)]\ \text{g}}{1\ \text{g/cm}^3} = (m_3 - m_0) - (m_2 - m_1)\ \text{cm}^3.$$

$$\therefore Density = \frac{Mass\ of\ lead\ shots}{Volume\ of\ lead\ shots}$$

$$Density\ of\ lead\ shot = \frac{(m_1 - m_0)}{(m_3 - m_0) - (m_2 - m_1)} g/cm^3.$$

Density of a liquid

The density of a liquid can also be calculated if its mass and volume are known. Thus, the density of a liquid can be determined through the following steps:

1. Measure an empty beaker; record it as m_0.
2. Using a burette, run out a known volume (V) of the liquid into the beaker and measure the mass; record it as m_1.
3. Subtract m_0 from m_1 to get the mass of the liquid, that is, mass of liquid $= (m_1 - m_0)$.
4. Calculate the density of the liquid by dividing mass obtained in step (3) by the known volume of liquid, that is

$$Density\ of\ liquid = \frac{Mass\ of\ a\ liquid}{Volume\ of\ a\ liquid}$$

$$= \frac{(m_1 - m_0)\ g}{V\ cm^3}.$$

Example 5.5

In an experiment to determine the density of liquid Y, a Form One student obtained the following results: Mass of beaker = 500 g and Mass of beaker + liquid (25 cm^3) = 600 g. What did the student obtain as the density of liquid Y?

Solution

Volume of liquid $Y = 25\ cm^3$

Mass of empty beaker = 500 g

Mass of beaker + liquid Y = 600 g

Mass of liquid = $(600 - 500) g = 100 g$.

Density of liquid,

$$\rho = \frac{Mass\ of\ liquid}{Volume\ of\ liquid}$$

$$= \frac{100\ g}{25\ cm^3} = 4\ g/cm^3$$

Therefore, desity of liquid Y is 4 g/cm^3.

Activity 5.4

Aim: To determine the densities of kerosine and milk.

Materials: Beakers, pipettes, beam balance, kerosene, milk

Procedure

1. Weigh a dry empty beaker using a weighing balance and record it as, m_0.
2. Use a pipette to accurately measure 20 ml of kerosene and transfer it into the weighed beaker.
3. Measure the mass of the beaker with kerosene and record it as m_1.
4. Repeat steps 1 to 3 for milk.

Questions

(a) Calculate the mass of the 20 ml of kerosene and milk.

(b) Calculate the density of kerosene and milk.

(c) Why is it necessary to measure the mass of the empty beaker?

The mass of the 20 ml of liquid can be obtained by subtracting the mass of an empty beaker from the combined mass of the beaker and liquid.

The density of liquid can be calculated using the formula $\frac{(m_1 - m_0)\text{ g}}{20\text{ cm}^3}$.

Since the beaker is used to measure the mass of the liquid, its mass has to be known.

Relative density of a substance

It is common practice to express the density of a substance such as solid, liquid and gas (air) in relation to the density of water. The density of a substance in relation to the density of water is called relative density, R.D. Mathematically, it can be expressed as;

$$\text{R.D} = \frac{\textit{Density of substance}}{\textit{Density of water}}$$

$$= \frac{\textit{Mass of a substance}}{\textit{Mass of equal volume of water}}.$$

The relative density has no unit, since it is expressed as the ratio of the same quantity.

Relative density is also known as the specific gravity (S.G). It indicates how many times a substance is denser compared to water. If the relative density is greater than 1, it means that the substance is denser than water and if the relative density is less than 1, the substance is less dense than water.

Example 5.6

An object has a density of 7 g/cm³. Calculate its relative density, (R.D).

Solution

Density of object = 7 g/cm³

$$\textit{Relative density} = \frac{\textit{Density of substance}}{\textit{Density of water}}$$

$$= \frac{7\text{ g/cm}^3}{1\text{ g/cm}^3} = 7$$

Therefore, relative density of the object is 7.

Example 5.7

A piece of copper metal of volume 5.1 cm^3 has a mass of 41.6 g. Calculate the relative density of copper.

Solution

Mass of the piece of copper = 41.6 g

Volume of the piece of copper = 5.1 cm^3

Therefore,

$$\text{density of copper} = \frac{\text{mass}}{\text{volume}}$$

$$= \frac{41.6\ g}{5.1\ cm^3}$$

$$= 8.16\ g/cm^3.$$

$$\text{Relative density} = \frac{\text{Density of substance}}{\text{Density of water}}$$

$$= \frac{8.16\ g/cm^3}{1\ g/cm^3} = 8.16.$$

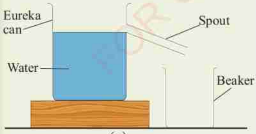
Therefore, relative density of copper is 8.16.

Relative density of a solid

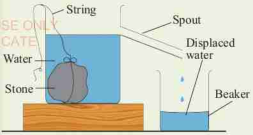
Activity 5.5

Aim: To find the relative density of a solid material

Materials: eureka can, measuring cylinder, stone, beam balance, water, string, and beaker



(a)



(b)

Figure 5.9: *Determination of relative density of solid*

Procedure

1. Find the mass, m_0 of the solid by using a beam balance.
2. Place an empty dry beaker of mass m_1 under the spout of the eureka can, as shown in Figure 5.9 (a).
3. Fill the eureka can with water until it just begins to overflow, as shown in Figure 5.9 (b).
4. Lower gently the solid into the water with the help of a thin string until it is completely immersed, as shown in Figure 5.9 (b).
5. Collect into the beaker the water which overflows. Find the mass m_2 of the beaker and its contents.

Results

Mass of a solid = m_0

Mass of dry empty beaker = m_1

Mass of beaker and water = m_2

Mass of equal volume of water = $(m_2 - m_1)$

$$\text{Relative density} = \frac{\text{Mass of substance}}{\text{Mass of equal volume of water}}$$

$$= \frac{m_0}{m_2 - m_1}\ g/cm^3.$$

Example 5.8

A block of metal has a mass of 264 g. The block is totally immersed in water filling up an eureka can. If 24 g of water overflows through the spout of the can into a beaker, calculate the relative density of the metal.

Solution;

Mass of a solid = 264 g

Mass of equal volume of water = 24 g

$$Relative\ density = \frac{Mass\ of\ substance}{Mass\ of\ equal\ volume\ of\ water}$$

$$= \frac{264\ g}{24\ g} = 11$$

The relative density of the block is 11.

Determination of relative density of a liquid

The relative density of a liquid can be determined using a relative density bottle shown in Figure 5.10. A bottle is fitted with a stopper made of ground glass having a narrow hole. The hole enables air to escape from the bottle when it is being filled with a liquid.

Figure 5.10: *Relative density bottle*

Relative density of a liquid can be determined using the following procedure

1. Find the mass of an empty bottle, m_o.
2. Fill in the bottle with the liquid and measure the mass of the bottle with its contents. Record this mass as m_1.
3. Empty the bottle, clean and dry it thoroughly.
4. Fill in the bottle with water and measure the mass of the bottle containing water. Record this mass m_2.

Hence, mass of liquid = $(m_1 - m_0)$

Mass of an equal volume of water = $(m_2 - m_0)$.

$$R.D = \frac{Mass\ of\ substance}{Mass\ of\ an\ equal\ volume\ of\ water}$$

$$= \frac{m_1 - m_0}{m_2 - m_0}.$$

Activity 5.6

Aim: To determine the relative density of cooking oil.

Materials: Relative density bottle, cooking oil, beam balance, water

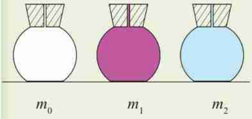


Figure 5.11: *Determination of relative density of liquid using relative density bottle*

Procedure

1. Measure the mass of an empty relative density bottle with its stopper. Record the mass as m_0.
2. Fill in the bottle with cooking oil, replace the stopper and wipe out any excess liquid. Measure the mass. Record the mass as m_1.
3. Replace the cooking oil with water and measure the mass. Record it as m_2.

   The procedure in illustrated in Figure 5.11.

Questions

(a) Calculate the relative density of cooking oil.

(b) What is the significance of the narrow hole in the relative density bottle?

The relative density of cooking oil can be obtained by:

(i) Finding the mass of cooking oil, $(m_1 - m_0)$.

(ii) Finding the mass of an equal volume of water, $(m_2 - m_0)$.

(iii) *Calculating the relative of cooking oil* $= \frac{m_1 - m_0}{m_2 - m_0}$.

(iv) The narrow hole in the stopper enables air to escape from the bottle when it is being filled with a liquid.

Example 5.9

In an experiment to determine the relative density of liquid *X*, Form One physics students obtained the following results after various measurements.

Mass of an empty relative density bottle = 15 g

Mass of bottle + liquid *X* = 35 g

Mass of bottle + water = 40 g

Volume of bottle = 25 cm^3

Calculate,

(a) The density of water in kg/m^3,

(b) The density of liquid *X* in kg/m^3,

(c) The relative density of liquid *X*.

Solution

(a) Mass of water = 25 g

Volume of water = 25 cm^3

$$\text{Density of water} = \frac{25\text{ g}}{25\text{ cm}^3} = 1\text{ g/cm}^3$$

In kg/m^3, density of water = 1 000 kg/m^3.

(b) Mass of liquid *X* = 20 g

Volume of liquid *X* = 25 cm^3

$$\text{Density of liquid } X = \frac{20\text{ g}}{25\text{ cm}^3} = 0.8\text{ g/cm}^3$$

In kg/m^3, density of liquid = 800 kg/m^3.

(c) Relative density of

$$\text{liquid } X = \frac{800\text{ g/cm}^3}{1000\text{ g/cm}^3} = 0.8.$$

Exercise

Answer all questions

1. (a) What is the volume of 2 400 kg of gasoline (petrol) if its density is 0.7 g/cm^3?

   (b) Use the table below to answer the questions that follow.

Item	Mass (g)	Length (cm)	Width (cm)	Height (cm)
A	480	5	4	4
B	800	10	5	2
C	360	10	4	3
D	600	5	4	2

   (i) Which item is the densest?

   (ii) Calculate the density of item *D*.

   (iii) Which items have the same density and volume?

2. The water collected in a cylinder during an experiment using a eureka can is 30 cm^3. When the object that displaced this volume was dried and weighed, its mass was found to be 90 g. Calculate its density.
3. Asha, a Form One student at Kijitonyama Secondary School, obtained the following results from an experiment:

   Mass of an empty beaker = 48 g

   Mass of beaker + liquid *M* = 60 g

   If she had used a 25 cm^3 pipette to transfer liquid *M* to the beaker, calculate the density of the liquid *M*.
4. What is relative density? Express relative density in terms of mass.

Applications of the concept of density and relative density in everyday life

Relative density has many applications in everyday life, including the following:

1. It aids in the identification of gemstones such as gold and diamond.
2. Density is used by geologists and mineralogists to determine the mineral content of a rock or other sample.
3. Density is considered during the selection of building materials.
4. Density is also considered during the design of swimming and diving equipment.
5. Density is considered during design of various marine and air vessels so that they can float. For example, aeroplanes are made up of aluminium alloys and not steel. This is because the density of aluminium is less than that of steel, thus, it is lighter than steel. Moreover, aluminium's resistance to corrosion ensures safety to the aeroplane and passangers. Figure 5.12, shows an aeroplane made of a light materials flying in air.

Figure 5.12: *An aeroplane*

6. Relative density can be used in determining the density of an unknown substance using known density of another substance.

Chapter summary

1. Density of a substance is expressed as the mass of the substance per unit volume. Its SI unit is the kilogram per cubic metre, kg/m^3. It can be expressed mathematically as $\rho = \frac{m}{V}$.
2. The determination of the density of a solid depends on the shape of a particular solid. That is, whether the solid has a regular or irregular shape.
3. The density of solids is generally higher than the density of liquids.
4. Relative density of a substance is the ratio of the substance's density to the density of water. It has no units since it is a ratio of the same quantity.
5. A relative density bottle is used to determine relative density of liquids.
6. Density is used in designing various structures for ships and aircraft.
7. Density is considered during the selection of building materials and design of swimming equipment.

Revision exercise 5

Section A

Choose the most correct answer

1. A cuboid with length 3 cm, width 4 cm and height 10 cm is made from wood of density $0.5\ g/cm^3$. The mass of the cuboid is:
   (a) 17.5 g.
   (b) 60 g.
   (c) 120 g.
   (d) 240 g.
2. What is the density of the liquid in Figure 5.13?

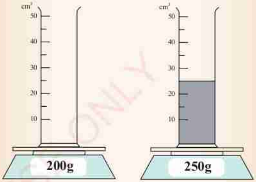


Figure 5.13

   (a) $0.5\ g/cm^3$.
   (b) $2.0\ g/cm^3$.
   (c) $8.0\ g/cm^3$.
   (d) $10.0\ g/cm^3$.
3. Two cylinders are made of the same metal. Both cylinders have the same cross-sectional area but one is longer than the other. Which quantity is the same for both cylinders?

Cylinder 1

Cylinder 2

(a) Density.
(b) Mass.
(c) Weight.
(d) Volume.

4. A person measures the length, width, height, and mass of a rectangular metal block. Which of these measurements must be used in order to calculate the density of the metal?
   (a) Mass only.
   (b) Height and mass only.
   (c) Length, width, and height only.
   (d) Length, width, height, and mass.

5. A liquid has a volume of 100 cm^3 and a mass of 85 g. The density of water is 1.0 g/cm^3. How does the density of the liquid compare with the density of water?
   (a) Its density is higher than that of water.
   (b) Its density is lower.
   than that of water.
   (c) Its density is the same as that of water.
   (d) It is impossible to say with only this data.

Section B

6. A rectangular block measures length 4.00 cm, width 2.50 cm, and height 1.00 cm.

   (a) Name the instrument used to measure the sides of the rectangular block.
   (b) Calculate the volume of the rectangular block.
   (c) If the mass of the rectangular block is 300 g, find the density of the block.

7. Explain how each of the following quantities differs from each other.
   (a) Density and relative density.
   (b) Mass and weight.

8. (a) The density of water is 1 000 kg/m^3. What does it imply?
   (b) The mass of a stone is measured to be 410 g. The stone is then immersed in water contained in a cylinder in graduated cm^3. The water level increases as shown in Figure 5.14. What is the density of the stone?

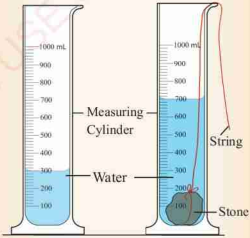


Figure 5.14

What is the density of the stone? (Note: 1 ml = 1 cm^3).

9. The length of one side of a metal cube is 5.22 cm and its mass is 65.8 g. What is the density of the cube?
10. If the volume of an object is increased while its mass is held constant, what happens to its density?
11. If a 200 g solid lead ball is placed in a eureka can filled with water, what volume of water will overflow?
12. A small quantity of powdered charcoal is placed in a 100 cm^3 density bottle and the total mass is measured to be 255 g. If the mass of empty density bottle is 20 g and when the bottle is filled with water, the total mass is 289 g, what is the density of the powdered charcoal?
13. Fishes are very sensitive to a change in salinity. Explain how you can monitor the water in a fish tank to ensure the proper amount of salt.
14. Is the relative density of milk the same as that of skimmed milk? Explain.
15. The diameter of a solid metal sphere is measured using a micrometer screw gauge. Figure 5.15 shows an enlarged shaft of the micrometer screw gauge when taking the measurement.

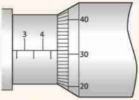


Figure 5.15

If the mass of the sphere is 0.450 g. What is the density of the metal used to make the sphere?

Chapter Six

Archimedes' principle and the law of floatation

Introduction

Upthrust is a phenomenon discovered by Archimedes during the third century. The concept of upthrust plays a great role in designing marine and air transport vessels. Archimedes' principle and the law of floatation are important laws of physics deduced from the observation of upthrust. These laws account for the floating ability of an object in fluid. The concepts of upthrust, the Archimedes' principle and the law of floatation will be discussed in detail in this chapter. The competencies developed will enable you to apply the law of floatation in designing and constructing simple models of transport vessels used for fishing, crossing rivers, seas, or oceans.

Concept of upthrust

Consider a cork being held at the bottom of a beaker that contains a liquid, as shown in Figure 6.1 (a). When the cork is released it immediately rises to the surface of the liquid, as shown in Figure 6.1(b).

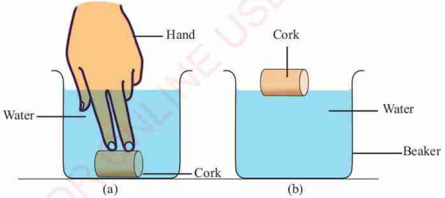


Figure 6.1: *Upthrust in water*

The rising of the cork shows that while inside the liquid, an upward force acts on the cork. Since this force is greater than the weight of the cork, the cork is pushed up to the surface of the liquid. An upward force acting on an object that is totally or partially immersed in a fluid is called upthrust or buoyant force. Upthrust enables an object to float or feel lighter in a fluid. When one is swimming in water, his or her weight is balanced by the upthrust acting on the body. Water vessels like ships and boats float and sail on water due to this force, otherwise they sink.

The tendency or ability of an object to float on a fluid suspended on it is called buoyancy and an upward force exerted by a fluid on that object is called upthrust (buoyant force).

Apparent weight of an object

If one tries to lift an object in a swimming pool and then, he or she tries to lift the same at the edge of the pool, the object feels much lighter in the water. This is the effect of upthrust.

When a body is totally or partially immersed in a fluid, it experiences an upthrust exerted by the fluid. The exerted upthrust is equal to the weight of the fluid displaced by the immersed object. Because of upthrust, an object that is submerged in the fluid appears to weigh less than its actual weight in air. The weight of the submerged object is known as **apparent weight.** The difference between the actual weight and the apparent weight of an object is referred to as **apparent loss in weight.**

Therefore,

Apparent loss in weight

= *Actual weight – Apparent weight of body in fluid.*

= *Weight of the displaced fluid*

= *Upthrust*

Thus, *Upthrust = Apparent loss in weight.*

Activity 6.1

Aim: To determine the apparent loss in weight of objects immersed in water

Materials: Measuring cylinder, spring balance, solid objects such as stones, water, and string

Procedure

1. Tie the stone using a string and measure its weight in air using a spring balance as shown in Figure 6.2. Record this weight as w_1.

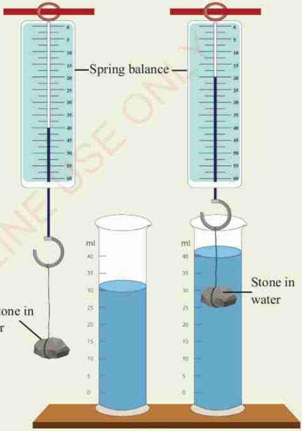


Figure 6.2: *Stone in air and stone immersed in water*

2. Fill a measuring cylinder with water to about 30 ml of its volume.
3. Lower the stone suspended at the end of the spring balance into the water. It should be partially immersed. Note the reading on the spring balance as w_2 and the level of liquid in the measuring cylinder.
4. Lower the stone such that it is totally immersed in the water, as shown in Figure 6.2 as w_3.
5. Remove the stone, dry and re-weigh it in air. Record this weight as w_4.
6. Calculate the apparent loss in weight of the stone and record it as w_L.
7. Repeat steps 1 to 6 for other objects, one at a time.

Questions

(a) What do you notice about the values w_1, w_2, w_3, w_4, and w_L?

(b) What is your conclusion?

In activity 6.1, you have learnt that, the weight of an object in air (w_1) is larger than its weight when it is submerged in water (w_2). There is an apparent loss in weight (w_L) which is obtained by the difference between the weight in air and the weight while in liquid. That is,
Apparent loss in weight = weight in air – weight in water.

$$w_L = w_1 - w_2 \text{ or } w_L = w_1 - w_3$$

Note that the apparent loss in weight is equal to the upthrust exerted on the object by water.

Task 6.1

Hold a stone in one hand and sense its weight. Tie the same stone using a string and submerge it in water. Hold the string and try to pull it. What do you feel on its weight? Present your findings in the class.

Task 6.2

Form groups and carry out the following task. Suspend a slotted mass of 50 g by a thread from spring balance. Note the reading of the spring. Pour 60 cm^3 of water into a measuring cylinder and immerse the suspended mass in water. (Ensure that the mass does not touch the walls of the cylinder). Record the readings on the spring balance and on measuring cylinder. Repeat the same procedure using 100 g and 200 g masses. Illustrate your work using clear diagrams.

Archimedes' Principle

If an object is immersed in water, it displaces some of the water. The relationship between the upthrust acting on a body and the weight of the displaced fluid when the body is partially or totally immersed in the fluid was discovered by a Greek scientist known as Archimedes. This relationship is known as the Archimedes' principle, which is also referred to as the law of buoyancy. The Archimedes' principle states that, "*Any object partially or totally immersed in a fluid experiences an upthrust which is equal to the weight of the fluid displaced by the object*".

It is important to note that the weight of an object acts downwards while the upthrust exerted by the displaced fluid acts upwards.

Verification of Archimedes' principle

Activity 6.2

Aim: To verify Archimedes' Principle.

Materials: Beaker, eureka can, spring balance, measuring cylinder, stone, water and digital balance. The setup is shown in Figure 6.3

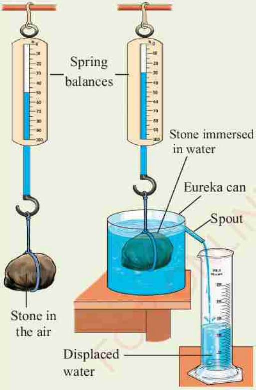


Figure 6.3: *Stone in the air and stone immersed in Eureka can*

Procedure

1. Measure the weight of the stone in air using a spring balance and record its weight.
2. Using a digital balance, measure the mass of a dry empty measuring cylinder, and record its mass.
3. Pour water into a eureka can up to its spout level.
4. Place the dry beaker under the spout of the eureka can.
5. Weigh the stone when it is totally immersed in water and record its weight. Wait until all the displaced water overflows into the measuring cylinder.
6. Weigh the measuring cylinder containing the displaced water. Record its weight.

Questions

(a) Calculate the weight of an empty measuring cylinder.

(b) Calculate the weight of the measuring cylinder containing displaced water.

(c) Determine the mass of the displaced water.

(d) Calculate the weight of the displaced water.

(e) What do you conclude about the upthrust and the weight of the water displaced?

In activity 6.2, you observed that upthrust is equal to the weight of the displaced fluid. This observation verifies the Archimedes' principle, which applies to objects of all densities. It is important to note that upthrust depends on the weight of the fluid displaced.

Example 6.1

When an object is totally immersed in water, its weight is recorded as 3.1 N. If its weight in air is 4.9 N, calculate the upthrust acting on this object.

Solution

Weight of the object in air = 4.9 N

weight of the object in water = 3.1 N

$$upthrust = weight\ of\ an\ object\ in\ air - weight\ of\ an\ object\ in\ water$$

$$= 4.9\text{ N} - 3.1\text{ N}$$

$$= 1.8\text{ N}$$

Therefore, upthrust acting on the object is 1.8 N.

Example 6.2

A body immersed in water weigh 1.1 N in liquid. If its weight while in water was 3.3 N, find its weight in air.

Solution

Weight of the displaced water = 1.1 N

Weight of the body in water = 3.3 N

But,

upthrust = weight of liquid displaced

= apparent loss in weight

Upthrust = 1.1 N

Weight of the body in air = Apparent loss in weight + Apparent weight

$$= 3.3\text{ N} + 1.1\text{ N}$$

$$= 4.4\text{ N}$$

Therefore, weight of the body in air is 4.4 N.

Factors affecting upthrust

According to Archimedes' principle, an object submerged in a fluid experiences an upthrust which is equal to the weight of the fluid displaced. That is,

Upthrust (U) = Weight of displaced fluid (w_f).

But,

Weight of the fluid displaced

$$(w_f) = mass\,(m_f) \times acceleration\ due\ to\ gravity\,(g)$$

Thus, $U = m_f\, g$

Mass of the fluid (m_f) = density of the fluid (ρ_f) × volume of the displaced fluid (V_f)

$$m_f = \rho_f V_f$$

In Chapter Five, you learned that, the volume of the displaced fluid is equivalent to the volume of the immersed object.

That is,

$$Volume\ of\ the\ fluid\ displaced\,(V_F) = volume\ of\ object\,(V_o)$$

Since, $V_f = V_o$

$$m_f = \rho_f V_0$$

Thus, $U = m_f\, g$

That is,

$$upthrust = density\ of\ the\ fluid \times volume\ of\ the\ object \times acceleration\ due\ to\ gravity$$

Hence, upthrust is affected by:

(i) the volume of the immersed object; and

(ii) the density of the fluid in which the object is immersed.

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Example 6.3

Calculate the resulting buoyant force, if a steel ball of radius 6 cm is immersed in water. Assume density of water is 1000 kg/m^3 and acceleration due to gravity is 10 N/kg.

Solution

Given data:

Radius of steel ball = 6 cm = 0.06 m

Density of water, $\rho = 1\,000\ kg/m^3$

Acceleration due to gravity, $g = 10$ N/kg

Volume of steel ball, $V = \frac{4}{3}\pi r^3$

$= \frac{4}{3}\pi(0.06)^3$

$= 9.04 \times 10^{-4} m^3$

We know that,

The magnitude of upthrust (U_B) = weight $(w_B = mg)$ of a displaced fluid.

Then,

$U_B = (\rho V)g$

$= 1\,000\ kg/m^3 \times 9.04 \times 10^{-4} m^3 \times 10$ N/kg

= 9.04 N

∴ The magnitude of upthrust is 9.04 N.

Example 6.4

A man whose weight is 690 N which contains $5.3 \times 10^{-3}\ m^3$ of blood. Calculate the weight of the blood if its density is 1060 kg/m^3.

Solution

Given data:

Volume of blood $(V) = 5.3 \times 10^{-3}\ m^3$

Density of blood $(\rho) = 1060\ kg/m^3$

Recall, $w = mg$, where $m = \rho V$

$w = (\rho V)g = \rho V g$

$= 1060\ kg/m^3 \times 5.3 \times 10^{-3}\ m^3 \times 10$ N/kg

= 56.18 N

∴ The weight of the blood is 56.18 N.

Exercise 6.1

1. (a) Explain the following terms in relation to Archimedes' principle.
   (i) Buoyancy.
   (ii) Apparent weight.
   (iii) Actual weight.

   (b) How is the apparent weight of an object in a fluid related to its actual weight in air?
2. An aluminium cube has a volume of 800 cm^3. If it is totally immersed in water, calculate the upthrust acting on it. Assume density of water is 1000 kg/m^3 and acceleration due to gravity is 10 N/kg.
3. An iron piece of mass 360 g and a density of 7.8 g/cm^3 is suspended by a rope so that it is partially submerged (halfway) in oil of density 0.9 g/cm^3. Find the tension in the string.

4. A body lost 0.6 N in weight when immersed in water. Calculate its volume in cubic centimetres.
5. State Archimedes' principle and state its application in daily life.
6. Describe activities that can verify the Archimedes' principle at home environment.
7. Assume a body weighs X N in the air and experiences an upthrust of Y N in a liquid. Write the expression for apparent weight in terms of X and Y.
8. Why does a stone weigh more in air than when immersed in water?

Determination of relative density using Archimedes' principle

In Chapter 5, you learnt the concept of relative density (R.D) of a substance. The relative density of a substance was expressed as:

$$\text{R.D} = \frac{\textit{density of a substance}}{\textit{density of water}}$$

In this chapter, the concept of relative density will be discussed using Archimedes' principle. From Archimedes' principle the upthrust acting on the body immersed in water is equal to the weight of water displaced.

It is important to note that at any place on the earth's surface, the mass of a substance is proportional to its weight. It is therefore, convenient to express the relative density of a substance in terms of its weight.

Since, $\rho = \frac{m}{V}$,

then,

$$R.D = \frac{\dfrac{mass\ of\ substance}{volume\ of\ substance}}{\dfrac{mass\ of\ water}{volume\ of\ water}}$$

If the volume of a substance equals to the volume of water, then

$$R.D = \frac{mass\ of\ substance}{mass\ of\ equal\ volume\ of\ water}$$

Since,

$$weight\ in\ air = mass\ of\ a\ substance \times acceleration\ due\ to\ graviy$$

Then,

$$R.D = \frac{weight\ of\ substance\ in\ air}{apparent\ loss\ in\ weight\ of\ water}$$

But the weight of equal volume of water equals the upthrust, then R.D can be writen as:

$$R.D = \frac{weight\ of\ substance\ in\ air}{upthrust}$$

We know that, Upthrust = apparent loss in weight of a substance,

Therefore, R.D can be express as

$$R.D = \frac{weight\ of\ substance\ in\ air}{apparent\ loss\ in\ weight\ in\ water}$$

Thus, the relative density of substances (both solids and liquids) can also be determined by applying the Archimedes' principle.

Activity 6.3

Aim: To determine the relative density of a stone using Archimedes' principle.

Materials: Stone, spring balance, water, beaker, and string

Procedure

1. Suspend the stone on a spring balance using the string, as shown in Figure 6.4 (a)
2. Record the reading on the spring balance.
3. Measure the weight of the stone in water while it is suspended on a string as shown in Figure 6.4 (b).
4. Record your results.

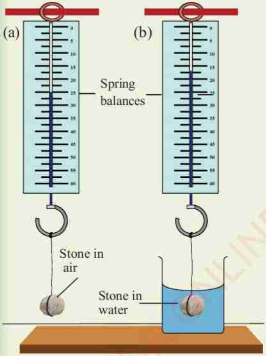


Figure 6.4: *Determination of a relative density of a stone*

Questions

(a) What is the weight of the stone in air?

(b) What is the weight of the stone when immersed in water?

(c) Calculate the apparent loss in weight.

(d) Calculate the relative density of the stone.

Relative density of the stone can be calculated from the obtained results. For example, the stone's weight in air is 25 N and 17 N in water as shown in Figure 6.4, then,

Relative density (R.D) of the stone =

$$\frac{\textit{weight of the stone in air}}{\textit{weight of a stone in air - weight of a stone in water}}$$

$$\text{R.D} = \frac{25\text{ N}}{(25-17)\text{ N}}$$

$$= \frac{25\text{ N}}{8\text{ N}}$$

$$= 3.125$$

Therefore, the relative density of the stone is 3.125.

Activity 6.3 demonstrates the determination of relative density of the solid by using Archimedes' principle. The principle can also be used to determine the relative density of liquids. Recall that,

$$R.D = \frac{\textit{density of a substance}}{\textit{density of water}}$$

Since, the volume is fixed, then, the relative density of liquid can be written as;

$$RD = \frac{\textit{mass of any given volume of liquid}}{\textit{mass of equal volume of water}}$$

Also,

$$RD = \frac{\textit{weight of any given volume of liquid}}{\textit{weight of an equal volume of water}}$$

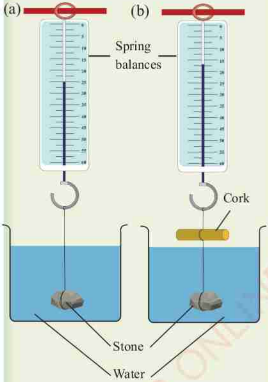
Activity 6.4

Aim: To determine the relative density of a solid that floats.

Materials: Cork, stone (sinker), spring balance, string, and water

Procedure

1. Tie a stone with a string and suspend it from a spring balance. Record its weight as w_1.
2. Immerse the stone in a beaker that contains water, as shown in Figure 6.5 (a).



3. Record its apparent weight as w_2.
4. Using the same string, tie the cork so that it is above the stone.
5. Immerse the stone in water while the cork is in air, as shown in Figure 6.5 (b).
6. Record their weight as w_3.
7. Immerse both the stone and the cork in the water, as shown in Figure 6.5 (c) and record their combined weight as w_4.

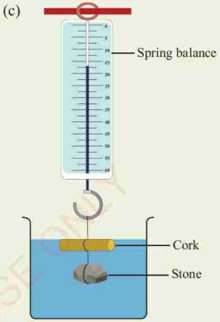


Figure 6.5: *Determination of relative density of solid that floats*

Questions

(a) What is the function of a stone?

(b) From your results, fill in the following blanks.

(i) Weight of the stone in air, (w_1).	____N
(ii) Weight of the stone in water, (w_2).	____N
(iii) Weight of the stone in water + cork in air, (w_3).	____N
(iv) Combined weight of the stone + cork (both immersed), (w_4).	____N
(v) Weight of the cork in air is obtained by ($w_3 - w_2$).	____N
(vi) Apparent weight loss of the cork.	____N

(c) Calculate the relative density of the cork using the above information.

A sinker is a solid substance that sinks in water. In this case, it is used to sink with a body that floats on water. In activity 6.4, the sinker is the stone and the cork is used as a floating body. Then, relative density of the solid that floats can be calculated as follows,

$$\textit{Relative density of a cork} = \frac{\textit{weight of cork in air}}{\textit{apparent weight loss of cork in water}}$$

$$= \frac{w_3 - w_2}{w_3 - w_4}$$

Activity 6.5

Aim: To determine the relative density of kerosene, using Archimedes' principle.

Materials: Stone, beaker, water, and kerosene

Procedure

1. Using a spring balance, weigh the stone in air. Record its weight in air as w_1.
2. Weigh the stone when it is fully immersed in water inside a beaker and record its weight as w_2.
3. Remove the stone from the water and dry it. Weigh the stone when fully immersed in kerosene and record its weight as w_3.

Questions

(a) Calculate the upthrust in kerosene.
(b) Calculate the upthrust in water.
(c) Calculate the relative density of the kerosene.
(d) Compare the density of water and kerosine.

Upthrust in kerosene = weight of kerosene displaced

Upthrust in kerosene = $w_1 - w_3$

Upthrust in water = Weight of water displaced

$$= w_1 - w_2$$

Since an object immersed in a fluid displaces its own volume of the fluid, and considering the relation for the relative density of liquid,

$$RD = \frac{weight\ of\ any\ given\ volume\ of\ liquid}{weight\ of\ an\ equal\ volume\ of\ water},$$

it follows,

$$R.D\ of\ kerosene = \frac{weight\ of\ a\ displaced\ kerosene}{weight\ of\ the\ displaced\ water}$$

Therefore, the relative density of kerosene $= \frac{w_1 - w_3}{w_1 - w_2}$.

Example 6.5

In an experiment to determine the relative density of a liquid, a solid Q weighed as follows:

Weight in air, $w_0 = 8.6$ N

Weight in water, $w_1 = 6.0$ N

Weight in liquid, $w_2 = 5.4$ N.

Calculate the density and use it to determine the relative density of the liquid.

Solution

Upthrust in water =

$w_0 - w_2 = 8.6\text{ N} - 5.4\text{ N} = 3.2\text{ N}$

Upthrust in liquid =

$w_0 - w_1 = 8.6\text{ N} - 6.0\text{ N} = 2.6\text{ N}$

By Archimedes' principle

Upthrust = weight of the displaced fluid

Note that, 1 g = 0.01 N,

Mass of displaced water = $\frac{w}{g}$

$= \frac{3.2}{0.01}\text{g} = 320\text{ g}$

Volume V of water displaced = $\frac{m}{\rho}$

$= \frac{260\text{ g}}{1\text{ g/cm}^3} = 260\text{ cm}^3$

Hence, the volume of liquid displaced is 260 cm^3

Mass of liquid displaced = $\frac{w}{g}$

$= \frac{3.2\text{ N}}{0.01\text{ N/g}} = 320\text{ g}$

Then,

Density of liquid = $\frac{m}{v}$

$= \frac{320\text{ g}}{260\text{ cm}^3} = 1.2\text{ g/cm}^3$.

$$Relative\ density\ of\ liquid = \frac{density\ of\ liquid}{density\ of\ water} = 1.2.$$

Alternatively,

$$Relative\ density\ of\ liquid = \frac{Upthrust\ in\ liquid}{Upthrust\ in\ water} = \frac{w_0 - w_2}{w_0 - w_1}$$

$$Relative\ density\ of\ liquid = \frac{3.2\text{ N}}{2.6\text{ N}} = 1.2.$$

Exercise 6.2

Whenever necessary use acceleration due to gravity $g = 10$ N/kg.

1. What volume of iron of density 7.8 g/cm^3 must be attached to wood whose mass is 100 g and density of 0.5 g/cm^3 if both iron and wood have to be submerged in the water?

2. An object is hung from a spring balance. If it weighs 40 N in air and 30 N when immersed in water:
   (a) Calculate upthrust on the object.
   (b) Determine the weight of the displaced water.
   (c) What is the mass of the displaced water?
   (d) What is the volume of the displaced water?
   (e) Calculate the relative density of the object.
   (f) Calculate the density of the object.
3. An object weighs 60 N when in air and 40 N when immersed in water. What is its:
   (a) Relative density?
   (b) Density?
4. A piece of sealing-wax of helium weighs 0.27 N in air and 0.12 N when immersed in water. Deduce:
   (a) its apparent weight in a liquid of density 800 kg/m^3; and
   (b) its relative density.
5. Mr Anuar's metal cube of side 2 cm weighs 0.56 N in air. Determine:
   (a) its apparent weight when immersed in methylated spirit of density 0.585 g/cm^3; and
   (b) the density of the metal of which it is made.

Task 6.3

In groups of four students, carry out the following task and record your observations. Determine the relative density of cooking oil, kerosene, and ethanol by using Archimedes' principle. Present the results in class.

Sinking and floating

When you place a sealed empty plastic bottle in water in a bucket, it floats as shown in Figure 6.6. If the same bottle is filled with sand, it sinks in water.

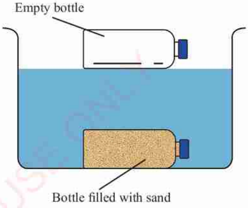


Figure 6.6: *Sinking and floating*

Whether an object floats or sinks in a fluid depends on the relative size, weight, and the upthrust acting on the object. If the weight of the object is larger than the upthust, the object moves downward and therefore, sinks. If the weight of an object is less than the upthrust, the object will stay on the surface of the fluid and therefore, it floats. The action of weight and the upthrust on an object in the fluid is shown in Figure 6.7.

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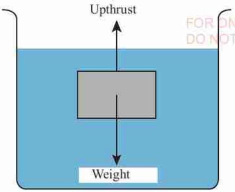

Figure 6.7: *Forces acting when a body is submerged in a liquid*

The empty plastic bottle floats because its weight is less than the upthrust of water while the sand filled bottle sinks because its weight is larger than the upthrust of water.

Therefore, *floating* is the tendency of an object suspended in water to stay on the surface of the fluid. On the other hand, *sinking* is the tendency of an object to go to the lower level.

In the preceding sections, it was shown that an object immersed in a fluid displaces its own volume of the fluid. It was also shown that upthrust acting on the immersed object depends on the volume of the object and the density of the liquid in which the object floats. Therefore, sinking and floating can also be explained in terms of density of the object and that of the fluid.

If the object's density is larger than that of the fluid, the object will sink. The object floats if its density is less than that of the fluid. Ships and boats float on water because their average density is less than the density of water. Inflated balloons float in air because their density is less than the density of air. Metallic objects such as spoons and coins sink in water because they have a higher density than water.

Conditions for floating

For an object to float, the upthrust exerted by the surrounding fluid must be larger than the objects weight. Upthrust depends on the volume of the submerged part of the object and the density of the surrounding fluid. Thus, the larger the submerged volume of the object and the density of the fluid the larger the upthrust.

A ship is normally with large hollow space. This means that the ship has a large volume which allows it to displace a large volume of water, resulting into a large upthrust equaling the weight of the ship. If the hollow space is filled with air, the average density of the ship and air is less than the density of water and so, the ship floats. What happens when the empty space in the ship is filled with water?

Therefore, the following conditions must be satisfied for an object to float in water:

(i) The volume of submerged part of the object must be large enough to displace a large volume of water.

(ii) The average density of the object must be less than the density of the surrounding water; and

(iii) The upthrust due to water must be equal to the total weight of the object.

Relationship between upthrust and floatation

Upthrust depends on the density of the fluid. If the density of an object is less than that of the surrounding fluid, the object will float. If the density of the object is larger than the density of the fluid, the object will sink. This is the reason why an object seems lighter, for example, in salt water than in fresh water and appears to weigh less in water than in air. A ship floats more easily in the sea, and also it is easier to swim in the ocean than in the lake, because sea water is denser than lake water. Figure 6.8 shows a marine vessel floating in sea water.

Figure 6.8: *Marine vessel floating in a sea*

For an object to float on a fluid the upthrust exerted on it by the fluid must be equal to the weight of the object. That is, $U = w$. Since, upthrust is equal to the weight of the displaced fluid, then,

Weight of the displaced liquid = Apparent loss in weight of the object.

But, apparent loss in weight = upthrust.

But,
Upthrust = actual weight – apparent weight.

Since, upthrust = weight of the object, then for an object to float, its apparent weight must be zero.

Floating on Dead sea

Note that if the salt concentration in sea water becomes higher than the normal (for example in the Dead sea where it is 34% of the normal), the density of the sea water can become larger than that of the human body. In that case a human body floats on the sea.

Recall that the apparent weight of an object is equal to the difference between its actual weight and the upthrust. That is;

Apparent weight = actual weight – upthrust

Also,
upthrust = weight of displaced fluid.

Therefore,

Apparent weight = actual weight – weight of the fluid displaced.

Activity 6.6

Aim: To investigate the relationship between upthrust and floatation.

Material: Piece of wood, large beaker, water, spring balance, and digital balance

Procedure

1. Suspend the piece of wood from a hook of a spring balance and record its weight, as shown in Figure 6.9 (a).

2. Weigh a dry and empty beaker, as shown in Figure 6.9 (b)

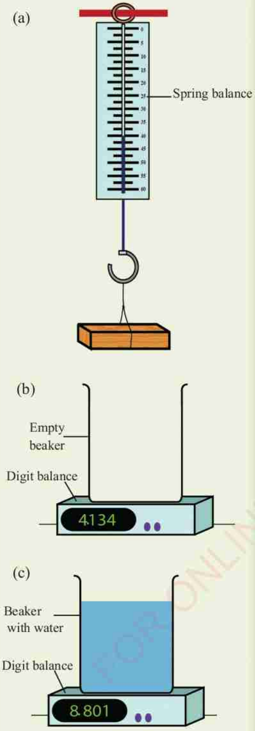

Figure 6.9

3. Fill the beaker with 65 cm^3 of water and weigh it as shown in Figure 6.9 **(c).** Record the new weight.
4. Dip the suspended piece of wood in the beaker of water and record its apparent weight.

Question

What is the apparent weight of the floating piece of wood?

The apparent weight of the floating piece of wood is zero. This implies that an object floats on water when the apparent weight is zero.

Law of floatation

The previous activity implies that it is possible for a body to float on a fluid if certain conditions are satisfied. This leads us to the law of floatation which states that: '*A floating body displaces its own weight of the fluid in which it floats*'. The actual weight of an object can also be expressed in terms of its density.

Relationship between volume of submerged part of the floating body and the density of fluid

Consider, a cork in Figure 6.10 submerged in water of a particular volume and density. The two forces acting on a submerged body are upthrust U and the weight of a floating body w_B. When an equilibrium is reached, these two forces balance. Hence,

The upthrust in a liquid = weight of the liquid displaced.

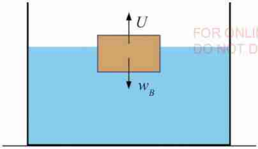

Figure 6.10: *A cork submerged in water*

Consider a body of volume V_1 and density ρ_1

Volume of submerged part is V_2

Weight of the body, $w_B = V_1\rho_1 g$

Upthrust of the fluid $U = V_2\rho_2 g$

From the principle of floatation;

Weight of a body = Upthrust of the fluid

$$V_1\rho_1 g = V_2\rho_2 g$$

$$\frac{V_1}{V_2} = \frac{\rho_2}{\rho_1}$$

$$\frac{\text{volume of floating body}}{\text{volume of the submerged part of the object}} = \frac{\text{density of liquid}}{\text{density of body}}.$$

Example 6.6

Suppose a 60 kg woman floats in fresh water with 97% of her volume submerged when her lungs are full of air. What is her average density? Take the density of water to be 1 000 kg/m³.

Solution

Let the volume of a woman = V_1

Volume of the submerged body of a woman = V_2

Density of a woman = ρ_{person}

Density of water = ρ_{water}

We find the woman's density by solving the equation,

$$\frac{V_1}{V_2} = \frac{\rho_{water}}{\rho_{person}}$$

$$\rho_{person} = \frac{V_2}{V_1} \times \rho_{\text{water}}$$

$$\rho_{person} = \frac{0.97V_1}{V_1} \times \rho_{\text{water}}$$

$$\rho_{\text{person}} = 0.97 \times 1\,000 \text{ kg/m}^3$$

$$\rho_{\text{person}} = 970 \text{ kg/m}^3$$

Therefore, the woman's density is less than the density of the fluid, hence, she will float in water.

Example 6.7

Calculate the density of a body, if a floating body is 95% submerged in water. The density of water is 1 000 kg/m³.

Solution

Given,

Density of water, $\rho = 1\,000$ kg/m³

From Archimedes' principle, buoyant force = weight of the body

$$F_b = \rho_b \times V_b \times g$$

$$\rho_b \times V_b \times g = \rho \times V \times g$$

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where, ρ, g, and V are the density of a water, acceleration due to gravity, and volume of water and V_b and ρ_b are the volume and density of the body, respectively.

Since 95% of the body is immersed,

$$\rho_b = \frac{0.95V_b}{V_b} \times \rho_{water}$$

$$= 0.95 \times 1\,000 \text{ kg/m}^3$$

$$= 950 \text{ kg/m}^3$$

Therefore, the density of the body is 950 kg/m^3.

Law of floatation in everyday life

There are many objects and vessels that float or can be made to float. Balloons, canoes, ships, boats and submarines obey the law of flotation in their operations. These bodies are designed in such a way that the average density of the body is less than the density of fluid in which they float. Therefore, an object made of a material of high density, such as a metal, must have a lot of space filled with material of very low density like air. Remember that an object will float if its average density is less than the density of the fluid in which it is immersed. The operation principles of various floating objects are discussed in the forthcoming sections.

Balloons

Suppose we have a 5.5 g balloon made of rubber, which has a density of 1.52 g/cm^3. The volume of the balloon is 3.62 cm^3. Since the density of rubber is much greater than the density of air (0.001293 g/cm^3) a deflated balloon would not float in air.

Now let us inflate the balloon with helium gas, which has a density of 0.000178 g/cm^3. Suppose we put 3 000 cm^3 of helium in the balloon. The mass of this helium is 0.534 g, therefore the balloon has a total mass of 6.034 g and a total volume of 3 003.62 cm^3. The density of the helium balloon becomes 0.00200 g/cm^3, which is still greater than the density of air. Let us add 2 500 cm^3 more helium to the balloon. Now, the total mass is 6.479 g and the total volume is 5 503.62 cm^3. The density of the helium balloon is now 0.00118 g/cm^3, which is less than the density of air. The balloon will then float in air.

Hot-air balloon

A hot-air balloon in Figure 6.11, consists of a bag called envelope that is capable of containing hot air. Suspended beneath the envelope is the gondola, which carries a source of heat and passengers. As the temperature of the air in the envelope is increased, it expands. As the air expands, its volume increases while mass remains constant resulting to a decrease in density of air in the envelope. This makes the air in the envelope less dense than the cooler surrounding air. This difference in densities produces an upthrust that lifts the balloon and its passengers into the air.

Figure 6.11: *Hot-air balloon*

A hot-air balloon can be made to rise or descend by changing the temperature of the air in the envelope. If the temperature is increased, the air expands more resulting to a greater upthrust causing the balloon to rise higher in air. If the air in the envelope is cooled, it contracts to a smaller volume producing less upthrust and thus lower its height. You should note that the rise and fall of the hot-air balloon is influenced by factors such as the temperature of outside air and the variation of air density with altitude.

Submarines

Submarines are made of steel and other dense materials with a lot of empty space filled with air. The result is that the average density of the submarine is less than that of seawater so it floats. If we wish to submerge (sink) the submarine, seawater is allowed to flow into its ballast tanks until the average density of the submarine becomes greater than that of the sea water. To make the submarine resurface (float), air is forced into the ballast tanks pushing out the water until the submarine's average density is again less than that of the seawater.

Figure 6.12: *Submarine*

Ships

A ship is made up of steel which is denser than water. One would expect the ship to sink in water due to a high density of steel. However, the ship has a large volume with a hollow space. Large volume allows the ship to displace large volume of water leading to a greater upthrust. Furthermore, the hollow space makes the average density of the ship to be less than the density of the seawater. Therefore, the ship floats on water.

When the ship is loaded, its mass increases, resulting to the increase of average density. This causes the ship to move lower into the water. Putting more load into the ship will make the ship to move deeper into the water. If the load is increased beyond a certain limit, the ship will sink completely. Therefore, the amount of load in the ship must be controlled to avoid overloading. It is for this reason ships are marked with a special line which shows the maximum loading that the ship can take. This line is known as the Primsoll lines, shown in Figure 6.13.

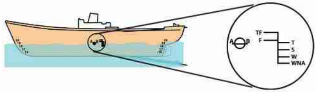


Figure 6.13: *Plimsoll lines*

Hydrometer

A hydrometer is an instrument used to determine the relative density of liquids. It is consisting of a cylindrical stem which is graduated and a glass bulb at its end as shown in Figure 6.14. The bulb is weighed with mercury or lead ballast to make it float upright. The stem is made thin to allow great change in height for a small change in density.

The graduations in the stem of the hydrometer start with small numbers at the top and end with large numbers at the bottom, since, it sinks more in less dense liquids.

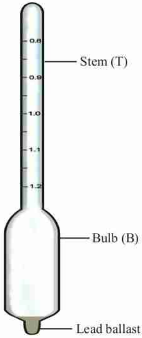


Figure 6.14: *The Hydrometer*

Structure of a hydrometer

A practical hydrometer has the following parts, as shown in Figure 6.14.

(a) A hollow narrow graduated glass tube or stem (T).
(b) A wide bulb (B).
(c) A lead or mercury ballast to make the hydrometer float upright in liquid.

Note that the volume of the bulb determines the range of densities that can be measured. This is largely because the bulb sinks so as to push the surface of the liquid up to the stem. The narrower the stem, the more sensitive the hydrometer. This means that a small difference in density results to a large change of the reading on the stem.

Mode of action of hydrometer

A hydrometer is made to float in the liquid whose relative density is to be measured. It sinks to different levels depending on the relative density of the liquid in which it is floating, as shown in Figure 6.15.

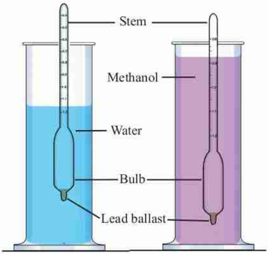


Figure 6.15: *Hydrometer in water and in methanol*

The liquid whose relative density is to be determined is poured into a tall jar and the hydrometer is gently lowered into the liquid until it floats freely. The point where the surface of the liquid touches the stem of the hydrometer indicates the relative density of the liquid. Remember that since the density of water is 1 g/cm^3, the density of the liquid in g/cm^3 is numerically equal to its relative density. Considering Figure 6.15, the hydrometer sinks more in methanol whose relative density is 0.8 and sinks less in water whose relative density is 1. This means that water is denser than methanol.

Determination of relative density of a liquid using hydrometer

Activity 6.7

Aim: Determination of relative density of a liquid.

Materials: Liquid, hydrometer, sand or lead ballast

Procedure

1. Take a thin-walled test tube of cross-section area A and put a strip of graduated graph paper inside it. Ensure that the strip is water proofed.
2. Take a glass jar containing water.
3. Try to float the test tube in vertical position and partially sub-merged in water. Let the density of water be ρ_1.
4. Put some mass of sand or lead ballast in the test tube to make the bottom of the test tube heavy and read the level of water on the graph paper. Record the reading as L_1.
5. Replace water in the jar with the liquid whose density is ρ_2.
6. Again, record the level of the liquid on the graph paper as L_2.

Since, the weight of the test tube with the mass is the same in both cases, the Upthrust of water on the test tube = upthrust of the liquid on the test tube.

That means,

$$AL_1\rho_1 g = AL_2\rho_2 g$$

$$\frac{L_1}{L_2} = \frac{\rho_2}{\rho_1}.$$

Example 6.8

The hydrometer shown in Figure 6.16 is used to measure the densities of liquids between 1 g/cm^3 and 0.8 g/cm^3. Assume that density of water = 1 g/cm^3, the cross-section area of the stem is 0.5 cm^2 and the height of the stem above the liquid level is 16 cm. Determine the volume of the hydrometer below 1.0 mark.

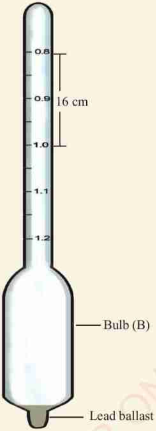


Figure 6.16: *Hydrometer*

Solution

Let V_1 cm^3 be the volume of the hydrometer below 1.0 mark.

The volume between 0.8 and 1.0 marks be V_2

The volume below the 0.8 mark be V_3

Then, $V_2 = Area \times height$

$$= 16 \text{ cm} \times 0.5 \text{ cm}^3$$
$$= 8 \text{ cm}^3$$

So, $V_3 = V_1 + V_2 = (V_1 + 8)\text{cm}^3$

The upthrust on the hydrometer when in water is $U = \rho_{\text{water}} \times V_1 \times g$

Upthrust on the hydrometer when in the liquid $U = \rho_{\text{liquid}} \times V_3 \times g$

From the law of floatation,

The weight of the hydrometer = upthrust in water = upthrust in liquid

That is

$$\rho_{\text{water}} \times V_1 \times g = \rho_{\text{liquid}} \times V_3 \times g$$

Thus,

$$V_1 = \frac{\rho_{liquid} \times V_3}{\rho_{water}} = \frac{\rho_{liquid}}{\rho_{water}} \times (V_1 + 8)$$

$$V_1 = \frac{0.8}{1.0} \times (V_1 + 8)$$

$$V_1 = 0.8V_1 + 6 \cdot 4$$
$$0.2V_1 = 6.4$$
$$V_1 = 32 \text{ cm}^3$$

Therefore, the volume of hydrometer below 1 cm mark is 32 cm^3.

Chapter summary

1. An object immersed partially or totally in a fluid (liquid or gas) experiences an upward force called the buoyant force or upthrust.
2. The buoyant force causes the object to have an apparent weight that is less than its true weight. Apparent weight = real weight – upthrust.
3. Archimedes' principle states that 'The upthrust on a body is equal to the weight of fluid displaced'. That is, upthrust = weight of displaced fluid.
4. The density and relative density of solid and liquid can be determined using Archimedes' principle. The same principle applies whether determining density or relative density.

   Therefore,

   For a solid

   $$R.D = \frac{weight\ of\ a\ solid\ in\ air}{weight\ of\ a\ solid\ in\ air - weight\ of\ a\ solid\ in\ water}.$$

   For a liquid

   $$R.D = \frac{weight\ of\ a\ solid\ in\ air - weight\ of\ a\ solid\ in\ liquid}{weight\ of\ a\ solid\ in\ air - weight\ of\ a\ solid\ in\ water}.$$

5. An object floats or sinks depending on its density and the density of the fluid in which it is placed.
6. An object will float if it displaces a weight of fluid equal to its own weight. In other words, an object will float if its density is less than the density of the fluid in which it is immersed.
7. Hot-air balloons, submarines, ships and weather balloons can be made to float by altering their volume to make them less dense than water or air.
8. A hydrometer is a device used to measure the relative density of different liquids. It works on the principle that the hydrometer sinks until it displaces a volume of liquid that has the same weight as itself. The hydrometer sinks further in low-density liquids than high-density liquids.

Revision exercise 6

Section A

Choose the most correct answer.

1. The same body is immersed in liquid *A* and then, in liquid *B*. The extent to which the body sinks in liquid *B* is less than in liquid *A*. What conclusion can be derived from such an observation?
   (a) The density of liquid A is more than the density of liquid *B*.
   (b) The density of liquid *B* is more than that of liquid *A*.
   (c) The density of solid body is less than that of the liquid in both cases.
   (d) The density of liquid *A* is the same as that of liquid *B*.
2. A sample of milk diluted with water has a density of 1040 kg/m^3. If pure milk has a density of 1080 kg/m^3, then, the percentage of water by volume in the diluted milk is:
   (a) 55%.
   (b) 40%.
   (c) 50%.
   (d) 45%.
3. A student lowers an object in a liquid filled in a container. He finds that there is a maximum apparent loss in weight of the object when:
   (a) it just touches the surface of the liquid.
   (b) it is partially immersed and also touches the sides of the container.
   (c) it is completely immersed in the liquid.
   (d) it is partially immersed in the liquid.
4. The sea water is denser than fresh water due to:
   (a) mixing of sand.
   (b) stagnation.
   (c) mixing salts.
   (d) evaporation.
5. Which of the following methods should be adopted in measuring the volume of the liquid displaced by a solid using a measuring cylinder?

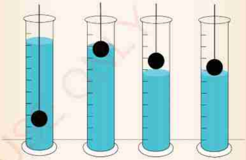


Figure 6.17

   (a) The solid should hang above the liquid surface in the jar, as in Figure 6.17 (III).
   (b) The solid should be well inside the liquid, as in Figure 6.17(I).
   (c) Just rest at the surface of liquid in cylinder, as in Figure 6.17 (IV).
   (d) The solid should be half immersed in liquid, as in Figure 6.17 (II) .

6. Consider Figure 6.18:

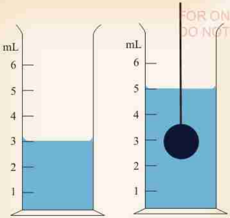


Figure 6.18

The volume of stone immersed in the liquid is:
(a) 2 ml.
(b) 5 ml.
(c) 1 ml.
(d) 3 ml.

7 Instrument used for measuring the density or relative density of liquid is known as:
(a) Spherometer.
(b) Mercury meter.
(c) Buoyancy meter.
(d) Hydrometer.

8. An object of weight 500 N is floating in the liquid. The magnitude of buoyant force acting on it is:
(a) 500 N.
(b) 400 N.
(c) 200 N.
(d) 100 N.

9. If the relative density of a substance is 11.3, the density of the substance is,
(a) 11.3 kg/m^3.
(b) 11.3 g/cm^3.
(c) 11.3×10^3 kg/m^3.
(d) 11.3×10^3 g/cm^3.

10. If the density of an object placed in the liquid is equal to the density of the liquid, the object will:
(a) float half immersed.
(b) float wholly immersed.
(c) float completely above the liquid.
(d) sink.

11. Write TRUE for correct or FALSE for incorrect statements for each of the following:
(a) Archimedes' principle is also known as the law of submergence. _________
(b) The relative density of an object is the ratio of its density to the density of water. _________
(c) A spring balance can directly give the mass of an object. _________
(d) The real weight of an object may be obtained by the sum of its apparent weight in a fluid and the upthrust the fluid exerts upon it. ________
(e) The relative density of an object cannot be used to determine the proportion of the object that will be submerged in a fluid. _________

Section B

12. Explain the following terms:
(a) Floating.
(b) Sinking.
(c) Upthrust.
(d) Actual weight.
(e) Apparent weight.

13. When an object with a mass of 250 g is submerged in water, its weight is measured to be 2.2 N. What is the upthrust and the density of the object?
14. A ship has a mass of 1 000 tonnes and floats in seawater of density 1023.6 kg/m^3. Calculate the amount of water displaced.
15. When an object of mass 250 g is submerged in the methanol, which has a density of 0.79 g/cm^3, what would be its apparent weight? Use $g = 10\ m/s^2$
16. A 300 g object weighs 2.5 N in air and 2 N in an unknown liquid. What is the density of the unknown liquid?
17. Objects 1 and 2 are placed on opposite ends of a beam balance as shown in Figure 6.19. When held in air the two objects are seen to have the same weight. When lowered in water the objects are no longer balanced. Which object has the higher density? Explain your answer.

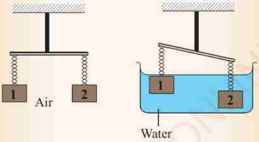


Figure 6.19

18. When an object of mass 200 g is submerged in the methanol, its apparent weight is 1.052 N. When submerged in benzene, its apparent weight is 0.951 N. If the density of methanol is 0.8 g/cm^3, what is the density of benzene?
19. To measure the density of a 100 g block of wood, a 100 g lead sinker is attached to make the block sink as shown in Figure 6.20. When lowered into the water, the combination has an apparent weight of 1.3 N. If the density of lead is 11.3 g/cm^3, what is the density of the wood?

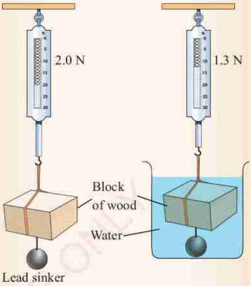


Figure 6.20

20. A hot-air balloon including the envelope, gondola, burner and fuel and one passenger has a total mass of 450 kg. The air outside the balloon is at 20 °C and has a density of 1.29 kg/m^3. The air inside the envelope is heated to a temperature of 120 °C, at which it has a density of 0.90 kg/m^3. What volume must the envelope expand in order to lift the balloon into the air?
21. An object with a volume of 150 cm^3 is found floating in water with 60%

of its volume submerged. What is the density of the object?

22. Listed below are the dimensions and mass of various objects. Identify the one that would float in water.
    (a) A 5 cm cube with a mass of 200 g.
    (b) A solid sphere with a radius of 5 cm and a mass of 200 g.
    (c) A rectangular solid with dimensions of 10 cm × 5 cm × 2 cm and a mass of 200 g.
    (d) A solid cylinder whose height is 10 cm, base radius is 3 cm and mass is 200 g.
23. An object floats in water with 40% of its volume submerged.
    (a) If the object was placed in methanol with a density of 0.79 g/cm^3, what percentage of its volume would be submerged?
    (b) If it were placed in liquid carbon tetrachloride with a density of 1.58 g/cm^3, what percentage of its volume would be submerged?
24. A salvage ship is attempting to raise an iron anchor off the ocean floor. The anchor has a mass of 560 kg and the density of iron is 7 800 kg/m^3. The cable used to lift the anchor can support a weight of 5 000 N before breaking. Use 1 025 kg/m^3 as the density of seawater.
    (a) Can the cable support the anchor while it is completely submerged?
    (b) Can the cable support the anchor when it is completely out of the water?
    (c) What percentage of the anchor will be out of the water when the cable breaks?
25. Icebergs are hazardous to shipping because so much of their volume is below the water level. If the density of seawater is 1 025 kg/ m^3 and the density of ice is 919 kg/m^3, what percentage of an iceberg is below the water level?
26. A certain hydrometer has a scale of 1cm (g/cm^3). It is being used to measure the density of two unknown liquids.
    (a) When immersed in liquid A, the distance between the water mark and the liquid mark is +0.77 cm. What is the density of liquid A?
    (b) When immersed in liquid B, the distance between the water mark and the liquid mark is –0.42 cm. What is the density of liquid B?

Chapter Seven

Structure and properties of matter

Introduction

Study of structure and properties of matter plays a significant role in physics and engineering. When constructing houses, bridges, and fly-overs, the proper selection of materials, based on their properties, is required. In this chapter, the concepts involving the structure of matter, elasticity, adhesion and cohesion, surface tension, capillarity, diffusion, and osmosis will be discussed. The competence developed will enable you to analyse and understand the properties of different materials found in your environment.

Structure of matter

All physical and chemical substances are classified as matter. A physical object refers to the collection of a large number of particles making a whole object. The particles of a particular object are arranged in regular or irregular pattern. In this subsection the concept of matter and its properties are discussed.

Concept of matter

Physics is the study of matter and energy and their interaction. Matter refers to any substance that occupies space and has mass. Matter includes everything that can be seen, and touched, or those that cannot be seen like air.

Matter is anything which has a mass and occupy space.

Examples of matter are shown in Figure 7.1.

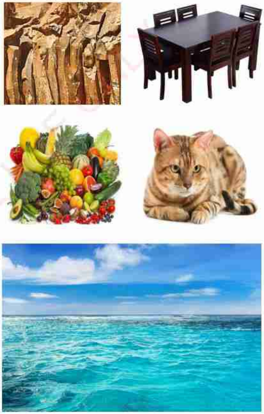


Figure 7.1: *Examples of matter*

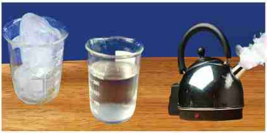
Task 7.1

Brainstorm the properties of different common substances. Do they have mass? Do they occupy space? Can they be referred to as matter? Present your findings in the class.

States of matter

A state of matter refers to one of the possible distinct forms in which matter can exist. There are three physical states of matter, namely solid, liquid, and gas. Primary factors which determine the state of matter are temperature and pressure. Each state of matter has its own characteristics. Furthermore, the states of matter can be changed from one form to another.

Some substances do exist in all three states of matter. For example, water can exist in solid state as ice, in liquid state as water, and in gaseous state as vapour, as shown in Figure 7.2.



(a) Ice (b) Water (c) Vapour

Figure 7.2: *Water in its three states*

Other substances, for example wood shown in Figure 7.3, exists in only one state of matter, that is, a solid even when the temperature has changed.

Figure 7.3: *Piece of wood*

Particulate nature of matter

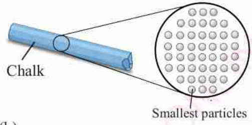
If you keep cutting a material into smaller and smaller pieces, you will eventually come to smallest indivisible particles. Each indivisible particle is a building block of the materilal. Based on this idea, scientists have developed a model to explain the structure and the behaviour of matter. The model is called 'the particle model of matter'.

According to the particle model, matter is made up of tiny particles called atoms or molecules. Most substances cannot exist by themselves as individual atoms, rather they combine their atoms with themselves or with other atoms to form molecules. Thus, a molecule may be made up of similar atoms of the same element or different atoms of two or more elements. For example, a molecule of hydrogen is made up of two atoms of hydrogen but a molecule of water consists of two atoms of hydrogen and one atom of oxygen. The size of a molecule is extremely small - of the order of 10^{-9} - 10^{-10} m. as a result of the small size, molecules cannot be with the naked eyes or even with the aid of a microscope: Again because of the small size, one gramme of an element contains several millions of molecules.

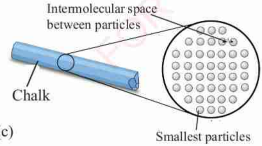
For example, one gramme of hydrogen contains about 10^{23} molecules. Atoms are the building blocks of matter just as bricks are to the wall. The following ideas are based on the particle model of matter.

1. All matter is made up of small particles. Figure 7.4 (a) shows the model of the small particles of matter.
2. The particles of the same substance are identical. Figure 7.4 (a) shows the model of arrangement of particles of matter in the chalk.
3. The particles of matter have space (intermolecular space). Figure 7.4 (b) shows the space between the particles.
4. The particles exhibit the forces (intermolecular forces) between them as shown in Figure 7.4 (c)
5. The particles of matter are always moving randomly as shown in Figure 7.5.
6. Adding heat to the matter makes the particles move faster.

(a)



(b)



(c)

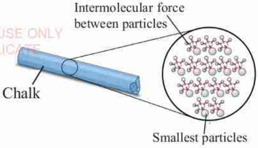


Figure 7.4 *Smallest particles of a chalk*

The particle model of matter is very useful for the following reasons:

1. It provides reasonable explanations for the behaviour of matter.
2. It presents an important idea that particles of matter are always moving.

Thus, the particle model of matter can successfully be used to explain the properties of solids, liquids, and gases. It is also useful in explaining the changes of states of matter.

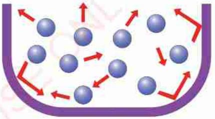


Figure 7.5: *Random motion of particles of matter*

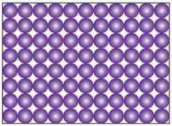
Classification of states of matter

Particles that build matter behave differently in the three states of matter. This results into different properties of solids, liquids, and gases.

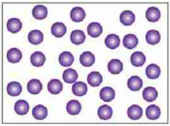
Particles in solids

The particles in solids are packed close to each other in fixed positions as shown in Figure 7.6 (a). The distance between one particle and another is almost negligible.

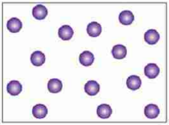
This explains why a solid materials definite shape and volume. The particles are held together by a strong attractive force. Thus, they vibrate in their fixed positions. Ice is an example of solid state of water. Other examples of solid material are wood, stone, and book.



(a) Particles in a solid



(b) Particles in a liquid



(c) Particles in a gas

Figure 7.6: *Models showing the arrangement of particles in solid, liquid and gas*

Particles in liquid

Unlike in a solid, particles in a liquid state do not have a fixed position. Thus, a liquid material has indefinite shapes. Liquid matter will always assume the shape of the container in which it is held. In liquid state, the atoms and molecules are slightly farther apart compared to solids state, as shown in Figure 7.6 (b). Forces of attraction between particles in liquid state are slightly weaker than in solid. The particles in liquid have an increased freedom of motion. An example of matter liquid state is water. Other examples of liquid are honey, kerosene and milk.

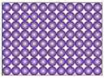
Particles in gas

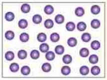
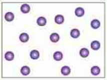
In gas, particles move freely at high speed in all directions. The particles are so far apart such that they weakly interact with each other. Particles in gas have the weakest forces of attraction; as a result, they move very fast. Gas has no definite shape and volume. Gas will always occupy the volume of its container. A good example of gas is vapour. Figure 7.6 (c) shows the model of arrangement of gas particles.

Properties of the states of matter

The properties of solid, liquid and gas are summarised in Table 7.1.

Table 7.1: Properties of solids, liquids and gases

State of matter	Properties
Solids 	1. Has a definite shape and volume. 2. Has strongest force of attraction. 3. Cannot be compressed. 4. Does not flow.

Liquids 	1. Has a definite volume but no definite shape. 2. The force of attraction is weaker than that of solid. 3. Cannot be easily compressed. 4. Flow easily.
Gases 	1. Has neither definite shape nor volume. 2. Has the weakest force of attraction. 3. It is compressible. 4. Flow easily.

Task 7.2

In groups of four students, collect various substances around your school environment. Classify them as solid, liquid and gas. Present your list in class and compare it with those of your classmates.

Activity 7.1

Aim: To observe the behaviour of water in its three states.

Materials: Beaker, source of heat tripod stand, and ice cubes

Procedure

1. Put some crushed ice cubes in a beaker.
2. Place the beaker over a source of heat under a tripod stand.
3. Record your observations.

Questions

(a) What happens when the ice is heated?

(b) What happens when the heating is continued?

The ice cubes have a definite shape. When heated, they melt into liquid water which does not have a definite shape but instead takes the shape of the beaker. Further heating of the water causes it to change into vapour. Vapour has neither definite shape nor volume. The particles of the ice are so close together that the ice has a definite shape. These particles can only vibrate due to the strong forces between them. In liquid form, the particles are further apart and can move past each other. This is why liquid water has no definite shape but flows to take the shape of the container holding it. When the water changes into vapour, the particles have more energy and move even faster and far away from each other. This is the reason why the vapour has no definite shape and eventually moves out of the container holding it. This is why the particles of air are almost everywhere.

Evidence for the particulate nature of matter

The particle model of matter is a powerful tool that can explain various experimental results which show its correctness. The model can also explain different observations that provide evidence for the particle nature of matter. One of the famous observations described by the particle model of matter is Brownian motion.

Brownian motion

Brownian motion or movement is a random motion of tiny particles suspended in a fluid. This motion consists of small random fluctuations in the fluid. This phenomenon was named after Robert Brown, a Scottish botanist who was the first to observe such fluctuations in 1827. He observed using a microscope that pollen grains which are suspended in water move shorter distances in an irregular or zig-zag manner.

Activity 7.2

Aim: To observe the Brownian motion in a liquid.

Materials: Beaker, potassium permanganate ($KMnO_4$) solution, distilled water, microscope slide, and dropper

Procedure

1. Put water in the beaker
2. Using a dropper put one drop of $KMnO_4$ in water.
3. Observe the movement of $KMnO_4$ in water.
4. Record your observations

Questions

(a) What do you observe?
(b) Explain the observation you noted in question (a)

The $KMnO_4$ particles move in a continuous random motion. This is because they are constantly being hit by the invisible particles of water which are randomly moving. This proves that liquid is made up of particles. Brownian motion shows that matter is made up of tiny particles that are in a state of continuous random motion.

Activity 7.3

Aim: To demonstrate the particulate nature of chalk.

Materials: Piece of chalk, paper, and magnifying glass

Procedure

1. Break a chalk into three parts.
2. Break the pieces further into smaller pieces.
3. Crush the pieces into powder and place it on a piece of paper.
4. Observe the powder using a magnifying glass.

Questions

(a) What observations did you make?
(b) What is your conclusion?

When a piece of chalk is crushed into powder and observed using a magnifying glass, its particles are clearly visible. This proves that chalks like other types of matter are made up of particles. This activity shows that the chalks are true forms of matter and can be further broken down into smaller particles.

Activity 7.4

Aim: To demonstrate the particulate nature of $KMnO_4$.

Materials: $KMnO_4$, digital balance, beakers, water, glass rod, and pipette

Procedure

1. Take four beakers of the same size and label them as A, B, C and D.
2. Pour 100 ml of water into beaker A.
3. Using a digital balance, measure 1 g of potassium permanganate.
4. Dissolve completely 1 g of crystals of potassium permanganate in water in beaker A by stirring using a glass rod. Note the colour of solution in beaker A.
5. Using pipette, remove 25 ml of solution from beaker A and transfer it into beaker B. Fill beaker B with water up to 100 ml mark. Note the colour of solution in beaker B.
6. Repeat this process by taking 25 ml of solution from beaker B and transferring it into beaker C, then filling it with water up to 100 ml mark. Note the colour of solution in beaker C.
7. Remove 25 ml of solution from beaker C and transfer it into beaker D. Fill the beaker with water up to 100 ml mark. Note the colour of the solution in beaker D.

Questions

(a) What do you notice about the colour of solutions in the four beakers?

(b) What causes the difference in colour?

The solutions in the beakers keep getting lighter with every dilution. This is because the particles of the potassium permanganate are broken down into smaller and finer particles with every dilution. The process of diluting the solution of potassium permanganate into a faint purple colour is actually the division of matter (potassium permanganate) into its constituent particles. This proves the particulate nature of solids.

Kinetic theory of matter

In particle model of matter, particles are always in motion. Since any moving object or particle has kinetic energy, the faster they move, the more kinetic energy they have. Thus, the particle model of matter can also be explained by the kinetic theory of matter. The kinetic theory of matter describes the physical properties of matter in terms of the behaviour of its component atoms or molecules. It states that *'All matters are made up of very small particles that are in constant motion'*. The more heat energy the particles possess the faster they move. The theory can be used to explain the properties of solid, liquid, and gaseous materials, as well as changes in the state of matter. The kinetic theory of matter is also known as "the molecular theory of matter". In solid state, particles are arranged close together in a regular pattern and vibrate in fixed positions. These particles have the lowest value of kinetic energy. In liquid state, particles are still close together but in an irregular arrangement. Unlike those in solid, the particles in liquid move around and are able to slide past one another. In gas, particles are far apart, moving rapidly and bouncing off the walls of the container.

Table 7.2 summarises the types of motion of the particles of solid, liquid and gas.

Table 7.2: Types of motion of particles of matter

State	Example	Type of motion of the molecules
Solid	Wood, box, lead shots	Vibration
Liquid	Milk, water	Random
Gas	Oxygen, carbon dioxide	Random

The temperature of a substance has an effect on the movement of its constituent particles. An increase in temperature causes an increase in movement of the particles. For example, when you boil water, as the temperature increases the movement of water molecules increases too.

Activity 7.5

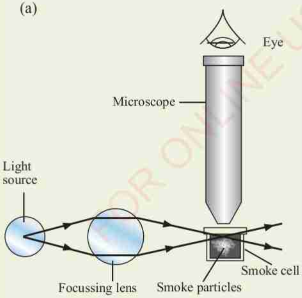
Aim: To observe the kinetic theory of matter.

Materials: Smoke cell, torch, microscope, and source of light

Procedure

1. Introduce some smoke into the smoke cell then cover it.
2. Set the smoke cell so that it is directly below the microscope lens, as shown in Figure 7.7 (a).

(a)



(b)

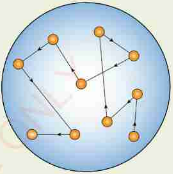


Figure 7.7

3. Use the torch to shine light on one side of the smoke cell.
4. Observe the particles in the cell using the microscope.

Questions for discussion

(a) What do you observe under the microscope?

(b) Give an explanation for the phenomenon.

The smoke particles can clearly be seen moving randomly as in Figure 7.7 (b). This explains the kinetic nature of matter, whereby particles of matter are constantly moving in a random motion.

Kinetic theory of matter in relation to the particles of matter

The kinetic theory of matter can be used to explain many of the observations and measurements that we make about the substances around us. These include mass, elasticity, adhesion and cohesion, surface tension, capillarity, diffusion, and viscosity.

Mass of substance

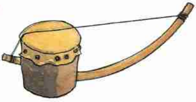
Mass is defined as the measure of the amount of matter in a substance. It depends on the number of particles in a substance. A given fixed volume of a solid material has more mass than the same volume of liquid or gas because it has a large number of particles. On other hand, a piece of lead is much heavier than the same size of a piece of aluminium because the individual mass of lead particle is greater than that of aluminium particle.

Elasticity

If you stretch and release a rubber band, it will return to its original shape. If you compress and release a coil spring, it will resume its original length and shape. When a rubber band is stretched, we say it is deformed because it is not in its original shape. A coil spring is also deformed when compressed. The ability of objects to return to its original shape after deformation is called elasticity. *Elasticity is the ability of a deformed body to return to its original shape and size when the forces causing the deformation are removed*. This means that elasticity is a reversible deformation. A body with this ability is said to be elastic.

Relationship between tension and extension of an elastic material

Elasticity varies from one solid to another. For example, steel is very elastic, which means that it can easily regain its original shape and size even after being subjected to relatively large deforming forces. The deforming force is referred to as tension. Some solid materials are elastic while others are not. To a great extent, most solid materials exhibit elastic behaviour. However, there is a limit of how much force can be applied to an object and to what extent it can be deformed. This limit is known as elastic limit. Therefore, elasticity has limits such that if the material is deformed beyond the elastic limit, it behaves as a plastic. This type of deformation is called plastic deformation. Plastic deformation is not reversible. Materials which undergo plastic deformation are known as plastic materials. Examples of elastic materials are shown in Figure 7.8. This includes a rubber band tying pens, strings used to make a bow and musical instruments. While a good example of inelastic materials is glass (breaking glass).



(a) A rubber band tying pens (b) A bow and an arrow (c) Musical instrument string

Figure 7.8: *Elastic materials*

Activity 7.6

Aim: To investigate the relationship between force (tension) applied to an elastic material and the degree of its deformation (extension)

Materials: Coil spring, pointer, slotted masses, mass holder, metre rule, retort stand and clamp

Procedure

1. Hang a coil spring from a retort stand as shown in Figure 7.9.

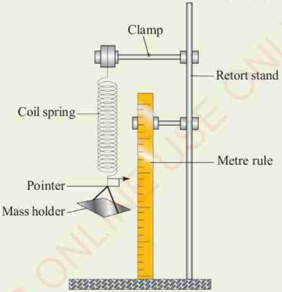


Figure 7.9: *Elasticity experiment*

2. Attach the pointer at the free end of the spring and hang the mass holder.
3. Place a metre rule adjucent to the apparatus so that the position of the pointer can be measured
4. Measure and record the position of the pointer when there is no mass placed on the mass holder as X_0

5. Place a 50 g mass on the holder, measure and record the pointer position as X_1, as shown in Figure 7.10.

6. Repeat the experiment with masses of 100 g, 150 g and 200 g. Record the respective pointer positions as X_2, X_3 and X_4.

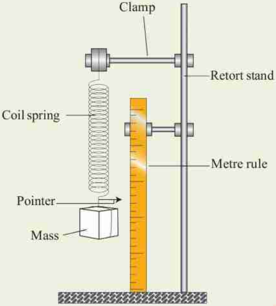


Figure 7.10 *Mass placed on the holder*

7. Tabulate the results of your observation.
   (a) The force on the spring, $F = mg$
   (b) The distance the spring is stretched (extension): Extension $(e) = X_1 - X_0$

Record your observation in the following table.

Mass (g) on holder	Force on spring (N) $F = \frac{\text{mass} \times g}{100}$	Extension (cm) $(e = X_i - X_0)$	$k = \frac{F}{e}(\text{N/cm})$
0			
50			
100			
150			
200			

Gravitational acceleration $(g) = 0.01$ N/g

Questions

(a) Plot a graph of force (F) against extension (e) of the spring.
(b) Give an explanation for the shape of the graph.

The graph of tension against extension is shown in Figure 7.11.

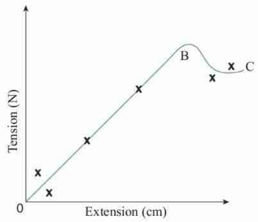


Figure 7.11: *Relationship between tension and extension of a stretched spring*

Certain observations can be made from the graph in Figure 7.11. For the portion between O and B, the tension (force) is directly proportional to the extension of the spring. This is in accordance with Hooke's law, which explains the relationship between the force applied on an elastic material and the extension produced.

Hooke's law states that: *"Provided the elastic limit is not exceeded, the extension is directly proportional to the force applied"*.

The elastic limit is the maximum point of deformation that a body can undergo and still return to its original shape when the force causing it is removed. Beyond the elastic limit, the body experiences plastic deformation. From the graph, in Figure 7.11, the part between points B and C, the spring undergoes plastic deformation, whereby it remains deformed even after the load is removed. The spring will continue to increase in length until a certain maximum tension is reached. Beyond this tension, the spring will finally break. In the elastic region, the ratio of the applied force (F) to the distance stretched (e) is called elastic force constant, k. Hence, $k = \frac{F}{e}$. The SI unit of k is N/m.

Task 7.3

Perform this task in groups of four students.

1. What is the elastic force constant, k, of the spring you used in activity 7.6?
2. If a mass of 400 g was placed on the holder, how far would the spring stretch?
3. If a mass of 100 g causes an extension of 2.5 cm, find the mass which will give extension of 8.7 cm.
4. Identify objects at home or school environment in which their functions depends on the concept of elasticity.

Applications of elasticity in daily life

Elasticity has a variety of applications at home, in transport, and industry.

At home, the applications of elasticity can be observed in:

(a) rubber gaskets that seal the refrigerator door;
(b) clothing;
(c) springs in furniture;
(d) rubber bands that hold things together; and
(e) toys like balloons and balls.

In transport, we find application of elasticity in:

(a) rubber tyres, hoses, belts and shock-absorbing springs for cars and trucks;
(b) aeroplane wings; and
(c) support cables for bridges.

In industry, the application of elasticity is found in;

(a) steel beams used in construction;
(b) conveyor belts;
(c) measuring weight;
(d) insulation against vibration and sound; and
(e) mechanical control devices.

Figure 7.12 shows the steel girder bridges often made using big steel bars due to their high elasticity.

Figure 7.12: *Girders used on a fly-over bridge at Buguruni - Dar es Salaam*

Adhesion and cohesion

Forces between molecules of the same kind, they are called cohesive forces. When there is attraction between molecules of different substances, these are called adhesive forces or forces of adhesion. Definite shapes of a solid material are due to strong cohesive forces among its molecules. So, water molecules can experience cohesion among themselves while a water molecule and a glass molecule will experience adhesion. Previously, you did activities that aimed to determine the volume of a liquid using a measuring cylinder. The description indicated that the surface of the liquid was curved, forming a meniscus. The volume must be read at the bottom or top of the meniscus depending on the type of liquid used. For mercury, the top of the meniscus is read.

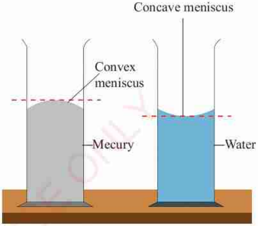


Figure 7.13: *Shapes of menisci of mercury and water*

The formation of a meniscus in a liquid is due to forces of adhesion between the liquid and the walls of the container. The adhesion of a liquid such as water to the walls of a vessel causes an upward force on the liquid at the edges. The forces of attraction act to hold the surface firm so that the whole liquid surface is dragged downward. The opposite pattern takes place in mercury.

Activity 7.7

Aim: To determine the adhesion and cohesion forces.

Materials: Water, glycerine, glass slides, cylinders, and droppers

Procedure

1. Pour about 50 ml each of glycerine and water into separate cylinders and carefully observe the meniscus of each liquid.
2. Using a dropper, place a drop of glycerine on glass slide and note down your observation.
3. Use another dropper to place a drop of water on another sheet of glass and note your observation.

Questions

(a) Compare the menisci of water with glycerine.

(b) What did you observe when drops of glycerine and water were placed on separate glass slides?

(c) Explain your observations.

The meniscus of water curves upwards forming a concave shape. When each of these liquids is dropped on a glass slide, the water spreads further unlike glycerine. This is because glycerine has a high cohesive force in its particles. A drop of glycerine on a glass sheet remains almost spherical because the cohesive force is larger than adhesive force. On the other hand, a drop of water on a glass slide spreads because the adhesive force between the water and the glass is larger than the cohesive forces between its particles. This is the reason why water wets glass.

Applications of adhesion and cohesion

The following are applications of adhesion and cohesion:

1. If we want to stick two different objects together, we use the adhesive effects of tape or glue.
2. Adhesion can also be used to remove harmful materials such as bacteria from drinking water.
3. Adhesive forces are the source of friction between surfaces.
4. Cohesion assists in the transport of water in plants and animals by allowing one molecule to pull others along with it.
5. The bodies of plants and animals also use the cohesion of tissue to repair damage.
6. Cohesion is responsible for viscosity.
7. Ink sticks on paper because adhesive forces between ink and paper are greater than the cohesive forces in the molecules of ink. This is the reason why what you write remains on the paper.

Task 7.4

In groups of four students, discuss other ways in which cohesion and adhesion are used in our day-to-day activities. Present your findings in the class.

Surface tension

Liquid surfaces have a tendency of shrinking into the minimum surface area. This tendency leads to surface tension. Surface tension is defined as the property of the surface of a liquid that allows it to resist an external force due to the cohesive nature of its molecules. This allows the liquid surface to behave like a fully stretched elastic skin. Small insects such as water striders and items like plastic, paper clips float on the surface of water, as shown in Figures 7.14 and 7.15, because of the surface tension of water.

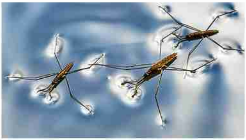


Figure 7.14: *Water strider*

Figure 7.15: *Paper clip floating on the surface of water*

Mechanism of surface tension

Surface tension is caused by cohesive forces between liquid molecules. Taking an example of water in a glass, the molecules at the surface of water do not have neighbouring water molecules above them, as shown in Figure 7.16. Consequently, these molecules cohere more strongly to the water molecules directly associated with them, that is the molecules that are next to and below them and not above them. Because of the stronger cohesive force between water molecules, it is more difficult to move an object through the surface than to move it when it is completely submerged. This resistance to an external force due to cohesive forces between molecules is what we call surface tension.

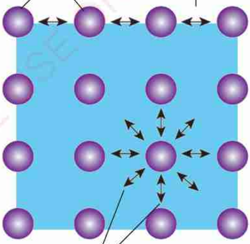


Figure 7.16: *Surface tension between water molecules*

Activity 7.8

Aim: To demonstrate surface tension in water.

Materials: Needle, water, trough, paper clip, chalk powder, liquid detergent, and razor blades

Procedure

1. Fill the trough with water.
2. Gently place the needle, razor blade and paper clip on the water surface.
3. Observe what happens.
4. Sprinkle some chalk powder on the water surface.
5. Note down your observations.
6. Add a little detergent to the water in the trough and observe what happens.

Questions

(a) What did you observe when the needle, paper clip, razor blade and chalk powder were gently placed on the water surface?

(b) What did you observe when some detergent was sprinkled on the water?

When the needle, paper clip, razor blade, and chalk powder were placed on the surface of water, they all floated on top, as shown using a razor blade in Figure 7.17. The surface tension of water was large.

Figure 7.17: *Razor blade floating in fresh water*

However, when some detergent is added in the water, the same objects sunk to the bottom of the trough, as shown using a razor blade in Figure 7.18. This means that, the introduction of the detergent reduced the surface tension of the liquid. A detergent lowers the surface tension of water.

Figure 7.18: *Razor blade sinking in soapy water*

If an object is placed on the surface of a liquid, its weight pushes the liquid downward causing a deformation, which increases the surface area of the liquid. The surface tension resists the increase in the area by pushing upward the object, as shown in Figure 7.19.

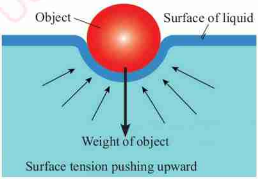


Figure 7.19: Surface tension supporting an object

However, when some detergent is added in the water, the metal object sinks. This is because the detergent decreases the surface tension of the water. The water's ability to push upward on the object is therefore lowered. The surface of the liquid expands and the object sinks to the bottom of the trough.

Detergents as examples of surfactant

A surfactant is a substance that reduces the surface tension of a liquid. The term ''surfactant'' is an acronym for surface active agent.

Activity 7.9

Aim: To demonstrate surface tension in a soap film.

Materials: Wire, thin thread, and soap solution

Procedure

1. Make a loop using the wire.
2. Make a smaller loop using the thin thread and suspend it in the wire loop, as shown in Figure 7.20.

Figure 7.20

3. Dip the wire loop in a soap solution and let a film (skin) of soap cover the whole area of the loop.
4. Gently pierce the soap film using a hot pin inside the loop of thread until it bursts.

Questions

(a) What is the shape of the thread when the loop is dipped in a soap solution?

(b) What happens when the soap film inside the loop of thread is pierced?

(c) Explain your observations.

The thread hangs loosely even after the wire loop is dipped in a soap solution. When pierced, the soap film inside the loop of the thread disappears but the one outside the loop remains intact. In fact, the thread is pulled outwards and forms a circular loop. Before piercing, the thread hangs loosely since there is a film of soap both within and outside the loop of the thread. The surface tension does not cause any tension in the thread. The sum of the forces on the thread is zero. However, on piercing the film inside the thread loop, the sum of the forces is no longer zero. The surface of the soap wants to be at a minimum and so the thread is pulled outwards causing it to form a ring, as shown in Figure 7.21.

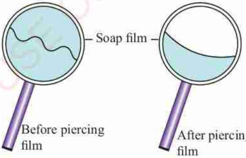


Figure 7.21: *Wire ring with loop of thread in a soap film*

Surface tension is what causes drops of water or soap bubbles to assume a spherical shape. Recall that surface tension attempts to form the minimum surface area and a spherical shape has the smallest surface area for a given volume.

The surface tension of any liquid is affected by the following factors:

1. **Nature of the liquid:** different types of liquids have different surface tension. For example, mercury has a higher surface tension than water.
2. **Contamination:** impurities in a liquid lower its surface tension.
3. **Temperature:** surface tension of a liquid decreases with increase in temperature.

Applications of surface tension

Surface tension has several practical applications:

1. The cleaning action of soap (detergents in general) is due to its ability to lower the surface tension of water. For example, when washing clothes, soap decreases the adhesion forces between the particles of a cloth and those of dirt. As a result, the dirt is easily removed since both water and soap particles penetrate the pores of the fabric.
2. Mosquitoes normally lay their eggs on water. The eggs hang on the water surface. When a small amount of oil is poured on the water, it reduces the surface tension. This breaks the elastic film and the eggs are drowned and killed.
3. Hot soup has a lower surface tension than cold soup. As a result, hot soup spreads over a large area of the tongue. Hence hot soup is tastier than cold soup.
4. Soap bubbles that consist of a layer of water between two layers of soap film can have a large surface area because the soap acts to decrease the surface tension of water. This is how surfactants are used to enhance the cleaning ability of water. Surfactants are also used to make emulsions of two liquids like oil and water, which normally do not mix.
5. In extraction of impurities during laboratory processes.

Task 7.5

In groups of five students, float two matchsticks on the surface of water. Touch the water surface between the matchsticks using a hot needle. Record your observations and present your findings in the class.

Capillarity

Capillarity is a consequence of cohesive and adhesive forces. It is defined as a phenomenon in which liquid rises or falls in a narrow space such as a thin tube or in the voids of a porous material without any assistance of external forces.

The effect of capillarity can be seen in drawing up of liquid between hairs of a paint brush, in a thin tube, in porous materials such as sponge and in some non-porous materials such as sand.

Mechanism of capillarity

Capillarity occurs because of the intermolecular forces between the liquid and the surrounding solid surfaces. If the diameter of the opening is sufficiently small, the combination of surface tension and adhesive forces between the liquid and the container act to propel the liquid through the opening. Note that surface tension is due to cohesive forces.

A common apparatus used to demonstrate capillarity is the capillary tube. Capillary tube is a narrow tube with a fixed length. When the lower end of the tube is placed in water, adhesion occurs between the liquid and the tube walls. This pulls the liquid column along the tube wall. The height of the liquid column increases until the weight of the liquid column is sufficient to overcome the cohesive and adhesive forces that propel the liquid.

Factors affecting capillarity

Capillarity is mainly affected by the following factors.

The radius of the tube or opening

The height of the liquid column is inversely proportional to the diameter of the tube or opening. The weight of the liquid column is proportional to the square of the tube's radius. It follows that a narrower tube will draw a longer liquid column than a wider tube.

For example, the water in the glass capillary tube will rise to a height approximated by $\frac{0.3}{d}$ where d is the diameter (in centimetre) of the tube. Thus, if a glass tube has a diameter of 0.5 mm, water will rise to a height given as; $h = \frac{0.3}{0.05} = 6$ cm

Tubes of different diameters will result to water columns of different heights, as shown in Figure 7.22.

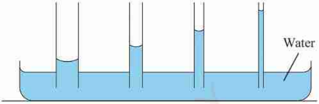


Figure 7.22: *Capillary rise in tubes of different diameters*

Nature of the Liquid

Capillarity also depends on the nature of the liquid since it is governed by cohesive and adhesive forces. For example, when the same capillary tube is dipped in water and mercury, mercury level in the tube falls while water rises, as shown in Figure 7.23.

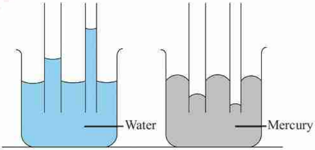


Figure 7.23: *Capillary rise and fall*

Activity 7.10

Aim: To observe capillarity in different liquids.

Materials: Beakers, 0.5 mm glass tubes, water, cooking oil, and ethanol

Procedure

1. Fill three beakers about half full of water, ethanol, and cooking oil.
2. Immerse a 0.5 mm glass tube into each liquid; make sure that the base of the glass tube in each liquid are at the same level, as shown in Figure 7.24.

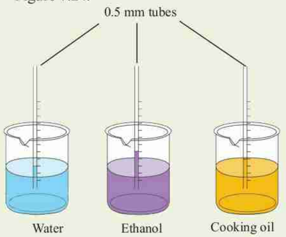


Figure 7.24

3. Measure and record the height of each liquid above the surface of the liquid in the beaker.

Questions

(a) Which liquid rose to the highest height?

(b) Which liquid had the least rise in height?

(c) Explain what this suggests about the adhesive and cohesive forces in each liquid.

Ethanol rises to the highest height while water rise the least. This suggests that ethanol has the strongest adhesive force than water and cooking oil. Also, ethanol has lowest density. This means that capillary action is greater in ethanol.

Applications of capillarity

1. Capillarity is essential to plants and animals. In plants, it facilitates the transportation of water and nutrients from the roots to the leaves. In animals, it assists in the circulation of blood.
2. Capillarity promotes the movement of ground water. This is in addition to the gravitational movement of water in the soil.
3. It is the principle on which paper and fabric towels work to absorb water. For example, soaking up moisture from the body using a towel is due to capillary.
4. Clothing worn in hot climate conditons uses capillary action to draw perspiration away from the body.
5. In an oil or kerosene lamp, capillarity draws the fuel up into the wick where it can be burnt.
6. A writing nib is split in the middle so that a fine capillary is formed. When a pen is dipped in ink, the ink reaches the nib by capillary action.

Diffusion

When a lid of perfume bottle is opened, the smell of the perfume spreads over the whole room. This happens even without the flow of the air. Such a phenomenon is called diffusion.

Diffusion is defined as the movement of particles from a region of high concentration to a region of low concentration. It can occur in both liquids and gases because their molecules are not fixed. Solids do not diffuse since the particles of a solid are fixed. Diffusion occurs faster in gases than in liquids, because the particles in gases move more easily than particles in liquid. Moreover, gas particles have plenty of space between them. Figure 7.25 shows diffusion of two types of gas.

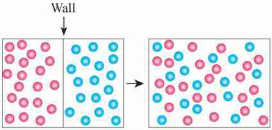


Figure 7.25: *Diffusion of two types of gas*

Activity 7.11

Aim: To demonstrate diffusion.

Materials: Potassium permanganate, perfume, water, and beaker

Procedure

1. Arrange yourselves uniformly in the classroom. At the front of the room open a bottle of perfume (or other strong-smelling substance). Ask your class members to raise their hands when they smell the perfume.
2. Drop a few crystals of potassium permanganate in a beaker of water. Observe what happens after a period of five minutes.

Questions

(a) How long does it take for everyone in the room to smell the perfume?

(b) What makes water to turn purple shortly after the crystals of potassium permanganate have been dropped into the beaker?

It takes a short while for the perfume to spread throughout the room. The molecules of potassium permanganate continuously collide and mix with those of water, hence changing the colour of water to purple. Diffusion is another piece of evidence which shows that substances are made up of particles.

Applications of diffusion

Diffusion can be applied in various ways including the following.

1. Balancing the concentration of water and nutrients in and out of the cells of living organisms.
2. Detecting harmful substances in the environment.
3. In the use of air fresheners and other sprays.
4. In the process of respiration, oxygen from the lungs diffuses into the bloodstream.

Osmosis

Osmosis is the movement of a solvent from a region of low concentration to a region of high concentration through a semipermeable membrane. Particles will diffuse through the membrane in an attempt to equalise the concentrations on either side.

Figure 7.26 shows two solutions of different concentrations separated by a semipermeable membrane. The membrane is permeable to the smaller solvent molecules but not to the larger solute molecules. Osmosis stops when the concentration becomes the same on either side of the membrane.

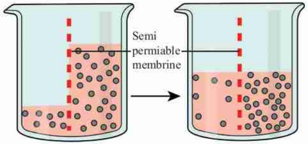


Figure 7.26 *Osmosis*

Activity 7.12

Aim: To demonstrate osmosis.

Materials: Large beaker, thistle funnel, semipermeable membrane, concentrated sugar solution, and water

Procedure

1. Tie the semipermeable membrane on the mouth of a thistle funnel.
2. Pour about 30 ml of the concentrated sugar solution into the thistle funnel.
3. Fill a large beaker about 3/4 full with water and immerse the thistle funnel into the water, as shown in Figure 7.27.

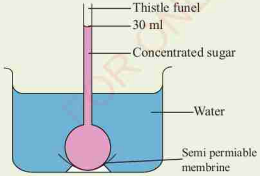


Figure 7.27 *Demonstration of osmosis*

4. Leave the set-up for a while and observe what happens.

Questions

(a) What is observed in the set-up after some time?

(b) Explain the phenomenon that takes place.

The level of the solution in the thistle funnel rises steadily while that in the beaker drops. This is because water molecules pass through the semipermeable membrane into the solution that has higher concentration of sugar.

Application of osmosis

Osmosis has various applications including the following

1. Controlling the movement of water and nutrients in and out of the cells. This helps to maintain the correct concentrations needed for the cells to function properly.
2. Filtration processes.
3. Removing harmful ingredients from drinking water.
4. Removing salt from seawater so as to make the water suitable for drinking and for other domestic uses.

Chapter summary

1. Matter is anything that has mass and occupies space. It is made up of tiny particles called atoms or molecules.
2. Matter can exist in three states, namely solid, liquid and gas. Solid has a fixed volume and shape, liquid has a fixed volume but a variable shape, and gas has neither definite shape nor volume. The principal factor that determines the state of matter is temperature.
3. Brownian motion indicates that matter is made up of tiny particles that are in a state of constant random motion.
4. The kinetic theory of matter demonstrates that all matter is composed of atoms and molecules that are in a state of constant random motion.
5. Elasticity is the ability of a deformed material to regain its original size and shape after the deforming force is removed.
6. Hooke's law states that 'provided that the elastic limit is not exceeded, the extension of elastic material is directly proportional to the force applied'.
7. Adhesion is the attraction of molecules of different substances. Cohesion is the attraction of molecules of the same substance. It is cohesive forces that create surface tension.
8. Surface tension is the ability of the surface of a liquid to behave like a fully stretched elastic skin. This elastic nature of the surface of a liquid is caused by the attraction of the liquid molecules at the surface.
9. Capillarity is the tendency of a liquid to rise and fall in narrow tubes or to be drawn into small openings. It occurs when the adhesive forces between the liquid and the walls of the tube are larger than the cohesive forces between the liquid molecules.
10. Diffusion is the spontaneous and random movement of particles from a region of high concentration to a region of low concentration. It leads to a uniform distribution and concentration of liquid or gas molecules
11. Osmosis is the movement of solvent molecules from a region of low concentration to a region of high concentration through semi-permeable membranes.

Revision exercise 7

Section A

Choose the most correct answer.

1. Which of the following statements is not true?
   (a) Matter is anything that occupies space and has mass.
   (b) The particle theory of matter states that matter is made up of a large number of tiny and discrete particles.
   (c) The kinetic energy of particles in matter increases if its temperature increases.
   (d) The particles in all kinds of matter are identical.
2. Which one of the following items shows the correct comparison of the average kinetic energy of the particles in solid, liquid and gas for a given substance?
   (a) solid > liquid > gas.
   (b) solid < liquid < gas.
   (c) solid = liquid = gas.
   (d) solid = liquid > gas.
3. The diagram in Figure 7.28 shows the arrangement of particles in a substance.

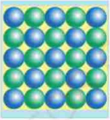


Figure 7.28:

   Which among the statement is the characteristic of the substance in this state?
   (a) Particles move randomly and slowly and sometimes will collide against each other.
   (b) The volume of the object is not fixed.
   (c) Most of the particles are still in contact with one another.
   (d) Difficult to be compressed.
4. Which one of the following statements is not true about the particles in a gas?
   (a) The particles of gas move at high speed.
   (b) The collision between the gas particles and the wall of the container is elastic.
   (c) The gas particles move randomly in all direction.
   (d) The gas particles are arranged in regular patterns.
5. Which one of the following takes place when water solidifies to become ice?
   (a) Water molecules get nearer to each other.
   (b) Energy is absorbed from the surrounding.
   (c) Water molecules are not arranged orderly.
   (d) The mass increases.
6. The particle theory of matter states that *'Matter is made up of a large number of tiny and discrete particles.'* Which one of the following phenomena supports this hypothesis?
   (a) Brownian motion.
   (b) The shape of a solid is fixed.
   (c) Diffusion of bromine vapour in gas.
   (d) the volume of a substance increases when it transforms from liquid into gas.

Section B

7. (a) Distinguish between solid and liquid states.
   (b) Explain why water has indefinite shape.
   (c) State the kinetic theory of matter.
8. (a) State Hooke's law and express it in mathematical form.
   (b) An object with the mass of 500 g was hang from the spring with a force constant 20 N/m.
   (i) How far in centimeters would the spring stretch?
   (ii) What is the mass of an object that stretches the spring 35 cm long? (take g = 0.01 N/g).
9. (a) Explain why water wets glass while mercury does not.
   (b) Explain how the knowledge of adhesion and cohesion is useful in daily life?
10. (a) Explain why mosquitoes can manage to walk on the surface of water?
    (b) Explain why when washing clothes, we use a soap/detergent.
11. (a) Differentiate between capillarity and surface tension.
    (b) Which phenomenon is taking place when kerosine rises up a wick?
12. (a) Explain why the smell of rotten body is felt at a bit far distance?
    (b) Explain the importance of knowledge of diffusion in daily life?
13. (a) Distinguish between osmosis and diffusion.
    (b) Sometimes beans are soaked in water before cooking them. Explain the phenomenon governing the soaking process.

14. Explain each of the following observations:
    (a) The smell of a dead rat located at a hidden corner of a room, soon fills the entire room.
    (b) A thermometer suspended in boiling water does not indicate any rise in temperature although heat is steadily supplied to the vessel containing the water.
    (c) Drops of water, dropping slowly from a tap, are spherical in shape.
15. (a) Two types of intermolecular forces are
    (i) ________________.
    (ii) ________________.
16. (a) What will happen when a narrow glass tube is dipped into mercury?
    (b) What is meant by the term meniscus? Name the kind of meniscus formed in a glass container:
    (i) In case of water.
    (ii) In case of mercury.
17. On the basis of the kinetic theory of matter explain:
    (a) why gas has neither definite shape nor volume.
    (b) why liquid has definite volume but no definite shape.
    (c) why solid has definite shape and volume.
18. A force of 9.6 N stretches a spring 6 cm while a force of 14.4 N stretches it 9 cm. What force would be required to stretch the spring by 15 cm?

Chapter Eight

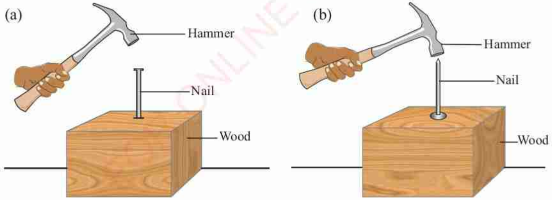
Pressure

Introduction

Pressure has many influences in daily life. Knife edges are made sharp to allow easy cutting while football shoes consist of spikes that help the player to have better grip on the ground. School bags are made with wide shoulder pads to reduce pain on the shoulder while a person carrying a clay pot uses head rings to reduce pain on the head. Pressure helps blood to flow around our body. All these facts, can be explained using the concept of pressure. In this chapter, you will learn about the concept of pressure in solid, liquid, and gas and its applications in daily life situation. The competencies developed will enable you to effectively utilise different tools that use the concept of pressure.

Concept of pressure

Consider an iron nail being driven into a block of wood through its sharp end as in Figure 8.1 (a) and the flat end as in Figure 8.1 (b). The iron nail with the sharp point will penetrate easily into the block of wood. On the contrary, when it is driven into the same block through its flat end with the same magnitude of force, it would not penetrate easily.



Sharp end of a nail driven into a wooden block

Flat end of a nail driven into a wooden block

Figure 8.1: *Driving an iron nail into a block of wood*

On the other hand, two wooden blocks of different surface areas driven into a soft surface using force of the same magnitude, the block with small surface area will penetrate deeper in the soil than the one with larger surface area, as shown in Figure 8.2.

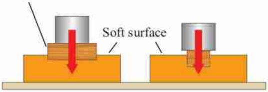


Figure 8.2: *Driving a wooden block into the soft surface.*

These situations show that when force acts on an object, the result can be strongly affected by the surface area over which it acts. The relationship between force and the surface area over which it acts, can be described by the concept of pressure. When a force is applied in a direction perpendicular to the surface of the object, the object experiences pressure.

Thus, pressure is defined as the force acting normally or perpendicularly on a unit surface area of an object. That is,

$$Pressure = \frac{Normal\ force}{Area}$$

$$= \frac{Force}{Area} = \frac{F}{A}$$

For a given amount of force, the smaller the area of application the larger the pressure exerted. The SI unit of pressure is Newton per square metre, (N/m^2). This unit is usually referred to as the Pascal, Pa, where 1 Pa = 1 N/m^2.

Other units of pressure are atmosphere, torr, bar and mmHg.

1 atmosphere (atm) = 760 mmHg.

1 atm = 1×10^5 N/m^2 = 1 bar (used by the meteorologists).

1 torr = 1 mmHg = 133.3 Pa.

Activity 8.1

Aim: To demonstrate the concept of pressure.

Materials: Two buckets one having a thin handle (A) and the other having a thick handle (B), and water

Procedure

1. Fill in the buckets with equal volume of water.
2. Use one hand to lift each of the buckets of water, one at a time.
3. Record your observations.

Question

Which of the buckets gave you a larger discomfort when lifted? Why?

If you lift a bucket of water by its handle which is thin, you will experience some discomfort. However, if the handle is made thicker, the discomfort will be much less. This is because, for a thicker handle, the area over which the force is applied is large and so, the pressure exerted is small.

Task 8.1

In groups of four students, identify other ways in which pressure manifests itself. Discuss your findings in class.

Pressure due to solids

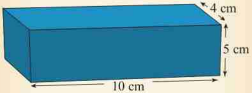
Pressure in solids depend on the surface of contact. A force (F) applied onto a small surface area exerts a greater pressure as compared to when it is applied onto a large surface area.

$$Pressure\ due\ to\ solid = \frac{Applied\ force}{Area\ of\ contact} = \frac{F}{A}.$$

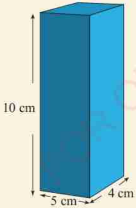
Example 8.1

A block of wood weighs 3 N and measures $5\ \text{cm} \times 10\ \text{cm} \times 4\ \text{cm}$. If it is placed on a table with its largest base area or smallest area face in contact with the table, it would exert different pressure on the table. Which surface would exert the largest pressure on the table? Explain.

Solution



(a) Large base area of contact



(b) Small base area of contact

Figure 8.3

From Figure 8.3 (a) the surface of sides $5\ \text{cm} \times 10\ \text{cm}$ makes the largest area of contact.

Therefore,
Largest base area

$$= 10\ \text{cm} \times 5\ \text{cm} = 50\ \text{cm}^2$$

$$P = \frac{F}{A}$$

$$= \frac{3\ \text{N}}{5.0 \times 10^{-3}\ \text{m}^2}$$

$$= 6.0 \times 10^2\ \text{N/m}^2$$

From Figure 8.3 (b) the surface of sides $4\ \text{cm} \times 5\ \text{cm}$ makes the smallest area of contact. Therefore,
smallest base area

$$= 4\ \text{cm} \times 5\ \text{cm} = 20\ \text{cm}^2$$

$$P = \frac{F}{A}$$

$$= \frac{3\ \text{N}}{2.0 \times 10^{-3}\ \text{m}^2} = 1.5 \times 10^3\ \text{N/m}^2$$

$$= 1.5 \times 10^3\ \text{N/m}^2$$

The smallest surface area provides the largest pressure of $1.5 \times 10^3\ \text{N/m}^2$ compared to that exerted by the largest surface area of $6.0 \times 10^2\ \text{N/m}^2$.

Example 8.2

The tip of a needle has a cross-sectional area of $1 \times 10^{-6}\ \text{m}^2$. If a doctor applies a force of 20 N to a syringe that is connected to the needle, what is the pressure exerted at the tip of the needle?

Solution

$$Pressure = \frac{Normal\ force}{Area}$$

$$P = \frac{20\ \text{N}}{1\times10^{-6}\ \text{m}^2}$$
$$= 2.0\times10^{7}\ \text{N/m}^2$$

Therefore, the pressure exerted at the tip of the needle is $2.0\times10^{7}\ \text{N/m}^2$.

Dependence of pressure on surface of contact

From examples 8.1 and 8.2, it is noticed that the greater the surface of contact, the lower the pressure exerted. Also, the smaller the surface of contact of an object, the greater the pressure it exerts. Generally, to create a large amount of pressure, you can either exert a large force or exert a force over a small area or do both.

Activity 8.2

Aim: To demonstrate dependence of pressure on surface of contact.

Materials: Wires of varying diameters, and bars of soap

Procedure

1. Use a very thin piece of wire to cut a bar of soap into half.
2. Use a thick piece of wire to cut a similar bar of soap into half.
3. Record your observations.

Questions

(a) What is the difference when a bar of soap is cut using a thin wire and when using a thick wire?

(b) Explain your observation.

It is easier to cut a bar of soap using a thin piece of wire than a thick one. This shows that the smaller the surface of contact of one object with another, the greater the pressure it exerts. Thus, the pressure between two solid surfaces depends on the force between the surface and the area of contact of the two surfaces.

Applications of pressure due to solids

Pressure due to solids has wide practical applications. Similar effects are obtained when using nails, screws, push pins, spears and arrow heads. These items are given sharp points to increase their penetration powers. Figure 8.4 shows examples of solid objects with sharp points.

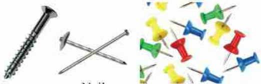


Figure 8.4: *Objects with sharp points*

Knife blades and razor blades have cutting sharp edges, as shown in Figure 8.5. Sharp edges have a minimal area over which an applied force exerts pressure, which facilitates cutting.

Figure 8.5: *Objects with sharp edges*

Some living organisms make use of pressure for self-defense. For example, a fish uses its sharp fins to protect itself. The fins inflict pain on an intruder's body. The fish fins are shown in Figure 8.6.

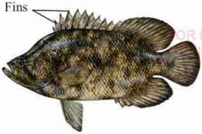


Figure 8.6: *Fish fins*

A sharp heel has a small area over which the body's weight (force) exerts pressure. Also, it is notable that when one walks on shoes with sharp-pointed heels, as shown in Figure 8.7 (a). The sharp-pointed heels exert greater pressure on the ground than the flat shoes, as shown in Figure 8.7 (b).

(a) Shoe with pointed heel

(b) Shoe with flat sole

Figure 8.7: *Sharp-pointed heel and flat sole shoes*

During construction of a railway line, wide wooden or concrete sleepers are placed below the railway tracks, as shown in Figure 8.8. This provides a large surface area over which the weight of the train acts. This is a safety measure to rail tracks.

Figure 8.8: *Railway*

Buildings are constructed with wide foundations as seen in Figure 8.9 to ensure that the weight of a building acts over a large area. As a result, the pressure exerted by the building on the ground is considerably reduced.

Figure 8.9: *Foundation of a building*

It is painful to walk with bare feet on a road that is covered by pebbles. The weight of the body exerts considerable pressure on the sharp-edged pebbles whose surface area is small. The pebbles exert an equal reaction on the feet.

Exercise 8.1

Answer all questions

(Use $g = 10$ N/kg)

1. A rectangular block of weight 15 N rests on a horizontal table. If it measures $40 \text{ cm} \times 30 \text{ cm} \times 20 \text{ cm}$, calculate the greatest and least pressure that the block can exert on the table.
2. Calculate the pressure under the feet of Fatima, if the area of contact of her foot is 80 cm^2 and her mass is 43.8 kg.
3. The mass of a cuboid is 60 kg. If it measures $50 \text{ cm} \times 30 \text{ cm} \times 20 \text{ cm}$, what is the maximum pressure it can exert on the floor?

4. A rectangular metal block with sides $1{\cdot}5\text{ m} \times 1{\cdot}2\text{ m} \times 1{\cdot}0\text{ m}$ rests on a horizontal surface. If the density of the metal is 7 000 kg/m^3, calculate the maximum and minimum pressure that the block can exert on the surface.

Pressure in liquids

A liquid will exert pressure on an immersed object as well as on the wall of its container. Note that the pressure exerted by the liquid at any point in the liquid is due to the weight of the liquid column above the point. As the depth of the liquid increases, the weight of the liquid also increases and hence the pressure increases. This concept can be explained using marble pile model. It is important to note that, since the particles in liquid are loosely packed, the pressure acts in all directions. Assume that the molecules of liquid are packed together but are not firmly tight to their neighbours, as shown in Figure 8.10.

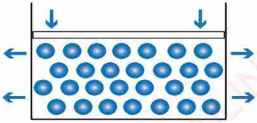


Figure 8.10: *Marble pile model*

If a downward force is applied as in Figure 8.10, the marbles are pushed out sideways as well as downwards. Similarly, the gravitational force pulls the liquid. This causes the liquid to be pushed out sideway as well, and so the liquid exerts a sideways pressure too.

Calculating the pressure in a liquid

Figure 8.11 shows a tank with base area A (m^2) filled with a liquid to a height h (m) and the gravity, g (N/kg) pushes liquid molecules down producing the force of gravity or weight (N) in the liquid. Because the area of the tank is fixed, increasing the height of liquid in the tank will also increase the weight of the liquid and the pressure, as previously stated. Therefore, the pressure in the liquid depends on the weight of liquid and the base area of a tank.

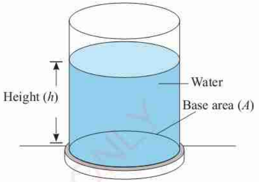


Figure 8.11: *Pressure exerted by water in a tank*

To calculate the pressure in liquids, consider the liquid column of cross-sectional area, A m^2 at a depth, h m below the surface of the liquid. If the density of the liquid is ρ kg/m^3, then,

Volume of the vertical column of liquid

$= \textit{Base area}(A) \times \textit{Height}(h) = Ah$

The mass due to the liquid column

$= \textit{Volume of liquid} \times \textit{Density of liquid}.$

$= Ah\rho$

But Force, $F = mg = Ah\rho g$

Therefore,

$$Pressure\ (P) = \frac{Normal\ \ force\ (Weight)}{Area}$$

$$= \frac{Weight}{area} = \frac{mg}{A}$$

$$= \frac{Ah\rho g}{A}$$

$$= h\rho g.$$

Pressure in liquids = height of the liquid column × density of liquid × acceleration due to gravity.

Thus, pressure at any point in a liquid at rest depends on depth of the liquid and density of liquid. It is important to note that pressure in liquid does not depend on the area or the shape of the container.

Characteristics of pressure in liquids

Pressure in liquids is characterised by the following parameters.

1. Pressure in a liquid increases with depth.
2. Pressure in a liquid acts equally in all directions.
3. Pressure in a liquid increases with increase in density of the liquid. Mercury exerts more pressure than an equal volume of water because mercury is denser than water.

Variation of liquid pressure with depth

The pressure in a liquid increases with depth of the liquid.

Activity 8.3

Aim: To demonstrate the variation of pressure with depth of a liquid.

Materials: Water, large can or big plastic bottles, nail, hammer, ruler, and cello tape

Procedure

1. Take a large can and punch two holes on opposite sides using a nail and hammer but at the same height from the bottom of the can.
2. Seal the holes using sellotape.
3. Pour water into the can to a certain height. Simultaneously, unseal both holes and record the horizontal distance covered by the water stream from each hole.
4. Stop pouring water.
5. Punch holes at different heights on a second can but on the same side
6. Seal the holes as in step 2.
7. Pour water into the can to a height above both holes.
8. Simultaneously, unseal the holes while keeping the water height constant by continuously pouring water into the can.
9. Record your observations.

Questions

(a) What causes the water to spurt out of the holes?

(b) What does this suggest about pressure in liquids?

The pressure at a certain point in the liquid is proportional to the height of the liquid column above that point. The larger the height above a point, the larger the pressure at that point. Thus, the holes on the can that are at the same level (depth) experience the same pressure and the liquid will be spurted to the same distance. This is because the pressure in liquid acts in all directions. It is also equal at the same depth, as shown in Figure 8.12.

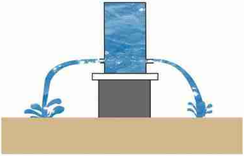


Figure 8.12: *Water spurting from holes at the same level*

The holes punched at different levels on the can will spurt water to different distances. The hole at the top has the least height of liquid above it. This means that the water spurts the shortest distance. This distance increases with an increase in the height above the hole, as shown in Figure 8.13.

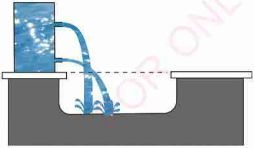


Figure 8.13: *Water spurting from holes at different heights*

Therefore, the hole at the bottom of the can will spurt water to the furthest distance. Note that liquid pressure increases with depth, the pressure at the bottom of the dam is greater than at the top. This explains why the wall of a dam is made much thicker at the bottom than at the top, as shown in Figure 8.14.

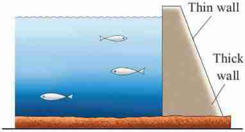


Figure 8.14: *Dam*

Consider a liquid that has been released into a communicating vessel as in Figure 8.15. When water or any other type of liquid is poured into a communicating vessel, it will attain the same level in all its tubes regardless of shapes of the tubes. This proves that for a given liquid, the pressure at a point within the liquid varies only with depth.

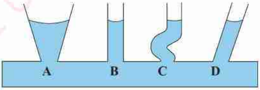


Figure 8.15: *Pressure in a communicating vessel*

The fact that the liquid rises to the same vertical height in all tubes is an indication that pressure at all points of similar depth in a liquid is the same. A liquid always finds its own level in a vessel in which it is contained. Pressure at A, B, C and D in Figure 8.15 is the same.

Task 8.2

In pairs of students, fill a polythene bag with water and hold or press the upper part. Using a pin, prick the polythene bag randomly. What did you find? Discuss your findings in the class.

Pressure in liquid and upthrust

When an object is submerged in a liquid its bottom side experience a greater pressure than the top side. The difference in pressure between these sides result to an upward force known as upthrust. Figure 8.16 shows an object submerged in liquid.

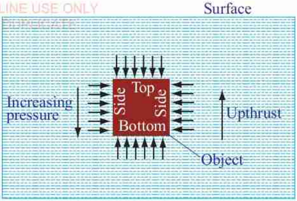


Figure 8.16: *Variation in pressure producing upthrust*

The pressure on the right side of the object increases with increasing depth but is exactly balanced by pressure on the left side so that the net force in the horizontal direction is zero.

Example 8.3

A cube of sides 2 cm is completely submerged in water so that the bottom of the cube is at a depth of 10 cm. If density of water (ρ) is 1 027 kg/m^3; and g = 10 N/kg:

(a) What is the difference between the pressure at the bottom of the cube and the pressure at its top?

(b) Determine the difference in the forces at the top and bottom.

(c) What is the weight of the water displaced by the cube?

Solution

(a) The bottom of the cube is at a depth of 10 cm = 0.1 m.

Pressure at the bottom $= h\rho g$

$$= 0.1\text{ m} \times 1\,027\text{ kg/m}^3 \times 10\text{ m/s}^2$$

$$= 1\,027\text{ N/m}^2$$

The top of the cube, the depth $= 0.1\text{m} - 0.02\text{m} = 0.08$ m.

Pressure on the top $= 0.08\text{ m} \times 1\,000\text{ kg/m}^3 \times 10\text{ m/s}^2 = 8\,00\text{ N/m}^2$.

The difference in pressure $= Pressure\ at\ the\ top - Pressure\ at\ the\ bottom$

$$= 1027\ \text{N/m}^2 - 821.6\ \text{N/m}^2$$

$$= 205.4\ \text{N/m}^2$$

So, the difference in pressure between the bottom and the top is $205.4\ \text{N/m}^2$.

(b) $Pressure = \dfrac{Force}{Area}$

$$Difference\ in\ pressure = \frac{Difference\ in\ force}{Area}$$

$$Difference\ in\ force = difference\ in\ pressure \times area$$

Area for a cube $= (length)^2$

Area $= (0.02\ \text{m})^2 = 0.0004\ \text{m}^2$

Difference in force $= 205.4\ \text{N/m}^2 \times 0.0004\ \text{m}^2 = 0.0822\ \text{N}$

This is the upthrust acting on the cube.

(c) $The\ weight\ of\ water\ displaced = mass\ of\ water \times acceleration\ due\ to\ gravity.$

$The\ weight\ of\ water\ displaced =$

$density \times volume\ of\ water\ displaced \times acceleration\ due\ to\ gravity$

But the volume of water displaced = volume of the cube

The length of the cube = width = height of the cube.

Then, Volume of the cube = L^3

$$L^3 = (2)^3 = 8\ \text{cm}^3 = 0.0008\ \text{m}^3$$

The volume of water displaced is equal to the volume of a cube = $0.0008\ \text{m}^3$

Mass of water displaced

$(M_{water}) = Density\ of\ water \times Volume\ of\ water\ displaced = \rho V_{water}$

Then,

$weight\ of\ water = Mass\ of\ water \times acceleration\ due\ to\ gravity = M_{water} \times g$

$Weight\ of\ water = 1027\ \text{kg/m}^3 \times 0.0008\ \text{m}^3 \times 10\ \text{N/kg} = 0.0822\ \text{N}$

Therefore, weight of displaced water is 0.0822 N.

Example 8.4

Calculate the pressure exerted on a diver at a depth of 20 m below the surface of water in a sea. Atmospheric pressure = 1.03×10^5 Pa, density of water = 1 000 kg/m^3, g = 10 m/s^2 or 10 N/kg.

Pressure due to the water in the sea

$= h\rho g$

$= 20 \text{ m} \times 1\,000 \text{ kg/m}^3 \times 10 \text{ N/kg}$

$= 200\,000 \text{ N/m}^2 = 2 \times 10^5 \text{ Pa}$

Pressure exerted on the diver = Atmospheric pressure + pressure due to the water.

$= 1.03 \times 10^5 \text{ Pa} + 2.00 \times 10^5 \text{ Pa}$

$= 3.03 \times 10^5 \text{ Pa}$

Transmission of pressure in fluids

Consider pressure applied to any part of an enclosed vessel containing a fluid. The atoms/molecules of fluid are free to move; thus, transmit the pressure equally throughout the enclosed container. This phenomenon was observed by a French scientist and philosopher known as Blaise Pascal in 1650 and it is called the principle of transmission of pressure in fluid.

Pascal's principle of pressure transmission in fluids states that, *"When pressure is applied at any point on the surface of a fluid contained in a closed container, the pressure is transmitted undiminished to all parts of the fluid and to the walls of the container".*

The principle of transmission of pressure in fluid can be demonstrated using the apparatus shown in Figure 8.17. The apparatus consists of a glass tube fitted with a movable piston and a bulb pierced with uniform size holes. Water is filled in by dipping the bulb in water and slowly pulling the plunger.

When pushing the piston in, the water squirts out from all the holes with equal strength. This shows that the piston exerts force per unit area (pressure) to the water which is then transmitted equally throughout the water. Pascal's principle is widely used in many devices. Hydraulic car jacks, car brakes, most of the mechanical diggers and bulldozers use the principle of transmission of pressure in fluid in their operations, and hence the name hydraulic machine.

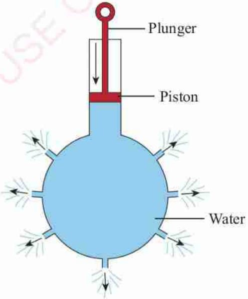


Figure 8.17: *Illustration of the Pascal's principle*

The hydraulic press

The hydraulic press uses Pascal's principle to convert a small force into a large force and vice versa. Consider a liquid confined in a container that is fitted with two pistons of different diameters, hence different cross-sectional areas. Figure 8.18 shows a simplified form of a hydraulic press. A downward force applied to piston 1, produces pressure P_1 which is equally transmitted throughout the liquid into piston 2. Since piston 1 has a smaller area than piston 2, a small force applied on piston 1 is multiplied at piston 2. Thus, a smaller force in piston 1 creates a larger force at piston 2.

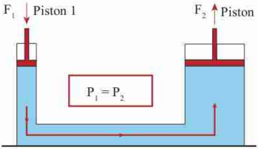


Figure 8.18: *Pascal's principle and hydraulic press*

Since, a force, F_1 is applied at piston 1 with cross section area, A_1, then,

$P_1 = \frac{F_1}{A_1}$. Therefore, P_1 is the increase in pressure under Piston 1. Since pressure is transmitted undiminished to the large piston with cross sectional area A_2, the pressure under piston 2 also increases by

$$P_2 = \frac{F_2}{A_2}.$$

Therefore, by using Pascal's principle,

$$P_1 = P_2$$

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

$$F_2 = \frac{F_1}{A_1} A_2$$

$$= F_1 \times \frac{A_2}{A_1}.$$

Since A_2 is larger than A_1, F_2 is also larger than F_1 so the output force is larger than the input force. A small force, F_1 applied at piston 1 can produce a larger force, F_2 to lift a very large weight resting on piston 2. A hydraulic press is a force multiplying device. Its multiplying factor is $\frac{A_2}{A_1}$. As the small piston is pushed down, the large piston is pushed up. However, the two pistons do not move through the same distance, d. The smaller piston moves through a larger distance than the large piston.

The distance, d moved by the piston is inversely proportional to the cross-sectional area:

$$\frac{d_1}{d_2} = \frac{A_2}{A_1}$$

Therefore, $d_2 = \frac{A_1 d_1}{A_2}$.

Example 8.5

The pistons of a hydraulic press have their areas given as 0.0003 m^2 and 0.02 m^2, respectively. If the small piston is pushed down with a force of 120 N, what is the force on the large piston?

Solution;

$$F_2 = \frac{F_1}{A_1} A_2$$

$$F_2 = \frac{0.02\,m^2}{0.0003\,m^2} \times 120\ N$$

$$F_2 = 8\ 000\ N$$

Therefore, force on the large piston is 8 000 N.

Example 8.6

A hydraulic press has pistons with areas of 0.02 m^2 and 0.1 m^2 as shown in Figure 8.19. A car weighing 5 000 N sits on a platform mounted on the larger piston.

(a) How much force must be applied to Piston 1 to lift the car?

(b) How far must Piston 1 be pushed downward to raise the car 0.3 m?

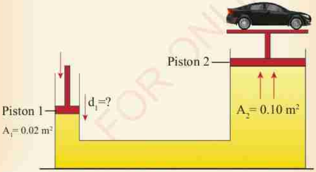


Figure 8.19

Solution

(a) Force applied on piston 1

$$P_1 = P_2$$

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

$$F_1 = \frac{F_2}{A_2} \times A_1$$

$$F_1 = \frac{5\ 000\ N}{0.10\ m^2} \times 0.02\ m^2$$

$$= 1\ 000\ N$$

Therefore, force on the large piston 1 is 1 000 N.

(b) Distance moved by Piston 1

$$\frac{d_1}{d_2} = \frac{A_2}{A_1}$$

$$d_1 = \frac{A_2}{A_1} \times d_2$$

$$d_1 = \frac{0.10\ m^2}{0.02\ m^2} \times 0.3\ m$$

$$= 1.5\ m$$

Therefore, distance moved by piston 1 is 1.5 m.

Applications of the hydraulic press

1. A hydraulic press can be used in industries to compress bulky items. The purpose is to compress a large object such as a bale of cotton into a small size for more economical transport, as shown in Figure 8.20.

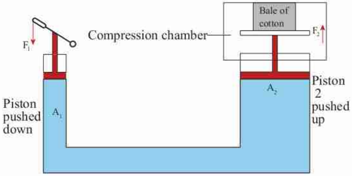


Figure 8.20: *Compressing bale of cotton*

As the small piston is pushed down, the large piston is pushed upwards compressing the bale of cotton. The amount by which the force applied to piston 1 is increased depends on the ratio of the areas of the two pistons.

2. Another application of the hydraulic press is in hydraulic brakes, as shown in Figure 8.21.

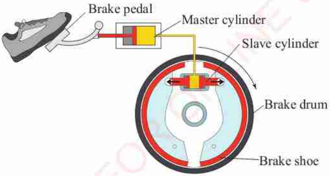


Figure 8.21: *Hydraulic brake system*

When pressure is applied to the brake pedal, it pushes the piston in the master cylinder forward creating a pressure in the brake fluid. This pressure is transferred to the slave cylinders where the force is multiplied and pushes the brake shoes against the brake drum that is attached to the wheel of the vehicle. Friction between the brake shoes and the drum slows down the wheels' rotation. There are identical systems on all four wheels ensuring the same braking force on each wheel so that the vehicle slows down uniformly. When the pressure on the brake pedal is removed, the return spring pulls the brake shoes away from the drum and the wheels become free to rotate.

3. It is used in industries in the forming of metals.

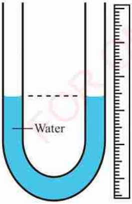
4. Since the hydraulic press acts like a lift, it is used for lifting heavy loads. The pressure applied on the small piston creates a large force on the large piston which lifts the load. Figure 8.22 shows a crane lifting heavy load.

Figure 8.22: *A crane lifting a heavy load*

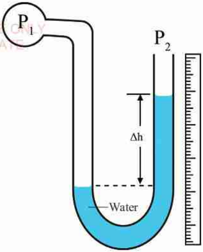
Measuring pressure using a manometer

A manometer is a simple device used to measure pressure (commonly gas pressure). It uses the property that the pressure due to weight of a fluid of constant density is given by $P = h\rho g$.

The simplest form of a manometer consists of a U-shaped tube filled with a liquid of a known density. The liquid is normally coloured to enhance visibility. The manometer is filled with the liquid until both sides of the tube are half-filled, as shown in Figure 8.23 (a).



(a) Pressure is equal in both arms



(b) Pressure is higher in the left arm

Figure 8.23: *Manometer*

When both ends of the tube are open, the pressure on both sides is equal. This water level is marked as zero point as in Figure 8.23 (a). When one end of the tube is connected to the unknown pressure P_1, the liquid level falls in one arm and rises in the other arm as shown in Figure 8.23 (b).

The change in height (Δh) is caused by the change in pressure (ΔP) which can be obtained by the equation,

$$P_1 = P_2 + (\Delta h)\rho g.$$

Since a manometer measures pressure by comparing with atmospheric pressure, it is sometimes called a gauge pressure.

Task 8.3

Your teacher will demonstrate the use of a manometer to measure the pressure of a liquid. Observe carefully. In your groups, take time to measure the pressure of different liquids using the manometer.

Atmospheric Pressure

The surface of the earth is surrounded by the atmosphere, which is the layer of air consisting of a mixture of gases. Atmospheric pressure is a result of the weight of this layer of gases. This is why air pressure is usually referred to as atmospheric pressure. The atmospheric pressure on the earth's surface and on objects on the earth is approximately 1.01×10^5 N/m^2 or 1 atmosphere. We do not experience this great pressure because the fluids in our bodies exert pressure slightly greater than the atmospheric pressure.

Variation of atmospheric pressure with altitude

The pressure exerted by the atmosphere decreases with increase in altitude from the mean sea level. For example, atmospheric pressure is found to be higher at the base and lower at the top of Mount Kilimanjaro as shown in Figure 8.24. This variation is due to the fact that the density of air is high at the mean sea level and decreases with altitude (air exert less pressure) above the mean sea level.

The variation of pressure with altitude has a practical impact to human life. The Mountain climbers may face nose bleeding at high altitude above the mean sea level because of the higher blood pressure compared to atmospheric pressure. It is important to note that astronauts wear space suits to maintain this pressure.

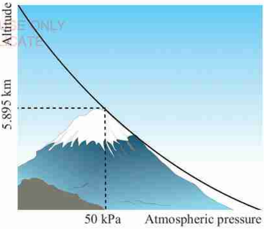


Figure 8.24 *Variation of atmospheric pressure with altitude along Mount Kilimanjaro*

The values of atmospheric pressure at some regions above and below sea level are shown in Table 8.1.

Table 8.1: Variation of atmospheric pressure with altitude.

Atmospheric pressure	kPa
Mount Everest summit (8 849 m)	33.7
Mount Kilimanjaro (5 895 m)	50
Mean sea level (0 m)	101.3
Dead sea (430 m) below sea level)	106.7

It can be generalised that atmospheric pressure at any given point of constant g depends on two factors:

(i) density (ρ) of air; and
(ii) height (h) of air column.

Thus, atmospheric pressure P, can also be expressed as, $P = h\rho g$.

Example 8.7

A mercury barometer in a physics laboratory reads 732 mmHg. Calculate the atmospheric pressure in Pascal. (Given density of mercury, $\rho = 1.36 \times 10^4$ kg/m^3 and acceleration due to gravitational $g = 9.8$ N/kg)

Solution:

Atmospheric pressure in the laboratory,

$P = h\rho g$

$= 0.732\text{m} \times 13600 \text{ kg/m}^3 \times 9.8 \text{ N/kg}$

$\therefore P = 9.96 \times 10^4 \text{ Pa}$ *or* 99 552 Pa

Exercise 8.2

1. Can high altitude cause difficulty in breathing? Why? Explain why there is a possibility of nose bleeding at high altitude.
2. Why do our ears pop when going on mountain? What is going on in our body and why does yawning help to solve the issue?
3. Does atmospheric pressure add to the gas pressure in a rigid tank of gas? In a toy balloon? When, in general, does atmospheric pressure not affect the total pressure in a fluid?

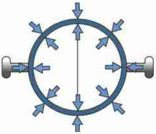
Evidence for the existence of atmospheric pressure

The existence of atmospheric pressure can be verified experimentally using the following apparatus:

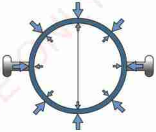
1. Magdeburg hemispheres.
2. Water cover with cardboard.
3. Crushing can.

Magdeburg hemisphere

Magdeburg hemispheres are two half-spheres of equal size joined to form an air tight sphere. Placing them together traps air between them. This air is merely trapped and not compressed, thus the pressure inside is the same as the pressure of the atmosphere outside the spheres as shown by arrows in Figure 8.25 (a). In this case, one can pull the spheres apart with nearly no resistance.



(a) The air pressure inside and outside the hemisphere is balanced



(b) The air pressure inside the hemisphere, the hemisphere is lower than the outside

Figure 8.25: *Action of Magdeburg hemisphere*

Now, what happens if all the trapped air inside the hemispheres is removed. On removal of air from inside, a partial vacuum is created inside the sphere. Thus, the external atmospheric pressure exerts a large unbalanced force and presses the spheres tightly together. Therefore, it becomes very difficult to pull the half-spheres apart.

Activity 8.4

Aim: To demonstrate the existence of atmospheric pressure using water cover with cardboard.

Materials: Glass tumbler or test tube, cardboard, water, and plunger

Procedure

1. Fill a glass tumbler with water and place the cardboard firmly on top of the glass so that there is no air between the glass and the cardboard.
2. With your hand on the cardboard, gently turn the tumbler upside down, as shown in Figure 8.26 then, remove your hand from the cardboard.
3. Record your observations.

Figure 8.26

Questions

(a) Explain why the cardboard does not fall when the glass tumbler is inverted?

(b) Explain your observations?

The cardboard does not fall when the glass tumbler is inverted due to the atmospheric pressure acting upwards on the cardboard. Atmospheric pressure is higher than that of the water acting downwards on the cardboard.

Activity 8.5

Aim: To demonstrate the existence of atmospheric pressure using a crushing can

Materials: Empty tin, hot water, cold water, and cork

Procedure

1. Pour a small quantity of hot water into a can and boil for few minutes while the can is open in order to drive off the air, as shown in Figure 8.27 (a).
2. Stop boiling and then close the can tightly with the cork.
3. Pour some cold water over the can to cool it as in Figure 8.27 (b).

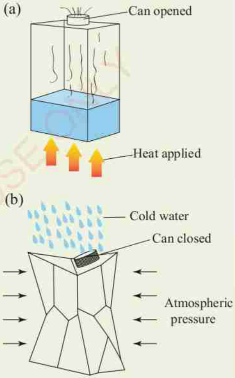


Figure 8.27: *Crushing can experiment*

Questions

(a) What happens to the can?

(b) Explain your observation.

Steam emerging from boiling water drives out air from the can. When the can is cooled by cold water the steam condenses, leaving partial vacuum inside the can. Consequently, the higher atmospheric pressure outside the can crushes it inwards.

Measurement of atmospheric pressure

Atmospheric pressure is commonly measured by using a barometer. In this section you will learn three types of barometers, namely simple barometer, Fortin barometer and aneroid barometer.

Simple barometer

A simple barometer is the most fundamental of the other types of barometers. The barometric liquid used is mercury. A simple barometer consists of a hard glass tube closed at one end and glass trough filled with mercury as shown in Figure 8.28.

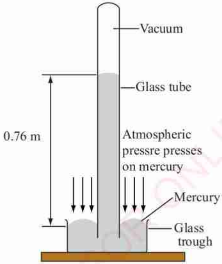


Figure 8.28: *A simple barometer*

Atmospheric pressure pushes mercury to a height of 76 cm at mean sea level.

Activity 8.6

Aim: Constructing a simple mercury barometer.

Materials: Thick-walled glass tube about 1 m long sealed at one end, mercury, and glass trough

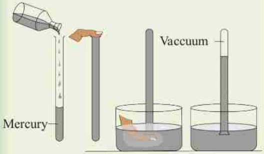


Figure 8.29: *Making a simple mercury barometer*

Procedures

1. Fill the glass tube with mercury to almost the top of the tube.
2. Ensure that no air bubbles are trapped on the wall of the glass tube. This is done by closing the open-end with a finger and invert it several times.
3. Now, fill the tube completely with mercury.
4. With a finger closing the open end, invert the tube into the trough of mercury. When the finger covering the open end is removed, the mercury is seen to settle to a height of about 760 mmHg.

Note: Mercury should be handled with care to avoid poisoning.

Questions

(a) Why is it necessary to close the open end of the tube when making a simple mercury barometer?

(b) What happens when a bubble is trapped in the mercury in the simple barometer?

(c) Why can't water be used as a barometric fluid?

Fortin barometer

A Fortin barometer is a modified simple barometer. It consists of an inverted tube closed at its upper end with the lower open end immersed in a reservoir of mercury, as shown in Figure 8.30. There is a vacuum at the upper end. As the atmosphere pushes down on the mercury in the reservoir the pressure is transmitted throughout the mercury, specifically to the open end of the tube. This pressure forces some of the mercury up into the tube until the weight of the mercury exactly balances the atmospheric pressure. The atmospheric pressure is measured in terms of the height of the column of mercury.

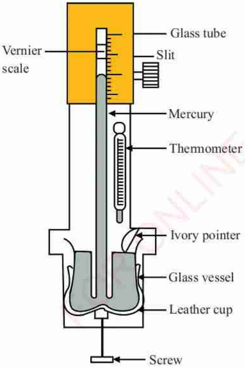


Figure 8.30: *Fortin barometer*

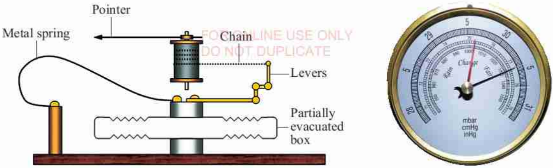
Before taking the readings, the mercury level is adjusted by the screw until it touches the ivory point.

However, the use of the mercury in a Fortin barometer has the following disadvantages:

1. Mercury is very expensive and toxic to use.
2. Mercury is in the form of liquid and the column is approximately 1 m tall, so it is not portable.
3. The Fortin barometer must be mounted in a vertical position.

Aneroid barometer

Aneroid barometer, shown in Figure 8.31, is a type of barometer for measuring atmospheric pressure without the use of a liquid, hence the word 'aneroid' means without fluid. It consists of a partially evacuated metal chamber and a thin corrugated lid which is displaced by variations in external pressure. A lever connected to the diaphragm of the chamber moves a pointer. Any change in pressure would cause the box to be squashed or expanded. The small deformation of the box will trigger a larger motion in the scale pointer by means of the lever.



(a) Internal appearance (b) External appearance

Figure 8.31: *Aneroid barometer*

The aneroid cell is prevented from collapsing under the pressure of the atmosphere by a strong spring. The spring is attached through a set of levers to a pointer that indicates the pressure on a calibrated scale, as shown in Figure 8.31 (b). Even though it contains no mercury, the pressure is still measured in units of mmHg.

Task 8.4

Draw a diagram of an aneroid barometer and label it. Explain how the aneroid barometer works. Discuss why it is advantageous to use the aneroid barometer instead of the Fortin barometer. Measure the atmospheric pressure using an aneroid barometer.

Common devices utilizing atmospheric pressure

There are a variety of common and even simple devices that make use of the atmospheric pressure. These include drinking straw, cupping therapy, siphon, bicycle pump, lift pump, force pump, vacuum cleaner and syringe.

Siphon

A siphon is a continuous tube that allows liquid to drain from a reservoir through an intermediate point that is higher than the reservoir. The liquid is able to flow without pumping because of pressure difference. To do this the end of the long arm has to be lower than the surface of the liquid in the reservoir as shown in Figure 8.32.

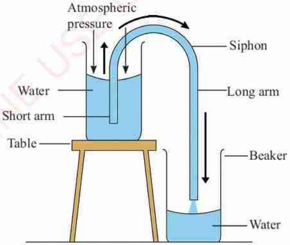


Figure 8.32: *The siphon principle*

The liquid rises in the tube because it is pushed by atmospheric pressure. The atmospheric pressure acts on both ends of the siphon but the long arm carries a more weight of the liquid. Then, force of gravity draws the liquid through the long arm and this maintains the low pressure that is established at the start. Once started, the siphon does not require additional energy to maintain liquid flow out of the reservoir. The siphon will pull the liquid out until the level in the reservoir falls below the intake point.

Activity 8.7

Aim: To demonstrate the principle of the siphon.

Materials: Rubber tube, water and two empty cans

Procedure

1. Pour water into can 1 up to about halfway and set it on the edge of a table.
2. Set an empty can 2 on the floor underneath can 1 on the table.
3. Take a piece of rubber tubing that is long enough to reach both cans and fill it with water.
4. Cover both ends of the tube with your fingers (you may need a partner to do this).
5. Immerse one end of the tube into the can with water and the other end into the empty can.
6. Uncover both ends of the tube and observe what happens.

Question

Does the water flow from one can to the other? Explain.

Applications of siphon

A siphon is applied in many areas and devices that are used every day.

1. It is used in the toilet flushing cisterns (chain and ball tank). The flush is triggered by a handle that operates a simple diaphragm like piston pump that lifts enough water. The same procedure is used in the automatic flushing tank, which does not require a handle to trigger the flushing.
2. It is used to drain excess water in special rain gauges called siphon rain gauge.
3. A siphon cup is a reservoir attached to a spray gun.
4. It is used to drain water in some drainage systems.

Task 8.5

In groups of four students, discuss the application of siphon in the automatic flushing tank and toilet flushing system. Discuss other areas where the siphon is applied. Present your findings in the class.

Vacuum cleaner

A vacuum cleaner shown in Figure 8.33 is used in cleaning floors and carpets. It also utilizes the atmospheric pressure to work. When it is on, the fan inside the cylinder blows air out as the result a partial vacuum is created inside. Thus, atmospheric pressure outside becomes higher; as such, it forces air and dust particles into the cleaner.

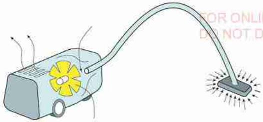


Figure 8.33: *The vacuum cleaner*

Plunger

A plunger shown in Figure 8.34, is a cup-like rubber sucker, with a long handle at one end. When used correctly, a plunger can unclog pipes and make them run more efficiently. Sometimes pulling the plunger is not easy. For example, if it is pressed hard on a table surface it is possible for all the air between it and the table to be squeezed out, hence creating a vacuum. In that case, the plunger will stick to the table because of the higher atmospheric pressure outside.

Figure 8.34: *Plunger*

Lift pump

A lift pump is used to raise water from underground sources. This is a pump that is used to lift the liquid, rather than force liquid up. This pump is illustrated in Figure 8.35.

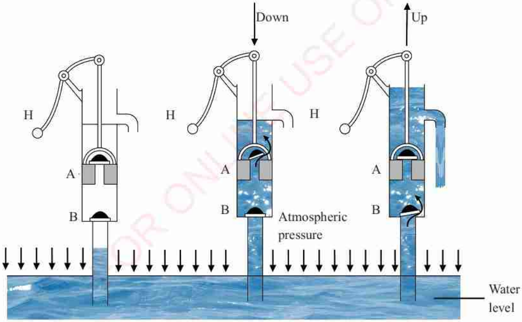


Figure 8.36: *Lift pump*

The handle operates a reciprocating mechanism that raises and lowers a piston with a transfer valve at its centre. The piston acts to separate the pump cylinder into upper and lower chambers and the transfer valve controls the flow of water between them. At the bottom of the lower chamber is an intake valve that controls the flow of water from the external source. The pump starts with the piston at the bottom of the empty cylinder and both valves closed.

The pump handle is then pushed down lifting the piston upwards. The transfer valve remains closed and the intake valve opens to allow water from the external source to fill the lower chamber. This is due to the low-pressure region created between the transfer valve and the piston.

The handle is lifted upwards pushing the piston down. The intake valve closes and the transfer valve opens allowing water to pass into the upper chamber.

The pump handle is pushed down again lifting the piston upward. The transfer valve closes and the intake valve opens to allow water from the external source to fill the lower chamber. The water in the upper chamber is lifted and flows out of the spout.

The process is repeated; hence, it is continuous. Atmospheric pressure can support a water column of about 10 m. This means that the pump cannot be higher than 10 m above the water level.

Task 8.6

Your teacher will show you a model of the lift pump. Discuss its main features, mode of operation and limitations. In which areas of everyday life is the lift pump used?

Force pump

A force pump is a modification of a lift pump. It consists of a cylinder fitted with a solid piston, as shown in Figure 8.36. There are intake (B) and output valves (A). The piston is moved up and down by a motor or by hand. When the piston moves up, the intake valve opens and the output valve closes due to the low pressure created between the piston and the intake valve. This draws water from the external source into the pump cylinder. When the piston moves down, the intake valve closes and the output valve opens; this forces the water in the cylinder going out of the pump.

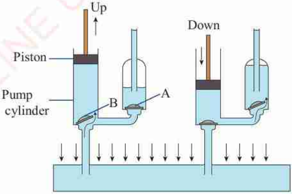


Figure 8.36: *Force pump*

A force pump moves water from deeper depths than the lift pump.

Syringe

A syringe is a simple pump that consists of a plunger that fits in a cylindrical tube, as shown in Figure 8.37. The plunger can be pulled and pushed inside the tube or barrel. This enables the syringe to take in and expel fluid through the opening (nozzle) at the end of the tube.

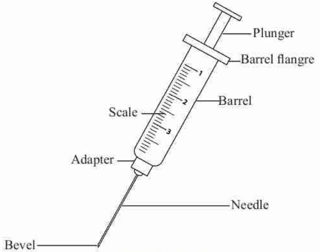


Figure 8.37: *Syringe*

Task 8.7

Your teacher will demonstrate how to use the syringe. Observe carefully and use the syringe to take in and expel different fluids. Investigate and list down situations in our everyday life in which the syringe is used. Present your findings in the class.

By pulling the plunger out, pressure in the cylinder decreases. Consequently, the high atmospheric pressure outside pushes the liquid into the cylinder.

Uses of the syringe

The following are the uses of a syringe:

1. A syringe can be fitted with hypodermic needles and used to administer injections. The injectable medicine is expelled through the needle into the body of a patient by pushing the plunger.
2. A syringe is used to measure or transfer liquids in a laboratory.
3. A syringe is used to apply certain compounds such as glue or lubricant.

Bicycle pump

A bicycle pump is a type of force pump that consists of a hollow metal cylinder and a movable piston. It is specifically designed for inflating bicycle tyres. The piston consists of a cup shaped leather washer which is fixed to a metal rod by a metal washer, as in Figure 8.38 (a).

When the the piston is pulled out, a low pressure is created in the region just below the leather washer. Atmospheric pressure then forces air into the pump through the inlet valve as in Figure 8.38 (b).

When the piston is pushed forward, the trapped air below the piston is compressed and the tube of the bicycle can be inflated using a valve as shown in Figure 8.38 (c).

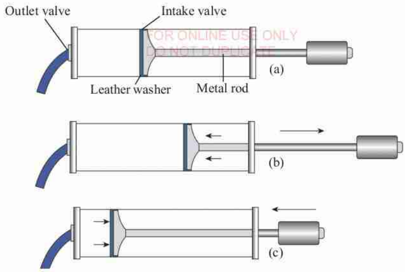


Figure 8.38 *Operation of a bicycle pump*

Task 8.8

Visit a nearby bicycle repair shop and observe a bicycle pump. Discuss its mode of operation. Draw a well-labelled diagram of the bicycle pump. What is the significance of the intake and outlet valves? Discuss your findings in the class.

Chapter summary

1. Pressure is defined as the force acting normally per unit surface area.

$$Pressure = \frac{Force}{Area}.$$

2. The SI unit of pressure is N/m^2. Other units of pressure are Pascal (Pa), atmosphere (atm), torr and mmHg.
3. Fluids (liquid or gas) exert pressure on an immersed object and the walls of their container. The pressure in the fluid at a depth h is given by $P = \rho gh$. Pressure in a liquid depends on the density of the liquids and the depth.
4. Pascal's principle states that, any pressure applied on the surface of an enclosed fluid will be transmitted equally to all points in the fluid. This principle is the basis for the hydraulic lift, hydraulic press and hydraulic brakes.
5. Pressure in liquids and gases can be measured with a manometer that works on Pascal's principle.
6. Air pressure is measured using either a Fortin barometer or an aneroid barometer.
7. Standard atmospheric pressure at sea level is 101.3 kPa.
8. Siphons, syringes, lift and force pumps are used to transfer liquids and gases.

Revision exercise 8

Section A

Choose the most correct answer.

1. Pressure can be defined as:
   (a) the spread out of a force over the length.
   (b) the concentration of a force on a surface area.
   (c) the spread out of area.
   (d) the product of a force and area.
2. One Pascal is the pressure generated by:
   (a) force of 1N on 1 m^2.
   (b) force of 1 kg on 1m^2.
   (c) force of 1N on 1 000 cm^2.
   (d) force of 1 N on 1 cm^2.
3. An object immersed in a liquid in a tank experiences an upthrust. What is the physical phenomenon that causes the upthrust?
   (a) The density of the body differs from that of the liquid.
   (b) The density of the liquid increases with depth.
   (c) The pressure in the liquid increases with depth.
   (d) The value of g in the liquid increases with depth.
4. The diagram in Figure 8.39, shows a rectangular block of mass 8.2 kg immersed in sea water of density 1100 kg/m^3. What is the difference in pressure between the top and the bottom surfaces of the block?

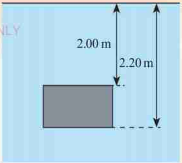


Figure 8.39

   (a) 220 Pa .
   (b) 2 200 Pa .
   (c) 18 000 Pa .
   (d) 23 000 Pa .
5. A horizontal plate of area $0 \cdot 036\ m^2$ is beneath the surface of a liquid of density 930 kg/m^3. The force on the plate due to the pressure of the liquid is 290 N. What is the depth of the plate beneath the surface of the liquid?
   (a) 0.87 m.
   (b) 1.13 m.
   (c) 8.7 m.
   (d) 9.1 m.
6. A rectangular metal bar exerts a pressure of 15 200 Pa on a horizontal surface on which it rests. If the height of the metal is 80 cm, what it the density of the metal?
   (a) 19 kg/m^3.
   (b) 190 kg/m^3.
   (c) 1 900 kg/m^3.
   (d) 19 000 kg/m^3.
7. Water in a bath varies in depth from 20.0 cm at the shallow to 30.0 cm at the end of the plug, as shown in Figure 8.40.

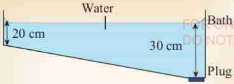


Figure 8.40

What is the pressure of water acting on the plug? The density of water is 1 000 kg/m^3.

(a) 0.98 kPa.

(b) 2.0 kPa.

(c) 2.9 kPa.

(d) 290 kPa.

8. A submarine is in equilibrium in a full submerged position, as shown in Figure 8.41. What causes the upthrust on the submarine?

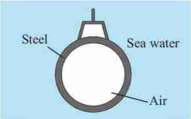


Figure 8.41

(a) The air in the submarine is less dense than sea water.

(b) The sea water exerts a greater upward force on the submarine than the weight of the steel.

(c) The submarine displaces its own volume of sea water.

(d) There is a difference in water pressure acting on the top and on the bottom of the submarine.

9. The diagram in Figure 8.42, represents a sphere under water. P, Q, R and S are forces acting on the sphere, due to the pressure of water. Compare these forces.

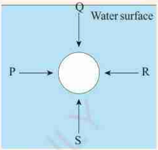


Figure 8.42

(a) P < R and S = Q.

(b) P > R and S = Q.

(c) P = R, S = Q and P ≠ S.

(d) P = R, S = Q and P = S.

10. Match each item from Column A with its corresponding item in Column B. Then, write letter of the correct response in the provided space.

Column A	Answers	Column B
1. Atmospheric pressure 2. Pascal's principle 3. Pressure 4. Razor blades, knife and blades 5. Application of atmospheric pressure		A. Minimum force B. Hydraulic press C. N/m^2 D. Pascal E. Maximum force F. Manometer G. High pressure H. Low pressure I. Aneroid barometer J. Bicycle pump

Section B

11. (a) Describe the concept of pressure.

(b) State the SI unit of pressure.

(c) Name devices that are used for measuring pressure.

12. State Pascal's principle.

13. (a) How can the pressure of a gas be measured?

(b) The open end of a rubber tubing of a mercury manometer is placed in a fluid of density 1.2 g/cm^3. The mercury in the manometer rises by 3.0 cm. What is the depth of the fluid at the end of the rubber tubing?

(Density of mercury = 13.6 g/cm^3).

14. Explain why hitting an inflated balloon with a hammer will not cause it to burst but sticking it with a pin will.

15. A can holds water with a constant depth of 0.5 m. Hole A is punched in the can 0.1 m below the surface of the water and hole B is punched 0.4 m from the surface. From which hole will the water spurt the furthest? Explain your answer.

16. Why are dam walls constructed thicker at the bottom than at the top?

17. Explain why a diver at the bottom of a dam experiences greatest pressure?

18. A can holds water with a constant depth of 0.5 m. The surface of the water is exposed to the atmosphere. What is the pressure on the bottom of the can? (g = 10 N/kg and atm. pressure = 101.3 kPa).

19. (a) A submarine has a surface area of approximately 82 000 m^2. If it is travelling at a depth of 300 m in the ocean, what is the total force on the submarine's outer hull? Use ρ = 1 025 kg/m^3 for the density of seawater.

(b) Winds in the atmosphere blow from regions of high atmospheric pressure towards regions of low atmospheric pressure. Would you expect winds to blow from warm regions to cooler ones or from cooler to warmer areas? Explain your answer.

20. In a hydraulic brake system, the piston in the master cylinder has a diameter of 2.0 cm and the piston in the slave cylinder has a diameter of 3.5 cm. The brake pedal is pushed down 10 cm with a force of 50 N. How far do the brake shoes move and with what force do they press against the brake drum?

21. Explain why it would not be practical to make a Fortin type barometer with water instead of mercury. Hint: Compare the densities of water and mercury.

22. The advantages of an Aneroid barometer over the Fortin barometer are:

(i) _______.

(ii) _______.

Chapter Nine

Work, energy and power

Introduction

The terms 'work', 'energy' and 'power' are frequently used in everyday life. A farmer ploughing the field, a construction worker carrying bricks, a student studying for a competitive examination, an artist painting a beautiful landscape, all are said to be doing work. In physics, the word 'work' covers a definite and precise meaning. In this Chapter, the concepts of work, energy and power will be discussed. The competencies developed will enable you to build the strength and capacity to perform a given task.

Concept of work

In everyday life the word work means any activity in which effort (either mental or physical) is exerted. However, in physics, work is done when a force acts on a body and the body moves in the direction of the applied force. The work done is measured by the product of force and the distance moved by a body in the direction of the applied force.

Suppose, a force F is applied to push a block resting on a table. Suppose the block moves through a distance d in the direction of the applied force, as shown in Figure 9.1.

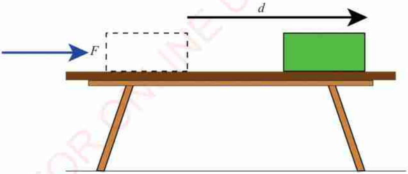


Figure 9.1: *Illustration of work done*

Thus, $Work\ done\left(W\right) = force\left(F\right) \times distance\left(d\right)$

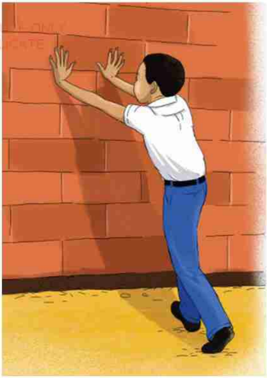
Therefore, $W = Fd$.

The SI unit of work is Joule (J) which is equivalent to Newton (Nm). 1 Joule is defined as the work done when a force of one Newton (N) moves an object through a distance of one metre in the direction of the force.

Other units used for measuring work are: 1 kiloJoule (kJ) = 1 000 Joules (J) and 1 MegaJoule (MJ) = 1 000 000 J.

From the Physics point of view, work is specifically meant to describe what is accomplished by the action of a force that makes an object move through a certain distance in the direction of the force. For example, a boy does work by lifting up books from the floor, as shown in Figure 9.2 (a). But in Figure 9.2 (b) the boy is pushing a wall which is not moving and hence, no work is done by pushing the wall because there is no distance moved in the direction of the push.

(a) A boy lifting a pile of books from the floor.



(b) A boy pushing against a wall

Figure 9.2: *Illustrations of work done*

For example, if a boy applies a force of 3 N on a box and the box is pushed through a distance of 1.5 m, work is done on the box. The magnitude of this work is 4.5 J. Lifting a bag onto your head and lifting the books from the floor are examples of work, since, there is a distance moved. Thus, there are two conditions for work to be done.

1. There must be a force acting on an object.
2. The object must move along the direction of the applied force.

These conditions are illustrated in Figure 9.3.

(a) Lifting or lowering an object. Work is done

(b) Force holding an object but an object does not move. No work is done

(c) Force and distance acts perpendicular to each other. No work is done

Figure 9.3: *Illustration of the conditions for the work to be done*

- If an object is lifted or lowered as shown in Figure 9.3 (a), a vertical force is exerted on the object and it moves parallel to the force so work is done.
- If an object is simply held in the air as shown in Figure 9.3 (b), an upward force is exerted on the object but the object is not moving. Thus, no work is done.
- If an object is held while walking across the room as displayed in Figure 9.3 (c), an upward force is exerted on it and the object is moving. But since the movement is not parallel to the force, no work is done.

Determining work done by an applied force

In measuring work, the directions of the force and the distance moved must be considered.

- If force and distance moved are in the same direction, work is done on the object.
- If force and distance moved are in opposite directions, work is done by the object.
- If force and distance moved are at some angle, work is done only by the component of the force parallel to the distance.
- If force and distance moved are perpendicular (at a right angle) to each other, no work is done.

Example 9.1

A force of 80 N pulls a box along a smooth and level ground through a distance of 5 m. Calculate the work done by the force.

Solution

Force = 80 N, distance = 5 m

$$W = F \times d$$
$$= 80\ \text{N} \times 5\ \text{m}$$
$$= 400\ \text{J}$$

Therefore, the work done is 400 J.

Example 9.2

How much work is done in lifting a 7 kg object through a height of 2 m and then hold it at that height for 10 s? (Assume, g = 10 N/kg)

Solution

Force$(F) = 7$ kg, distance$(d) = 2$ m,

$g = 10$ N/kg

To lift an object or hold it in the air, an upward force equal to its weight must be exerted.

Weight (N) of an object = mass (kg) of an object x acceleration due to gravity (N/kg)

$w = mg$

But, $weight = Force$

Then,

$Force = mg = 7\text{ kg} \times 10\text{ N/kg} = 70\text{ N}$

So, you must exert on the object an upward force of 70 N.

To lift the object a distance of 2 m, the work done is calculated as follows:

$$W = F \times d$$
$$= 70\text{ N} \times 2\text{ m}$$
$$= 140\text{ J}$$

To hold the object for 10 s:

F = 70 N, d = 0 m

$$W = F \times d$$
$$= 70\text{ N} \times 0\text{ m}$$
$$= 0\text{ J}$$

So, 140 J of work was required to lift the object 2 m, but no additional work was required to hold the object at that height for 10 s.

Exercise 9.1

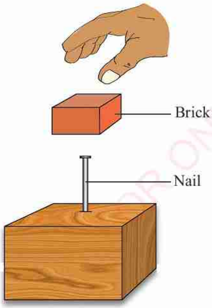
Answer all questions (where necessary use $g = 10$ N/kg).

1. If a man pushes a van with a force of 300 N for a distance of 10 m, how much work does he do?
2. A man lifts a load of 20 kg through a height of 3 m. Calculate the work done.
3. Zenge lifts a brick of mass 10 kg from the floor to a shelf 3 m high. How much work does she do?
4. In each of the following cases, state whether work is done or not.
   (i) A cow pulling a 50 kg cart of maize along rough road.
   (ii) A teacher holding a book in his hand while talking to his friend.
   (iii) An aeroplane climbing upward at take off.
   (iv) An aeroplane moving horizontally 3000 m above sea level.
5. A sack of rice which weighs 900 N is lifted to a height of 2 m. Calculate the work done against gravity.

Energy

The fundamental concepts used to describe and explain the physical universe are matter, energy, space and time. All these concepts have been discussed in previous chapters. Anything which is able to do work as explained earlier is said to possess energy. Energy is defined as the ability to do work. This is a general statement about the relationship between work and energy. Work is therefore done with the availability of energy. Work is a form of energy. Therefore, work and energy are measured in the same SI unit, Joules (J).

Suppose we drop a brick onto a nail that has been partially driven into a wooden block. When the brick hits the nail, it will push it further into the wood, as shown in Figure 9.4.



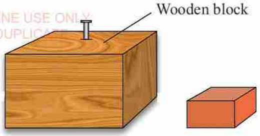


Figure 9.4: *Driving a nail into wood*

The falling brick must have had some property that enabled it to do work on the nail, thus, driving it into the wood. That property is called energy. The concept of energy is used in all fields of science, including physics, chemistry, geology, meteorology, astronomy, and biology.

Forms of energy

Energy exists in different forms, including mechanical energy, chemical energy, electrical energy, heat energy, light energy, sound energy and nuclear energy. One form of energy can be converted into another form, as shown in Figure 9.5.

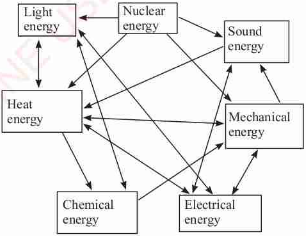


Figure 9.5: *Interconversion of some forms of energy*

Mechanical energy is the energy possessed by an object due to its position or motion. It is of two kinds called potential energy (*PE*) and kinetic energy (*KE*).

Electrical energy is due to the kinetic energy of the moving electric charges in a circuit. There is also the electric potential energy related to the electric force between charges. Batteries and generators deliver electrical potential energy. Batteries can be charged to store electrical potential energy that is to be used when needed. Figure 9.6 shows batteries connected to a charging unit.

Figure 9.6: *Battery connected to a charging unit*

Heat energy is the sum of the kinetic and potential energies of the microscopic particles that compose matter. On the macroscopic level, thermal energy is related to the temperature and physical states of matter. Thermal energy that is transferred between two points because of a temperature difference is called heat. Heat energy can be obtained at fire places as shown in Figure 9.7.

Figure 9.7: *Burning fire wood*

Nuclear energy comes from the potential energy possessed by the constituents of the nucleus of an atom. They are subject to both the strong and the weak nuclear forces and have nuclear potential energy. Nuclear energy can be harnessed during nuclear fission or fusion and radioactive decay. A sketch of a nuclear reactor is shown in Figure 9.8.

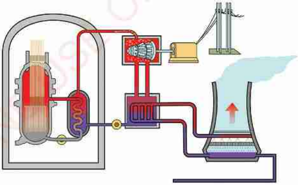


Figure 9.8: *Nuclear reactor*

Electromagnetic energy (infrared radiation, visible radiation, ultraviolet radiation, and so on) is associated with accelerating electric charge, and therefore with the changing velocity of that charge or oscillating electric and magnetic fields. Radiant light energy is the most common form of electromagnetic energy. The sun provides radiant energy to the earth as shown in Figure 9.9.

Figure 9.9: *Radiant energy from the sun*

Sound energy is also a form of energy that is transferred in the form of waves arising from vibration of a membrane and mechanical oscillations. Sources of sound may be speakers, sound box, and vibrations from wings of insects. A microphone converts sound energy into an electrical signal and a loudspeaker converts electrical energy into sound energy. Figure 9.10 shows an example of a loudspeaker.

Figure 9.10: *A loudspeaker*

Kinetic and potential energy

Potential and kinetic energy are due to position and motion of an object, respectively. In this section you will learn about kinetic energy and potential energy.

Kinetic energy

This is the energy possessed by an object due to its motion. Any matter that is moving has kinetic energy. Both a plane flying through the air and an atom vibrating in a solid have kinetic energy. Consider a lorry loaded with bricks and moving at 80 km/h. This lorry has high kinetic energy which can be dangerous in the event of an accident (damage to property and loss of life). The kinetic energy of an object depends on its mass and speed. For a body of mass *m* travelling at speed *v,* its kinetic energy (KE) is expressed as:

$$KE = \frac{1}{2}mv^2$$

The SI unit of kinetic energy is Joule (J) which is equivalent to kgm^2/s^2. When the velocity of a body increases or decreases, its kinetic energy changes. Consider an object of mass *m* initially moving with speed *u* and attains the final speed *v*. The corresponding change in kinetic energy (ΔKE) is given as the difference between the object's final kinetic energy and initial kinetic energy. That is:

$$\Delta KE = KE_{final} - KE_{initial}$$

$$= \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

$$\Delta KE = \frac{1}{2}m\left(v^2 - u^2\right).$$

Example 9.3

An object has a mass of 5 kg. What is its kinetic energy if its speed is:

(a) 5 m/s?

(b) 10 m/s?

Solution

Given that: mass (m) = 5 kg and speed (v) = 5 m/s.

(a) $KE = \frac{1}{2}mv^2$

$= \frac{1}{2} \times 5 \text{ kg} \times (5 \text{ m/s})^2$

$= 62.5 \text{ kgm}^2/\text{s}^2 = 62.5 \text{ J}$.

(b) $KE = \frac{1}{2}mv^2$

$KE = \frac{1}{2} \times 5 \text{ kg} \times (10 \text{ m/s})^2$

$KE = 250 \text{ J}$.

Comparing the two examples, it shows that, if the speed of an object is doubled, its kinetic energy increases by the factor of 4.

Example 9.4

What is the kinetic energy of a 12 g bullet travelling at the speed of 320 m/s?

Solution

$m = 12 \text{ g} = 0.012 \text{ kg}, v = 320 \text{ m/s}$

$KE = \frac{1}{2}mv^2$

$= \frac{1}{2} \times 0.012 \text{ kg} \times (320 \text{ m/s})^2$

$= 614.4 \text{ J}$.

Activity 9.1

Aim: To investigate the relationship between work and kinetic energy.

Materials: Wooden block, PVC tube, metre rule, and metal ball

Procedure

1. Rise one end of a PVC tube about 1 m long on a wall while the other end rests on a smooth table.
2. Using a metre rule measure perpendicular height (h) from the table to the point where the PVC tube rests on the wall. Record the value of h (start with h = 100 cm).
3. Place the wooden block as shown in Figure 9.11.

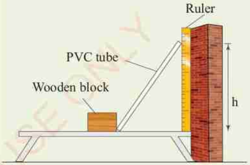


Figure 9.11

4. Release the metal ball from the upper end parallel to the wall, so it rolls inside the tube towards the lower end.
5. Using a metre rule measure and record the distances (d) that the wooden block moves as it is pushed by the rolling metal ball.
6. Repeat steps 2 to 5 for the values of h = 80 cm, 60 cm, 40 cm and 20 cm. Record your results as in Table 9.1.

Table 9.1: Results

h (cm)	d (cm)
100	
80	
60	
40	
20	

7. Plot a graph of distance d (cm) against the height h (cm).

Questions

(a) Discuss how the height of the raised end of the tube and the distance that the wooden block is pushed are related.

(b) Do you think that at a constant height the distance that the block is pushed would depend on the mass of the ball? Explain your answer.

A walking elephant in Figure 9.12 has high kinetic energy because of its large mass. If one collides with a walking elephant, part of its kinetic energy can be transferred to the person, resulting into serious injuries.

Figure 9.12: *A walking elephant*

Potential energy

Potential energy is the energy possessed by an object due to its position. An object can have potential energy if it is acted upon by a force that tends to restore it to its initial position after it has been displaced. For example, a body raised from the ground to a certain height has gravitational potential energy due to gravitational force. On releasing, it returns to the ground, thus its potential energy relative to the ground becomes zero. Another type of potential energy is due to elastic force in a compressed spring (Figure 9.13). This is elastic potential energy.

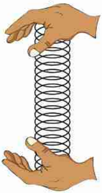


Figure 9.13: *Compressing spring*

These two types of potential energy are briefly discussed below.

Elastic potential energy is energy stored in objects like springs as a result of reversible deformation. When a force is applied on a spring it gets compressed or stretched. But when the force is removed, it regains its original shape and size. In the deformed state, the spring has elastic potential energy.

Gravitational potential energy

Suppose that a force F is used to lift an object with a mass (m) from an initial height (h_i) to a final height (h_f) at a constant velocity, as shown in Figure 9.14. Since the object moves in the direction of the force, work is done on the object.

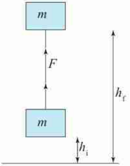


Figure 9.14: *An object is lifted from h_i to h_f*

The force required to lift an object at a constant velocity has a magnitude equal to the object's weight, mg.

$$F = mg.$$

Multiplying both sides by the displacement (d) gives:

$$Fd = mgd.$$

The displacement of the object is equal to the change in its height as shown in Figure 9.14. Thus,

$$d = h_f - h_i$$

h_i = initial height,

h_f = final height.

Substituting this expression on the right side of the above equation gives:

$$Fd = mg\left(h_f - h_i\right)$$

$$Fd = mgh_f - mgh_i\,.$$

The quantity on the left side of the equation is the work done. The quantities, mgh_i and mgh_f are the respective potential energy, values at the heights h_i and h_f. The difference between mgh_i and mgh_f is the change in the object's PE. It follows that change in potential energy is equal to work done (W) in lifting the object, that is $\Delta PE = W$.

If $h_i = 0$, that is the ground level is the reference level, then

$$PE = mgh$$
$$= mgh$$

where h is the height from the surface.

Thus, $PE = mgh$.

When determining the PE of an object, a reference level from which h is measured must be chosen. The choice is arbitrary and the reference level can be located anywhere. For convenience the reference level h_i is considerd to have zero PE. Note that while the PE of an object depends on the location of the reference level, the change in PE does not. Like kinetic energy, the SI unit of PE is Joules which is equivalent to kgm^2/s^2.

Unlike kinetic energy, PE depends on height of an object above a reference level while kinetic energy depends on velocity of a body. When a force lifts an object at a constant velocity, the work done by the force equals the change in the object's gravitational potential energy. That is, $PE = W = mgh$.

Example 9.5

A stone of 2 kg falls from a height of 25 m above the ground. Calculate the PE initially possessed by the stone.

Solution

$m = 2$ kg, $g = 10$ m/s^2

$PE = mgh$

$= 2 \text{ kg} \times 10 \text{ m/s}^2 \times 25 \text{ m}$

$= 500$ J

Therefore, PE of the stone is 500 J.

Example 9.6

A 2 kg object is at rest on a table 1.2 m above the floor. The ceiling in the room is 2.8 m above the floor as shown in Figure 9.15.

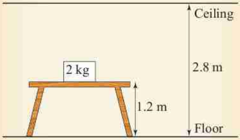


Figure 9.15

(a) What is the gravitational potential energy of the object relative to;
   (i) the table top?
   (ii) the floor?

(b) Find the work done in lifting the object from the top of the table to the ceiling.

Solution

(a) Gravitational potential energy

(i) $h = 0$, $PE = mgh$ hence,

$PE = mgh$ at the table top $h = 0$

(ii) $h = 1.2$ m,

$PE = mgh$

$= 2 \text{ kg} \times 10 \text{ m/s}^2 \times 1.2 \text{ m}$

$= 24$ J

(b) $d = 2.8 \text{ m} - 1.2 \text{ m} = 1.6 \text{ m}$

But $\Delta PE = mgh$

$= 2 \text{ kg} \times 10 \text{ m/s}^2 \times (1.6 \text{ m})$

$= 32$ J

Therefore, the work done = 32 J.

Exercise 9.2

Answer all questions (where necessary use g = 10 N/kg).

1. State five forms of energy.
2. (a) Determine the potential energy possessed by a particle of mass 0.2 kg resting on a table top 1.6 m above the floor.
   (b) Amina has a mass of 80 kg. If she runs at a speed of 10 m/s, calculate her kinetic energy.
3. A stone of mass 10 kg is dropped down to the ground from the roof of a building 10 m high. If it hits the ground with a velocity of 20 m/s, determine its:
   (a) kinetic energy.
   (b) change in potential energy.

Activity 9.2

Aim: To demonstrate the existence of potential energy and kinetic energy.

Materials: Helical spring, thread, retort stand, and 100 g mass

Procedure

1. Clamp a helical spring on a retort stand.
2. Attach a 100 g mass to the bottom of the spring.
3. Pull the mass down about 5 cm then release it.
4. Observe the up and down motion of the mass.

Questions

(a) What form of energy did the mass have at initial rest point?

(b) To what form of energy did the mass's energy change after being released?

When a helical spring is set in motion, the mass possesses kinetic energy. Initially it had potential energy due to position. A mass at rest possesses potential energy only.

Task 9.1

1. List down all forms of energy that you know.
2. Discuss and illustrate the forms of energies you have listed.

Transformation of energy

In Figure 9.4, the brick had energy to drive the nail into a wooden block. This energy came from the work required to lift the brick above the nail. In doing work on the nail, the brick lost its energy. If you want to drive the nail even further into the wood you must again do work on the brick to lift it above the nail. Therefore, work can be changed into another form of energy and energy in turn can do work. Useful jobs like lifting loads up the stairs or moving bags, whether done manually or by machines, require energy. Food provides energy. Energy can also be obtained from fuel and electricity.

Kinetic and potential energy can be transformed into each other. In the example of the brick and a nail, the brick first had potential energy as it was held above the nail. When dropped, the potential energy changed to kinetic energy as it fell towards the nail. When the brick hit the nail, its kinetic energy was converted to work in pushing the nail into the wood and into heat energy and sound. Figure 9.16 shows the relationship between work and energy.

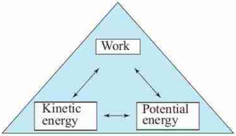


Figure 9.16: *Work and energy are interchangeable*

Note that, for any useful work to be done, energy is required. Cooking gas, petrol, and food store chemical energy which can only be used after changing it into other forms of energy through a chemical reaction. For example, a car is fueled at a petrol station as shown in Figure 9.17 before it can be driven. Chemical energy stored in petrol is eventually converted into mechanical energy, thus enabling the car to move.

Figure 9.17: *Fueling a car at a petrol station*

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Consider a locomotive diesel engine. The fuel is burnt to release chemical energy which is in turn converted to mechanical rotational energy. This rotation is transferred to wheels and makes the train move. Figure 9.18 shows a train driven a diesel engine.

Figure 9.18: *Train that uses diesel engine*

A stone dropped from a cliff of height, h, decreases its PE while its KE increases. On hitting the ground, some dust may fly off (KE) and some sound may be heard (sound energy). The point of impact may also become warmer as a result of the impact. This shows that, PE has been converted into heat energy. The energy changes are as follows:

$PE \rightarrow KE \rightarrow KE + sound\ energy + heat.$

Note: Although energy is transformed from one form to another, it is never used up or lost.

Other examples where energy is transformed include:

1. Water at the top of a dam has potential energy. This is transformed into kinetic energy as the water falls.
2. The PE of a stretched bow can be transformed into KE of an arrow.
3. Consider a footballer kicking a ball. The chemical energy in his muscles is converted into kinetic energy of the ball which partly changes into heat energy. In many other instances, heat energy is the final form of energy. Chemical energy→ KE→ Heat energy.

Principle of conservation of energy

Suppose a 3 kg object is dropped from a height of 5 m above the ground as in Figure 9.19. Ignoring the effects of air resistance, the object will fall to the ground with an acceleration due to gravity, g.

Choosing the ground as the reference level, the PE of the object when released is:

$$PE_i = mgH$$

$$= 3\ \text{kg} \times 10\ \text{N/kg} \times 5\ \text{m}$$

$$= 150\ \text{J}$$

$$= 150\ \text{J}$$

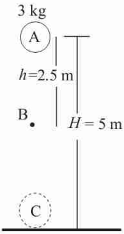

Figure 9.19

Since its initial velocity was zero, it had no KE when released, $KE_i = 0$.

Upon reaching the ground, it had no PE. Since $h_f = 0$, $PE_f = 0$. It does however has kinetic energy. Therefore, kinetic energy, $KE_f = 150$ J.

Note: $KE = PE = 150$ J. Since no energy is lost, final velocity can always be calculated.

This means that while falling under the influence of gravity, the initial PE of the object is completely converted into kinetic energy as it falls. This illustrates the principle of conservation of energy which states that: "*Energy is neither created nor destroyed but can be transformed from one form to another*."

Consider the object when it is halfway to the ground ($h_f = 2.5$ m).

The final PE and KE are:

$$PE_f = mgh$$
$$= 3 \text{ kg} \times 10 \text{ N/kg} \times 2.5 \text{ m}$$
$$= 75 \text{ J}$$
$$PE_f = 75 \text{ J and}$$
$$KE = E - mgh$$
$$= KE = 150 \text{ J} - 75 \text{ J} = 75 \text{ J.}$$

One half of the initial PE has been converted to KE.

The total mechanical energy, E, of an object is the sum of its potential and kinetic energies.

$E = KE + PE$.

What was the total mechanical energy of the object when:

(a) it was released?,

(b) it was half way to the ground?

(c) it reaches the ground?

Solution

(a) $E = PE + KE = 0 \text{ J} + 150 \text{ J} = 150$ J.

(b) $E = PE + KE = 75 \text{ J} + 75 \text{ J} = 150$ J.

(c) $E = PE + KE = 150 \text{ J} + 0 \text{ J} = 150$ J.

So, while the object was falling its PE decreased and its KE increased. In this case, its total mechanical energy remained constant. The total mechanical energy was therefore conserved.

Conversion of energy can also be studied by considering the motion of a simple pendulum as shown in Figure 9.20. A pendulum is a mass suspended by a string or wire from a fixed point so that it can move back and forth along an arc. The lowest point in its motion is called the equilibrium point and is usually considered as the reference point, as shown in Figure 9.20 (a).

There are two forces that act on the pendulum. The force of gravity (weight) of the pendulum and tension T in the string. The tension does not do work because it always acts along the string and is always perpendicular to the displacement (see Figure 9.20). Therefore, the total mechanical energy of the pendulum remains constant.

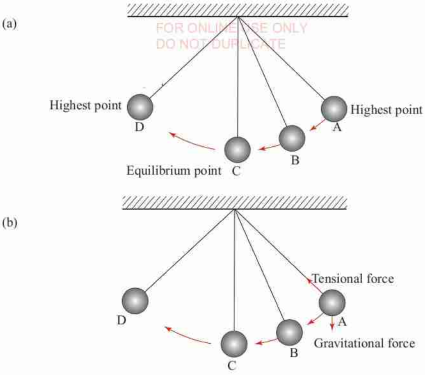

Figure 9.20: *Conservation of mechanical energy*

At points A and D, the pendulum's highest points above the equilibrium point, the total energy is equal to *PE*. At Point C, the pendulum is at its lowest point. Total energy is *KE*. At points like B, between the highest and the lowest points, total energy is the sum of *KE* and *PE*.

Transducer

Energy can be transformed from one form to another. An electronic device used to convert one form of energy to another is called a transducer. Table 9.2 shows some transducers and the corresponding energy transformation.

Table 9.2: Transducer and the respective energy transformation

Transducer	Energy conversion
Bulb	Electric energy ⟶ Heat energy ⟶ Light energy
Generator	Mechanical energy ⟶ Electrical energy
Motor	Electrical energy ⟶ Mechanical energy
Solar panel	Solar energy ⟶ Electrical energy
Battery	Chemical energy ⟶ Electrical energy
Heater	Electrical energy ⟶ Heat energy
Microphone	Electrical energy ⟶ Sound energy

Example 9.7

At its highest point A in Figure 9.21, a pendulum of mass 0.8 kg is 1.2 m above the equilibrium point. What will be its velocity as it swings through its lowest point?

Solution

Given data

Height, $h = 1.2$ m

Mass, $m = 0.8$ kg

$g = 10$ N/kg

Due to the law of conservation of energy, maximum *KE* at lowest position = maximum *PE* at the highest position

$$\frac{1}{2}mv^2 = mgh$$

Rearrange the equation to get v;

$$v = \sqrt{2gh}$$

$$= \sqrt{2 \times 10 \text{ m/s}^2 \times 1.2 \text{ m}}$$

$$= 4{\cdot}9 \text{ m/s}.$$

Therefore, the velocity of the pendulum is 4.9 m/s.

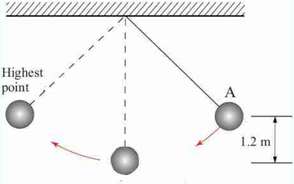

Figure 9.21

Uses of mechanical energy

Mechanical energy enables objects to apply a force on other objects in order to cause displacement and hence do useful work.

For a car, truck, train, or aeroplane to move, mechanical energy is needed to turn wheels or push the air behind. Electricity is normally obtained by dynamos driven by some forms of mechanical energy like *PE* and *KE* (example wind). Juicer uses mechanical energy to squeeze fruits.

Mechanical energy has various uses, including the following:

1. Gravitational potential energy keeps objects on the ground. It facilitates stability of motion;
2. Kinetic energy helps objects to keep moving; and
3. Transfer of energy is accompanied by performance of work. For example, a bow string does work on an arrow.

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Task 9.2

Identify and discuss the energy changes in:
(a) Rotating fan.
(b) Wood splitting.
(c) When throwing up a stone.
(d) Burning of charcoal.
(e) Striking a tuning fork.
(f) Eating potatoes.
(g) Lighting a torch.
(h) Swimming.

Is the law of conservation of energy obeyed?

Concept of power

Power is the rate at which work is done. It is a measure of the rate at which energy changes. This means that whenever work is done, energy changes into a different form.

Power is measured in Joules per second (J/s) or Watts (W). 1W=1J/s.

Mathematically, power may be expressed as:

$$Power\ (P) = \frac{work\ done(W)}{time(t)}.$$

$$P = \frac{W}{t}.$$

Alternatively;

Power, P	In terms of potential energy; $P = \frac{mgh}{t}$	
	In terms of kinetic energy; $P = \frac{mv^2}{2t}$	
	In terms of force and velocity; $P = Fv$	
	In terms of momentum; $P = mvg$ where mv- momentum.	

Note: These alternative formulae may be used depending on the given situation.

Other units of power are: kilowatts (kW), horsepower (hp) and Megawatts (MW). Their equivalence to the Watt is:

1 kW = 1 000 W.

1 MW = 1 000 000 W.

Power can also be expressed in horsepower (hp).

1 hp = 746 W.

When 1 joule of work is done per second, the power produced is one Watt. Watt is also the unit for measuring electrical power.

Task 9.3

Compare the rate of doing work by two cranes; *A* and *B*. Each lifts a body of mass 200 kg through a distance of 20 m. Crane *A* lifts the body in 15 s while crane *B* requires 20 s to lift it.

Assume they all lift the body at a constant velocity.
1. Do they do the same work?
2. Which crane has more power?

Sometimes power can be referred to as how fast or slow work is done. That is, the rate at which work is done.

Suppose that two cranes each lift objects having masses of 200 kg to a height of 12 m. Crane A lifts its object in 10 s while crane B requires 15 s to lift it. Assuming that they all lift the objects at a constant velocity, they do the same amount of work.

Work done = *change in gravitational potential energy*

$= mgh$

$= 200\ \text{kg} \times 9.8\ \text{m/s}^2 \times 12\ \text{m}$

$= 23\ 520\ \text{J}$

Therefore, each crane did work that was equal to 23 520 J.

What is different for the two cranes is the rate at which they did the work.

The power of crane A can be calculated as follows:

$$P_A = \frac{W}{t}$$

$$= \frac{23\ 520\ \text{J}}{10\ \text{s}}$$

$$P_A = 2\ 352\ \text{watts}.$$

Power of the crane B was:

$$P_B = \frac{W}{t}$$

$$= \frac{23\ 520\ \text{J}}{15\ \text{s}}$$

$$= 1\ 568\ \text{watts}.$$

Crane A has more power.

Example 9.8

A model car of mass 20 kg moves at a speed of 6 m/s for 10 s. Find the power developed by its engine.

(a) in watts.

(b) in horsepower.

Solution

(a) Data given

Mass of the model car = 20 kg

Speed of the car = 6 m/s

Time taken = 10 s

$$P = \frac{mv^2}{2t}$$

$$P = \frac{20\ \text{kg} \times (6\ \text{m/s})^2}{2 \times 10\ \text{s}}$$

$$= 36\ \text{W}$$

Therefore, Power is 36 Watts

(b) Converting watts into horsepower

1 hp = 746 watts

? = 36 watts

Thus,

$$P = \frac{1\ \text{hp} \times 36\ \text{watts}}{746\ \text{watts}}$$

$$= 0.048\ \text{hp}.$$

Therefore, Power is 0.048 hp.

Running upstairs is another area where power is required. Running or walking upstairs increases one's gravitational potential energy by the same amount as walking up them. However, the energy transferred in the former is at a higher rate. When you run upstairs, your power is more than when you decide to walk up as shown in Figure 9.22.

Figure 9.22: *Walking upstairs*

Wading through water is energy-draining hence more power is required for an individual or animal to cross from one bank of a river to the other as shown in Figure 9.23.

Figure 9.23: *An elephant wading through water*

Example 9.9

How much power is required for a car 1 000 kg in changing speed from 10 m/s to 40 m/s in 8 s?

Solution

The work done on the car increases its kinetic energy.

Work done $= \Delta KE$

$$= \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$= \frac{1}{2} \times 1\,000 \text{ kg} \times (40 \text{ m/s})^2 - \frac{1}{2} \times 1\,000 \text{ kg} \times (10 \text{ m/s})^2$$

$$= 750\ 000 \text{ J}$$

The energy used by the car is 750 000 J.

The power required is given by:

$$P = \frac{Energy\,used}{time}$$

$$= \frac{750\,000 \text{ J}}{8 \text{ s}} = 93\,750 \text{ W}.$$

Car engines are often rated in horsepower (hp) where 1 hp = 746 watts.

What is the required power measured in horsepower?

$$P = 93\ 750 \text{ W} \times \frac{1 \text{ hp}}{746 \text{ W}}$$

$$= 125.67 \text{ hp}.$$

Since work causes a change in energy, power can be considered as the rate of change of energy.

$$P = \frac{change\ in\ energy}{t}$$

For example, a light bulb converts electrical energy into light and heat. A 60-Watt light bulb converts 60 J of electrical energy each second from electrical to light and heat energy.

Most appliances have a rating plate on them showing exactly how many watts they use.

Activity 9.3

Aim: To determine the power developed by own legs.

Materials: A flight of stairs, weighing scale, stopwatch, tape measure

Procedure

1. Measure your weight in Newtons and note it down.
2. Measure the vertical height of the stairs as in Figure 9.24.

Figure 9.24

3. Record the height in metres.
4. Using a stopwatch, record the time taken to run from the bottom to the top of the stairs.
5. Other individuals can repeat step 4.

Questions

(a) Calculate the amount of work done.
(b) Calculate the power developed.
(c) Find out who developed the highest power.

Assume there are n stairs and the height of each stair is h cm. If a man of mass m kg runs up a staircase in t seconds then, the total work done is given by

$$W_{total} = mg(nh)$$

The power developed

$$\text{by a man} = \frac{Total\ work\ done}{time}$$

$$= \frac{nmgh}{t}.$$

Example 9.10

A man whose mass is 80 kg walks up a flight of 25 steps each 20 cm high in 10 seconds. Find the power developed by the man in kilowatts.

Solution

Given data

Mass of the man (m) = 80 kg

Number of steps (n) = 25

Height of each step (h) = 20 cm = 0.2 m

Time taken (t) = 10 s

$$P = \frac{nmgh}{t}$$

$$P = \frac{25 \times 80 \text{ kg} \times 10 \text{ N/kg} \times 0.2 \text{ m}}{10 \text{ s}}$$

P = 400 watts.

Conversion of watts into kilowatts

1 kW = 1 000 W

? = 400 W

Thus,

$$P = \frac{1 \text{ kW} \times 400 \text{ W}}{1\,000 \text{ W}}$$

Therefore, $P = 0.4$ kW.

Exercise 9.3

Answer all questions

1. A forklift is used to raise a mass of 400 kg to a height of 2 m in 4 seconds. Determine the power developed.
2. A truck for transporting sand is filled to its capacity. The total mass of the sand was 5 000 kg. If a digger had to climb through a height of 2 metres 100 times to fill the truck, calculate:
   (a) the work done in loading the truck; and
   (b) the power developed if the digger took 5 seconds per climb.
3. If a crane lifts a load weighing 3 000 N through a height of 10 m in 500 seconds, what is the power of the crane?
4. Convert the following
   (a) 11936 W into hp.
   (b) 2.5 hp into W.
5. A body of mass 50 kg is raised to a height of 2 m above the ground. What is its potential energy? If the body is falls down, find its kinetic energy:
   (a) when half way down.
   (b) just before impact with the ground.

Chapter summary

1. Work is done when a force acts on an object and the object moves in the direction of the force. Work is therefore the product of force and distance moved in the direction of this force. Work is measured in Joules.
2. Energy is the ability to do work and is also measured in Joules.
3. Mechanical energy consists of kinetic and potential energy.
4. Kinetic energy is the energy an object has due to its motion.

   $$KE = \frac{1}{2}mv^2$$

5. Potential energy is the energy stored in an object or energy due to its position. $PE = mgh$.
6. Kinetic and potential energy exist on both macroscopic and microscopic levels as exhibited in mechanical, thermal, electrical, chemical, and nuclear energies.

Revision exercise 9

Section A

Choose the most correct answer.

1. Work is said to be done when
   (a) force acts upon a body, but the body does not move.
   (b) force acts upon a body and it moves it in the direction of applied force.
   (c) force acts upon a body but the body does not move in the direction of the force.
   (d) force acts upon a body and the body moves.
2. A constant horizontal force F displaces a box by distance d over a rough horizontal surface. Study Figure 9.25.

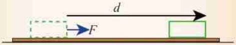


Figure 9.25

The normal force acting on the box does NO work on the box during the motion because it is
   (a) equal to the applied force.
   (b) perpendicular to the applied force.
   (c) equal and opposite to the weight of the box.
   (d) perpendicular to the displacement of the box.
3. The food consumed by a human being produces
   (a) only kinetic energy.
   (b) only heat energy.
   (c) both heat energy. and kinetic energy.
   (d) only chemical energy.
4. Work done and energy are related in that
   (a) they are both a result of mechanical process.
   (b) they have the same unit in which they are measured.
   (c) they all explain how fast a certain task is performed.
   (d) all are the typical examples of chemical energy.
5. Power always implies
   (a) how fast or slow work is done.
   (b) the strength to do work.
   (c) the work done.
   (d) kinetic energy.
6. When an object is set into motion it has
   (a) high potential energy and low kinetic energy.
   (b) kinetic energy.
   (c) potential energy.
   (d) high kinetic energy and low potential energy.
7. The magnitude of kinetic energy depends on
   (a) mass and distance it moves.
   (b) mass and its velocity.
   (c) force and gravity.
   (d) force and velocity.
8. Which one of the following quantities has the same unit?
   (a) speed and force.
   (b) work done and energy.
   (c) work done and power.
   (d) potential energy and power.

9. One Megawatt is equivalent to:
   (a) 10 000 000 watts.
   (b) 1 000 000 000 watts.
   (c) 1 000 000 watts.
   (d) 1 000 watts.

10. Which one of the following equations shows the relationship between power and work done?
   (a) $power = \frac{work\ done}{time\ taken}$.
   (b) $power = \frac{work\ done}{distance\ moved}$.
   (c) $power = work\ done \times time\ taken$.
   (d) $power = work\ done \times velocity$.

11. Match each item from **Column A** with its corresponding item in **Column B**. Then, write the letter of the correct response in the space provided.

Column A	Answer	Column B
1. 1 kW		A. Motion in upward or downward
2. Horse power		B. 1 000 W
3. *PE*		C. kgm^2/s^2
4. Joule		D. Motion parallel to force
5. Watt		E. Mechanical energy
		F. 750 W
		G. SI unit of power
		H. $\frac{1}{2}mv^2$
		I. SI unit of energy
		J. 746 W

12. Fill in the blanks by choosing the correct word from the list given below.

List: created, constant, destroyed, work, force, mechanical energy, displacement, *KE*, electric, chemical, and *PE*.

(i) The ability to do……………. is called energy.

(ii) Work is said to be done when a………causes ………in its own direction.

(iii) ………and………. are the two basic forms of mechanical energy.

(iv) When a dry cell is connected to an electric bulb, the ………...energy of cell changes into……………... energy and light.

(v) Energy can neither be……………, nor ………… and sum total of energy in a system remains a ……………quantity.

13. Write **TRUE** for a true statement and **FALSE** for an incorrect statement against the statements given below:

(i) Falling apple has potential as well as kinetic energy.

(ii) When water stored in dams is made to run a turbine, the potential energy of water stored partly changes into electric energy.

(iii) A boy standing on one leg during an exercise does a lot of work.

(iv) Light does not move heavy objects, and hence, it is not energy.

(v) Magnetic energy can cause motion thus it, is a mechanical energy.

Section B

Answer all questions in this section

14. (a) Define the term work.
    (b) What happens to work done when force and displacement are in the same direction?
    (c) What happens when force and displacement are in opposite direction?
15. (a) Define the term power.
    (b) How is power measured?
    (c) Express 6900 J/s in horsepower.
16. Explain why a rotating wonder wheel becomes hot after a sudden stop.
17. Calculate the work done in each case below. Indicate if the work is done on the object or by the object.
    (a) A 10 kg object is lifted to a height of 5 m above the ground.
    (b) The object is held at a height of 5 m for 7 s.
    (c) The object is lowered back to the ground.
18. A motor exerts a horizontal force of 200 N in pulling a box 10 m across a level floor. How much work does the motor do?
19. An object is dropped and falls to the ground. Is there any work done while it is falling? If so, what force is responsible? Is the work done on or by the object?
20. A 1 000 kg car is travelling down the road at a speed of 15 m/s. How much kinetic energy does it have?
21. A 1 000 kg car travelling at 15 m/s has its speed increased to 45 m/s. How much kinetic energy would it have? How many times greater is the kinetic energy at 45 m/s than at 15 m/s?
22. Rock A has a mass of 2 kg and a speed of 1 m/s. Rock B has a mass of 1 kg and a speed of 2 m/s. Which rock has more kinetic energy?
23. If your mass is 45 kg, how much work would you do in climbing a ladder that is 5 m high?
24. State the law of conservation of energy.
25. Discuss the energy changes in a firework.
26. Which object has more kinetic energy between a 10 kg object travelling at 5 m/s and a 5 kg object travelling at 10 m/s?
27. How much work is required to stop a 1 500 kg car travelling at 20 m/s?
28. A 2 kg object is on a table top 1.1 m above the floor. How much work is required to lift it at a constant velocity to a shelf 1.3 m above the floor?
29. A 0.5 kg ball is dropped from a height of 2.3 m above the floor. If on impact with the floor it loses 3 J of energy, how high will it bounce?
30. A 3 kg box starts down a hill 3.3 m deep with an initial velocity of 5 m/s. If on reaching the bottom of the hill its velocity is 7.5 m/s, how much work is done by the box to overcome friction?

Chapter Ten

Introduction to light

Introduction

We can recognise objects through our five senses, namely seeing, hearing, touching, tasting, and smelling. We see the mountains, oceans, rivers, and other fascinating events through the sense of sight. Light plays a main role in seeing objects. In the absence of light, for example in a very dark night, you cannot see objects near you. In this Chapter, you will learn the concept of light, sources of light, propagation and transmission of light, reflection of light and the effect of light. The competence developed will give you an insight to explain of some natural phenomenon such as solar and lunar eclipses. You will also develop the competencies in dealing with the principles and applications of image formation in mirrors and functioning of optical instruments such as telescope and periscope.

Concept of light

Seeing is possible only if there is an interaction between light and the eye. Sight begins when light enters the eye and stimulates the light sensitive cells called photoreceptors which are located on the retina at the back of the eye. When the photoreceptors are stimulated, they produce a signal which is sent to the brain for interpretation; thus, giving a sensation of seeing.

The human eye has two types of photoreceptors, rods and cones. Rods are extremely efficient in such a way that a tiny amount of light can stimulate them. Rods are responsible for our night vision. They detect lines, contrast, shape, and movement but they cannot distinguish colour. Cones are responsible for colour vision but they need plenty of light to be stimulated. This is why in dim light conditions, a person can recognize an object but fails to detect its colour.

Light is the form of energy which stimulates the sense of vision.

Nature of light

Light has some distinct features that differentiate it from other forms of energy. These features include the following.

1. Light is given out from its source. Lines known as light rays are used to show the direction of light.
2. Light travels in a straight line. This means that light can be observed as a beam of light. A beam is bundle of rays.
3. Light transfers energy. Objects gain energy when they absorb light. For example, solar cells absorb light from sun (solar energy) and converts it into electrical energy.
4. Light travels in a vacuum. Light does not require a material medium in order to travel.
5. Light travels at the fastest speed. The speed of light is 3×10^8 m/s, it is the highest speed recorded on earth.

Sources of light

There are several sources of light that can be categorised as either; natural source or artificial source.

Natural sources of light

The universe is filled with objects that naturally emit light. Some light from these sources reaches, the earth. The natural sources of light include the sun, stars and lightning. The sun is one among of the stars. There are also insects, animals, and plants that emit light. These includes fireflies, jellyfish, deep sea plants, and some micro-organism. Figure 10.1 shows some of the natural sources of light.

Note that the sun is a major source of light for the earth. It is a star at the center of our solar system. The sun is a huge nearly perfect sphere of hot glowing gas formed by nuclear fusion producing massive energy. This energy comes out as heat and light. Light from the sun is one of the major factors behind the sustainability of life on earth. All other stars produce light too, but only a small or no amount of it reaches the earth because of the long distance. The moon provides light as well but it cannot produce light on its own. The light that we get from the moon is the light reflected by it from the sun. Some living organisms have the ability to produce light too. The production of light by living organisms is called bioluminescence.

(a) Lightning flash

(b) Stars in the sky

(c) Bioluminescence fly

(d) The moon

Figure 10.1: *Natural sources of light*

Artificial sources of light

Artificial sources of light are those which are man-made. Examples of artificial sources of light are woodfires, candles, hurricane lamps, gas lamps, electrical bulbs (or lamps), and fluorescent tube, torch, compact fluorescent lamp (CFL) as shown in Figure 10.2.

 Hurricane lamp	 Gas lamp	 Electric filament bulb	 Compact fluorescence lamp (CFL)
 Torch	 Burning firewood	 Candle flame	 Fluorescenc tube

Figure 10.2 *Artificial sources of light*

The different sources of light that are produced artificially can be grouped into three categories: incandescent, luminescent, and gas discharge light sources.

Incandescent source

Certain objects when heated to a high temperature, can emit light. Both visible and infrared light can be produced in the process. Examples of the incandescent light sources are candles, hurricane lamp, torches, electric bulbs, firewoods, and gas lamp. In this process, electric energy is converted to heat energy by a filament of an electric bulb and then this filament becomes extremely hot and produces visible light. Because of this energy transfer process, the incandescent sources are considered to be very inefficient source of light.

Luminescent source

Luminescent sources are those sources that produce light which is not caused by heating. Light can be produced by accelerating charges in a luminescent material. Examples of luminescent sources are fluorescent tube and energy-saving fluorescent lamp.

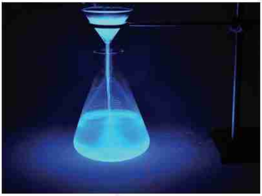
Luminescence mechanism sources can be classified as Chemiluminescence, Bioluminescence, Fluorescence, Phosphorescence, and Gas Discharge Sources.

Chemiluminescence

Emission of light is driven by chemical reaction. In these reactions the chemical energy is converted into light energy as shown in Figure 10.3 (a).

Bioluminescence

Few plants, insects and animals emit light as seen in the glow of a firefly's tail as shown in Figure 10.3(b). The mechanism emission of light by an organism is called bioluminescence. Bioluminescence involves a chemical reaction in which chemical energy is converted into light energy. In the process, a little amount of heat energy is given off. Due to this reason, this emission is called *cold light*.



(a) Chemiluminescence

(b) Bioluminescence

Figure 10.3: *Luminescent sources*

Fluorescence

This occurs when fluorescent materials absorb energy and emit light. For example, the gas in a fluorescent tube absorbs electrical energy and emit light. The fluorescence starts immediately after the absorption of energy and stop as soon as energy is cut off. Fluorescence source of light is more efficient than incandescent source because fluorescence light produces less heat.

Phosphorescence

This occurs when a phosphorescent material absorb energy and emit light continuously even after the incident energy is cut-off. Examples of phosphorescent materials are glow-in-the-dark stars, some safety signs, and glowing paints.

Gas Discharge Sources

Passing electrical energy through certain gases at very low pressure can produce light. Examples of the gas discharge source are neon lamps and sodium lamps which are shown in Figure 10.4.

(a) Sodium lamp

(b) Neon lamp

Figure 10.4: *Gas discharge sources*

At present time, new sources of light that use a different mechanism have been developed. For example, Light Emitting Diode (LED) and LASER.

Task 10.1

In your exercise book, make a list of objects that emit light. Which of these are natural sources of light and which are artificial sources? Present your list in the class.

Luminous and non-luminous bodies

Luminous objects are objects that emit (give out) light on their own. This includes the sun, stars, candles, and fireflies. Glowing TV screens and glow-worms also fall into this category. Certain insects and types of fish are also said to be luminous because they give out light. Figure 10.5 shows examples of luminous objects.

(a) The sun

(b) Bioluminescence

Figure 10.5: *Some of luminous objects*

On the other hand, non-luminous objects are objects that do not emit their own light on their own. These objects are only visible when they reflect light from a luminous source into our eyes. For example, moon and earth, shown in Figure 10.6 are non-luminous objects that reflect light from the sun and from other stars.

(a) Moon

(b) Earth

Figure 10.6: *Non-luminous objects*

Some objects, shown in Figure 10.7, can be luminous or non-luminous depending on their temperature. For example, charcoal and kerosene are non-luminous at room temperature, but they can be made luminous when burning at a sufficient temperature.

(a) Charcoal at room temperature (non-luminous)

(b) Burning charcoal (luminous)

Figure 10.7: *Luminous sources*

Difference between luminous and non-luminous objects

The main difference between luminous and non-luminous objects is that; luminous objects emit light on their own while non-luminous objects reflect light from the luminous objects. Luminous objects are visible in the darkness while non-luminous objects are not visible in the darkness.

Task 10.2

In groups of four students, list 10 objects that are luminous and 10 that are non-luminous. Give reasons for your answers. Present your answer in the class.

Propagation and transmission of light

Propagation of light

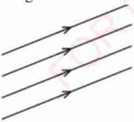
Propagation of light refers to the transfer of light energy from one point to another while transmission of light is when light passes through a medium. These two words are used in relation to light since light spread out from the source and travel in straight lines.

Rays and beams of light

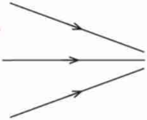
Light travels in a straight line. This is one of the properties of light. The movement of light from its source to the environment in straight lines is referred to as rectilinear propagation of light. Lines with arrows are used to indicate the direction in which light is travelling. They are known as rays. A ray is the path taken by light in moving from the source to another point. It is also said to be a narrow stream of light energy. An example of ray of light is shown in Figure 10.8.

Figure 10.8: *A ray of light*

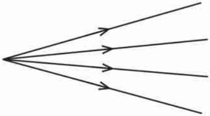
A collection of rays of light is called beam of light. A beam of light can either be parallel, convergent or divergent as shown in Figure 10.9.



(a) Parallel beam of light



(b) Convergent beam of light



(c) Divergent beam of light

Figure 10.9: *Beams of light*

The ray box is a device which contains a low voltage lamp used to produce light rays in the laboratory. Ray box is illustrated in Figure 10.10.

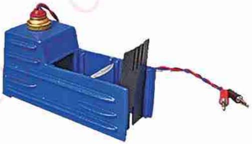


Figure 10.10: *A ray box*

Activity 10.1

Aim: To demonstrate a narrow beam of light.

Materials: Ray box, piece of paper, and source of light

Procedure

1. Place a ray box on a sheet of white paper.
2. Switch on the ray box as shown Figure 10.11.

Figure 10.11: *Action of a ray box*

3. Open the ray box window and observe light from the ray box.

Question

What do you notice on the edges of the beam of light from the ray box?

Verifying that light travels in a straight line

Activity 10.2

Aim: To verify that light travels in a straight line.

Materials: Candle, matches, 3 cards of equal sizes (about 20 cm by 8 cm), sellotape, string, nail, ruler, and screen

Procedure

1. Take three square cardboards of equal size. Locate the centre of each piece of cardboard by drawing the diagonals.
2. Using a nail, make a hole at the centre of each cardboard.
3. Fix the three cardboards so that they are upright as seen in Figure 10.12.
4. Arrange the three cardboards as A, B and C, one behind the other such that their centres are in the same horizontal line. You may pass a knitting needle through to confirm that they are in a straight line.

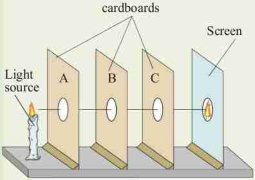


Figure 10.12: *Rectilinear propagation of light*

5. Now place a burning candle in front of the board A and look through the hole in board C. Now, move board B sideways slightly and again look through the pinhole in board A as shown in Figure 10.12.

Questions

(a) Is the candle flame visible when the holes are in a straight line?
(b) What happens when one of the card is moved slightly to the left or right side?

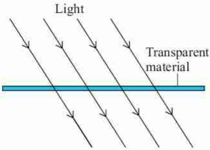
When the three holes are in a straight line, an observer is able to see the flame of the candle. This shows that the light travels in a straight line. When either cardboard or a candle is displaced, the flame will not be seen. This shows that light does not travel in a zig-zag path.

Transmission of light

The ability of light to travel through matter varies from one substance to another. When light travels through matter, it is said to be transmitted (passed through). When discussing light transmission, materials are classified into three categories, namely:

(a) transparent materials;
(b) translucent materials; and
(c) opaque materials.

Transparent materials are materials that allow light to pass through them. You can see through transparent materials without obstruction, as shown in Figure 10.13 (a). These materials appear to be clear. Examples of transparent materials are glass panes of windows, glass slabs, prisms, and clear plastics. In Figure 10.13 (b), it is possible to see a clearly a cabinet wall inside the house becaese the glass window is made up of transparent materials.

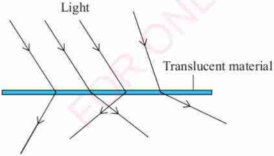


(a) Transparent material

(b) Clear glass window

Figure 10.13: *Light through a transparent material*

Translucent materials allow only part of the light to pass through them but not enough to make a defined image, as in Figure 10.14 (b). This happens as light rays get scattered when passing through the material as shown in Figure 10.14 (a). Oiled paper and tinted frosted glass are examples of translucent materials. Tinted glass is used in car windows. Some glass windows in houses are frosted so as to provide privacy. You cannot see clearly through a translucent material.

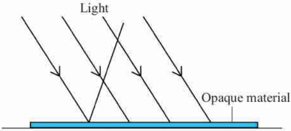


(a) Translucent material

(b) A flower as seen through a frosted glass wall

Figure 10.14: *Light through translucent materials*

Opaque materials, are materials which totally blocks the light, as shown in Figure 10.15(a). A block of concrete, wood, book, wall, and human body are examples of opaque materials. You cannot see through the wall, as shown in Figure 10.15(a) because the wall is an opaque material.



(a) Opaque material

(b) A brick wall

Figure 10.15: *Light falling on an opaque material*

Opaque materials differ from transparent materials in the following: Transparent objects completely allows light to pass through them and the object behind the transparent material can be seen clearly. Opaque materials do not allow light to pass through them and the object behind an opaque material cannot be seen.

Task 10.3

1. Hold a ball in one hand and shine light from a small light bulb on it. Record your observations.
2. Repeat step 1 using a table lamp instead of the small light bulb.
3. Make your conclusions and present your findings to the class.
4. From your school and home environment, collect and identify transparent, translucent and opaque materials. What is the importance of each material in your daily life?

Shadows

When an opaque object is in the path of a beam of light, a darkened region is formed behind the object. Little or no light reaches this region, because the opaque object does not allow light to pass through it. This region is called shadow. A shadow is formed because light travels in straight lines. Shadows have sharp edges as shown in Figure 10.16.

Figure 10.16: *Examples of shadows*

The type of shadow formed vary depending on the size of the source of light. Point sources of light such as the ray box produces a sharp shadow. An extended source of light produces a shadow that is not uniform. A shadow has two main parts. One part is totally dark and is called total shadow or umbra, and the other part is partially dark and is called partial shadow or penumbra. An example of an extended source of light is the hurricane lamp.

The shadow formed by an extended source of light is blurred at the edges. This is because each point on the source of light (lamp) causes a different shadow and they all overlap. An observer within the umbra region can not see the light source while an observer within the penumbra can see part of the source, as shown in Figure 10.17.

Condition necessary for the shadow formation are:

1. there must be source of light;
2. there must be an opaque object to obstruct the light; and
3. there must be an opaque screen where the image will be formed.

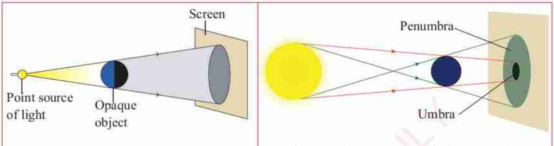


Figure 10.17: *Formation of shadows*

Activity 10.3

Aim: To demonstrate the formation of a shadow from a point source of light.

Materials: Piece of cardboard, torch, white screen, and object hanging on a string

Procedure

1. Make a small hole in the cardboard.
2. Place the white screen about 30 cm from the cardboard.
3. Suspend the object between the cardboard and the white screen as in Figure 10.18.

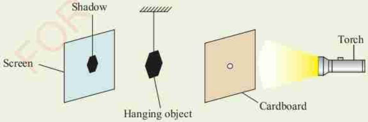


Figure 10.18: *Shadow formation*

4. Shine the torch from the back of the cardboard.
5. Record your observations.

Questions

(a) What did you see?

(b) Does light travel through straight lines?

A shadow of the suspended object is seen on the screen. The light source would have illuminated the whole screen but the opaque object blocks some of the rays given out by the torch. Due to this blockage, the portion of the screen that is not illuminated is the shadow of the object.

Task 10.4

Using a candle, soft board, sheet of paper, pencil and tennis ball, demonstrate the formation of a shadow. Use ray diagrams to illustrate your work.

The difference between umbra and penumbra is that umbra is the region of a total darkness in the shadow while penumbra is the region of partial darkness in the shadow. Umbra is normally surrounded by penumbra.

Eclipse

We know that, the earth and the moon are both opaque and non-luminous bodies and the sun is luminous. The earth and the moon both cast their shadows leading to the phenomenon known as eclipses. There are two types of eclipses; namely, the lunar eclipse and the solar eclipse.

Lunar eclipse

The lunar eclipse is sometimes known as the eclipse of the moon. It occurs when the earth comes between the sun and the moon. Lunar eclipse may be total or partial. In position A, as shown in Figure 10.19, the moon lies in the umbra of the shadow of the earth and thus, there is total lunar eclipse.

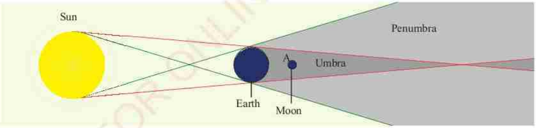


Figure 10.19: *Lunar eclipse*

Solar eclipse

The solar eclipse is sometimes known as the eclipse of the sun. It happens when the earth is in the shadow casted by the moon. The location marked C on the surface of the earth, in Figure 10.20, experiences a total shadow of the moon. At this place, the sun is cut-off completely from the view of moon. The places marked A and B are within the penumbra of the earth shadow and hence, experience a partial eclipse of the sun.

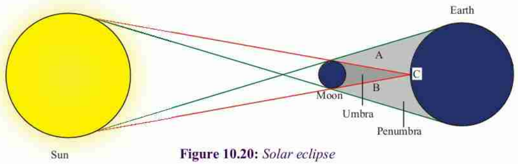


Figure 10.20: *Solar eclipse*

Note:
You can look at the moon during lunar eclipse directly with the naked eye. Never look the sun without protecting your eyes. This is due to the fact that, direct light rays from the sun are very strong, even during the solar eclipse. Take a piece of plane glass and blacken it with soot. The glass should be so black that nothing except the sun should be visible through it. Use this glass to look at the sun.

The pinhole camera

A pinhole camera in Figure 10.21, is a rectangular opaque box with a translucent window on one side. The pinhole camera is a simple camera which works because light travels in straight line. Light from the top of the object passes through the pinhole and on to the screen. Light from the bottom of the object also passes through the pinhole and on to the screen to form an image. Light from the upper point of the object passes through the pinhole and strikes the tracing paper at the lower end. The light from the lower part of the object passes through the pinhole, strikes the upper end of the tracing paper. The image formed by a pinhole camera is real, inverted and diminished in size when compared to the original object. Pinhole cameras are inexpensive and are easy to make. An eclipse can be viewed using a pinhole camera.

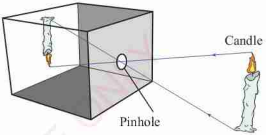


Figure 10.21: *Pinhole camera*

Tips:

(i) Painting black the inside of your box might help in obtaining a clear image.

(ii) High quality tracing paper makes the best screen.

(iii) The smaller the hole, the sharper the image. It implies that, the size of the hole affects the image's brightness. The bigger pinhole allows more light to get in, so the image becomes brighter. However, too big a pinhole leads to a fuzzy image.

Activity 10.3

Aim: To construct a simple pinhole camera.

Materials: A rectangular box, aluminium foil, sellotape, scissors, a square piece of tracing paper, and white paper

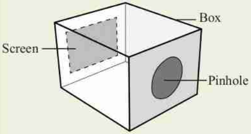


Figure 10.22: *Constructing a simple pinhole camera*

Procedure

1. Cut out a rectangle about $12\text{ cm} \times 8\text{ cm}$ on one side of the box using a scissor.
2. Cover the $12\text{ cm} \times 8\text{ cm}$ hole with white paper by using a sellotape.
3. Cut out about 4 cm in diameter on the opposite side of a the box by using a scissor.
4. Cover the hole with aluminium foil using a sellotape.
5. Using a pin, puncture a small hole at the centre of aluminium foil. The small hole is a pinhole and a box is a pinhole camera.

Magnification, *M* of pinhole camera

The magnification of a pinhole camera is a ratio of the height of image to the height of object and is given by the following expression:

$$Magnification\ (M) = \frac{Height\ of\ image\ (H_o)}{Height\ of\ object\ (H_i)} = \frac{Distance\ of\ image\ (D_i)}{Distance\ of\ object\ (D_o)}$$

$$M = \frac{H_i}{H_o} = \frac{D_i}{D_o}.$$

Exercise 10.1

Answer all questions

1. Calculate the distance from the pinhole to an object that is 3.5 cm high and whose image is 2 cm high in a pinhole camera 20 cm long.
2. A candle flame of height 2.5 cm is placed 10 cm in front of a pinhole camera in a dark room. If the distance between the pinhole and the camera plate is 14 cm, find the height of the image formed on the camera plate.
3. Is the image obtained in a pinhole camera erect or inverted? Give reasons for your answer.
4. Briefly explain how images are formed in a pinhole camera? How is the image size in a pinhole camera affected by increasing:
   (i) the object distance; and
   (ii) the diameter of pinhole.
5. Calculate the height of a building 300 m away from a pinhole camera that produces an image 3.0 cm high if the pinhole camera is 5.0 cm long. Also, determine its magnification.
6. A 1.5 cm inverted image is produced on the screen of a pinhole camera when a picture is taken from an 80 m tall tree. What is the magnification?

7. A pinhole camera, 25 cm long, is used to photograph a building 10 m high, located 30 m from the camera. Calculate the height of the image on the film.
8. A pinhole camera 20.0 cm long is used to photograph a student 175 cm high. If the image is 10.0 cm high, how far from the camera is the student? Determine the magnification.
9. A large pinhole camera has a magnification of 0.05 for a tree located 5.0 m from the camera. What is the size of the image on the screen?

Reflection of light

We see non-luminous objects because of the light they reflect. As you know, the light originates from some luminous object such as the Sun, an electric lamp or other luminous sources. When light rays fall on the surfaced of an object, it is absorbed, transmitted or reflected. Sometimes, however, a combination of the above processes may occur. When light strikes on a surface, the way it is reflected depends on the nature of the surface.

Reflection of light is the phenomenon of thrown back of the light rays when strikes the highly polished surface like a mirror.

While one cannot normally see behind oneself, by the use of a mirror one can see an object which is approaching from behind. This is possible because the light from the object, on falling on the mirror is thrown back to an observer's eyes. Therefore, this thrown back of light from the mirror is called reflection.It is possible to see an object because it either emits or reflects light. As already discussed, most objects reflect light from other objects. For instance, the walls in a room do not emit their own light but reflect from a source such as sunlight or an electric bulb. Polished surfaces reflect light. The best practical evidence that surfaces reflect light is the mirror. Now you can define reflection as the bouncing back of light rays when they encounter an obstacle.

Light rays that are neither transmitted nor absorbed but bounce back when light encounters an obstacle are called reflected light rays. The light rays that strike the surface are known as incident rays.

When using a plane mirror, a reflected ray bounces off the mirror. A plane mirror is a thin glass surface whose one side (the bottom/back) is silvered so as to obtain a shiny surface on the other side.

Figure 10.23 shows the reflection of light rays from a plane mirror. A polished metal surface can also reflect light rays like plane mirror.

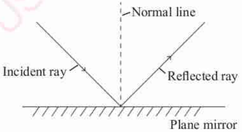


Figure 10.23: *Reflection of light on a plane mirror*

Task 10.5

By using a ray box and plane mirror, demonstrate how reflection of light takes place. Explain your observations and write down the meaning of the term reflection.

Regular and irregular reflection

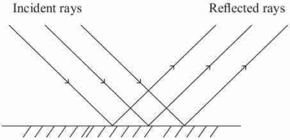
There are two types of reflection namely:

(a) regular or specular reflection; and (b) irregular or diffuse reflection.

Regular or specular reflection

In regular reflection, the reflecting surface is so smooth such that an image of the object that reflects the light is very clear. In a regular reflection, all the reflected rays are in one direction. The rays are also parallel to each other, as shown in Figure 10.24 (a). Examples of such surfaces are mirrors and polished metal surface like high reflecting aluminium sheet.

When viewing the image of an object in a plane mirror, rays of light originates from the object and travels parallel along a straight line to the mirror. The same rays reaches the eye after reflection, appering as if they are originating from the image, the results is a very sharp image, as seen in Figure 10.24 (b)



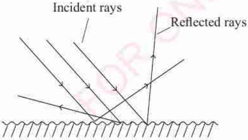
(a)

(b)

Figure 10.24: *Regular reflection results in sharp images*

Irregular or diffuse reflection

Irregular reflection is the type of reflection in which light rays meet a rough reflecting surface such that the incident light rays are reflected in different directions as shown in Figure 10.25 (a). In irregular reflection, the reflected rays are not parallel and either no image is formed or a distorted image is formed, as displayed in Figure 10.25(b).



(a)

(b)

Figure 10.25: *Diffuse reflection*

Figures 10.24 (a) and 10.25 (a) show the difference between regular reflection in a plane mirror and diffuse reflection on a wall, respectively. Since the surface of the wall is rough, the reflected rays become more and more distorted until there is no image at all. Diffuse reflection sometimes results in blurred images.

Regular reflection of light differs from irregular (diffuse) reflection in the following ways: in regular reflection, all light that falls on the reflecting surface are reflected in a definite direction while in irregular reflection, all the light that falls on the reflecting surface is not reflected in a definite direction. Regular reflection occurs on a smooth highly polished surface while irregular reflection occurs on a rough and uneven surface.

Activity 10.5

Aim: To demonstrate diffuse reflection and scattering.

Material: Torch, rough wall, and dusty rag

Procedure

1. Darken the room and shine a flashlight on one wall. Notice that the beam of light cannot be seen as it travels through clean air but one can see where it strikes the wall, as shown in Figure 10.26.

Figure. 10.26: *Diffuse reflection*

2. Shake a dusty rag in the air between the flashlight and the wall.
3. Record your observation.

Questions

(a) What is the type of reflection that occurs at the wall?
(b) Can you see the beam of light? Explain your observation.
(c) Do you observe any change in the light when it is reflected from the wall?

Figure 10.27: *Beam of light*

The light reflected from the walls forms diffuse reflection. This is because the wall is not smooth and shiny. A rough wall reflects light rays in all directions forming no image, thus, demonstrating the concept of diffuse reflection. In industry it is possible to see the beam of light as seen in Figure 10.27. The tiny dust particles enhance this by reflecting light into the eyes.

Light from the sun is composed of many different colours and this mixture gives sunlight its whitish colour. When sunlight enters the earth's atmosphere, it gets scattered by molecules of gases present in the atmosphere. This causes the blue light to be separated and scattered in all directions. Thus, when you look up on a clear sunny day the light that enters our eyes is blue and this explain why we see the sky looks blue as shown in Figure 10.28.

Figure 10.28: *A blue sky caused by the selective scattering of sunlight*

The sky in the moon is dark as shown in Figure 10.29 because there is no atmosphere to cause scattering of light.

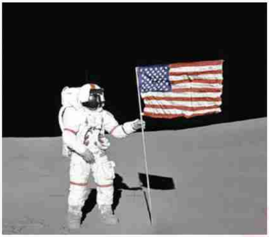


Figure 10.29: *A dark sky as seen from the moon*

Task 10.6

The following task should be carried out in groups of four students. List down as many surfaces around your school compound as you can. These would include surfaces of furniture, window panes, footpaths and so on. Classify them into surfaces that absorb light and those that reflect light. For those that reflect light, state whether the reflection is regular or diffuse.

Laws of reflection

Consider the Figure 10.30;

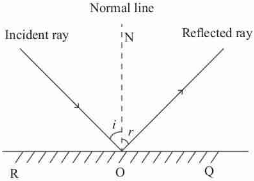


Figure 10.30: *Reflection from the plane mirror*

From Figure 10.30, ON is a line perpendicular to the surface of the mirror. It is called the normal line. Point O is the point of incidence. The angle between the incident ray and the normal is known as the angle of incidence (i), while the angle of reflection (r) is between the normal and the reflected ray. The laws that govern the reflection phenomenon are called laws of reflection.

1. First law of reflection of light states that 'The incident ray, the reflected ray and the normal ray, lie on the same plane'
2. The second law of reflection of light states that 'The angle of incidence (i) is equal to the angle of reflection (r) that is, $i = r$, as shown in Figure 10.31.

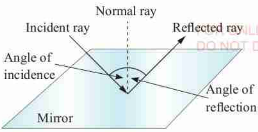


Figure 10.31: *Laws of reflection of light*

Activity 10.6

Aim: To investigate the laws of reflection.

Materials: Pins, soft board, plain paper, optical pins, mirror

Procedure

1. Pin the plane paper on a soft board and draw a horizontal line across it
2. Align a mirror vertically on the line.
3. Place an optical pin in front of the mirror so that you can see its image in the mirror.
4. Line up the pin and its image and place a second pin in front of the mirror along the line of sight, as shown in Figure 10.32.

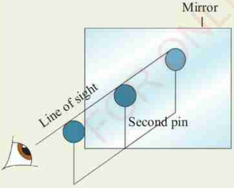


Figure 10.32

5. Look at the image in the mirror from another direction and place two pins along your line of sight, as shown in Figure 10.33.

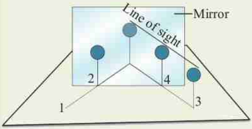


Figure 10.33

6. Remove the mirror and use a ruler, draw a line through the positions of pins 1 and 2. This represents the incident ray.
7. Draw a line through the positions of pins 3 and 4. This represents the reflected ray.
8. Extend the lines until they intersect. The point of intersection is where the image appear, as shown in Figure 10.34.

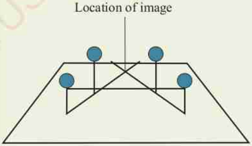


Figure 10.34

9. Measure the shortest distance from pin 1 to the mirror line. Also, measure the shortest distance from the location of the image to the mirror line.

10. Draw a line through the midpoint of the mirror line and the point representing the location of the image. This line will be perpendicular to the mirror line and it is therefore the normal, as shown in Figure 10.35.

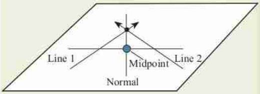


Figure 10.35

11. Using a protractor, measure the angle of incidence and the angle of reflection.

Questions

(a) Does the image in step 3 appear to be the same size as the object?
(b) Discuss your results in step 9.
(c) Compare the two angles formed by the rays and discuss your results.
(d) Comment on the position of the incident ray, the reflected ray and the normal.

The image pin formed in the mirror has the same size as the object pin. The shape of the image is also the same as the shape of the object. This indicates that the shape and size of the object and the image are the same. The object distance and the image distance from the mirror line are equal. It is also observed from the above activity that the angle of incidence equals the angle of reflection. The incident ray, reflected ray, and normal line were observed to lie on the same plane of the paper.

Activity 10.7

Aim: To verify the laws of reflection.

Material: Soft board, optical pins, thumb pins, protractor, ruler, plain paper, and plane mirror

Procedure

1. Pin a plane paper on a soft board using thumb pins.
2. Draw a mirror line MM1 across the paper and align the plane mirror vertically on it.
3. Stick a pin O into the paper so as to serve as an object, 8 cm from MM1.
4. Stick two pins, P1 and P2, so that they are in line with the image of O, as seen in the mirror.
5. Remove the pins and mark their positions.
6. Repeat steps 3, 4, and 5 on the opposite side of O.
7. Remove the mirror. Join the points where you had stuck the pins P1 and P2, and extend the line to join MM1 and beyond until they intersect behind the mirror.
8. Construct the normal line, and other lines are shown in Figure 10.35.
9. Measure i and r using a protractor.
10. Repeat for $i = 30°, 45°, 50°, 55°$.
11. Repeat steps 4-9 for different angles of sight to yield different values of i and r.

11. Record your results using a table shown in Table 10.1.

Table 10.1 Various angles of incidence and their angle of reflection.

Angle of incidence (i)	Angle of reflection (r)
30°	
45°	
50°	
55°	

Questions

(a) Compare the values of i and r for the various sighting positions

(b) What is your conclusion?

Image formed in a plane mirror

What we see in a mirror is not the object it self but an image of the object produced by the rays of light that are reflected from the mirror. Each reflected ray obeys the laws of reflection. The image is formed in our eyes but appears to be behind the mirror where no light can reach. The position of the image can be determined by drawing several reflected rays and extending them behind the mirror until they intersect as shown in Figure 10.36. In other words, the image appears to be where all of the reflected rays are coming from. Such an image is said to have been obtained through ray diagrams. Both incident rays, reflected ray, and normal lie in the same plane as shown in Figure 10.36.

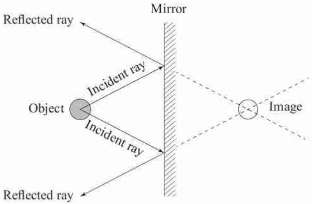


Figure 10.36: *Image formation in a plane mirror*

Characteristics of images formed in a plane mirror

A plane mirror is a simple glass with a flat surface. The only difference from other types of glass is that its back has been silvered. The image formed by a plane mirror has a number of characteristics. These include the following:

1. The image formed is virtual (not real).

   When an object is placed in front of the plane mirror, its image will appear to be in a position behind the mirror. This image is said to be virtual and not real, since it is in a location where the light does not actually reach, even though it appears like it does. It only appears to the observers although the light is coming from this point.

2. The image is upright.

   If you stand in front of a plane mirror, the image does not show you on your head and neither does the roof become the floor. This is because plane mirrors form upright images, not inverted images.

3. The image is the same size as the object.

   The image of an object placed in front of a plane mirror is the same size as the object. The ratio of the image size to the object size is the magnification. Plane mirrors produce images which have a magnification of 1.

4. The image is the same distance behind the mirror as the object is in front of the mirror.

   If you stand a distance of three metres from the plane mirror you must focus at a location three metres behind the mirror in order to view your image.

5. The image has a left-right reversal.

   If you view your image in a plane mirror, you will notice that it appears to be laterally inverted. This means that when, for example, you raise your left hand, the image appears to indicate a raised right hand. If you are wearing a shirt with lettering, for example WAY, it would appear as YAW. Note that both the order and orientation of the letters are reversed. They are laterally inverted. The alphabets that will have the image appear the same as the alphabet when kept in front of a plane mirror are A, H, I, M, O, T, U, V, W, X, Y. These letters are vertically symmetric. That means if we cut the letters in half, both the halves will look similar. There won't be any change even if the letter is interchanged sidewise.

   Lateral inversion is the phenomenon in which the image of the object turns through 180° about the vertical axis, such that right side of object appears as left side of object and vice versa.

   For example, a card printed with words **REAL**, when viewed through the mirror the word would appear as **⅃AƎЯ**.

Task 10.7

The following tasks should be done in pairs.

i. On an index card or sheet of paper, write the word 'SCHOOL'. Look at the word reflected in a mirror.

   What is the size of the image compared to the object?

   What do you observe about the position of the letters?

ii. Raise your right hand while you are standing in front of the mirror.

   Which hand did your image appear to raise?

   If a person was facing you, which hand would she raise to look like your image in the mirror? Present your findings to the class members.

Task 10.8

Figure 10.37 demonstrates an interesting fact about mirrors. A woman standing in front of a plane mirror sees her full image. The diagram shows rays from the top of her head and her feet reflected to her eyes.

I. Use a ruler to measure the height of the woman (distance between A and B); then measure the distance between points C and D.

II. Compare and discuss your measurement.

III. Measure the distance between EF and FG.

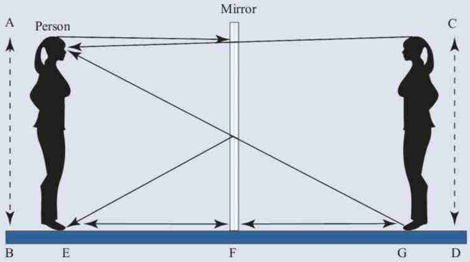


Figure 10.37

IV. Compare EF and EG. Do you think it matters how far from the mirror the woman stands?

$$Magnification\left(M\right)=\frac{Image\ distance\ from\ mirror}{Object\ distance\ from\ the\ mirror}=\frac{Image\ size}{Object\ size}.$$

Therefore, an image formed in a plane mirror is always the same size as the object, same distance behind the mirror as the object is in front of the mirror, erect (upright), virtual and laterally inverted.

Rotating a mirror

What happens to the reflected ray if the mirror is rotated through an angle? We have learnt that a ray of light reflected on a plane mirror has equal angles of incidence and reflection. Suppose the plane mirror was rotated through a given angle, what would happen to the angle of reflection?

Activity 10.8

Aim: To investigate the reflection of a ray of light by rotating a mirror.

Material: Ray box, plane mirror, soft board, protractor, plain paper, and pins

Procedure

1. Fix a sheet of paper on the soft board and draw it as a line L_1 L_2.

2. Place a plane mirror vertically with one of its sides along the mirror line $L_1 L_2$ so that it is perpendicular to the soft board.
3. Introduce a ray of light to strike the mirror at a given angle, say 30°.
4. Mark the paths of the incident ray and the reflected ray.
5. Without moving the ray box, rotate the mirror slightly through an acute angle, and mark the new line of the mirror as $L_3 L_4$.
6. Mark the path of the incident ray as $L_3 L_2$ and that of the reflected ray as $L_3 L_1$.
7. Measure and record the size of the angles of incidence and reflecion.

Questions

(a) Through what angle did you rotate the mirror?

(b) Through what angle did the reflected ray move?

The reflected ray moves through an angle twice the angle of rotation. If the mirror was rotated through an angle of $X°$, then the reflected ray would be rotated through an angle of $2X°$.

Multiple mirrors

Occasionally, there are systems which consist of two or more mirrors and produce several images of the same object. One such system is called a right-angle mirror.

Right-angle mirrors

Right-angle mirrors refer to two mirrors that are 'joined' at their edges at an angle of 90°. Suppose we take two mirrors and set them at right angles to each other. You will see a typical image in mirror 1 and another image in mirror 2 as shown in Figure 10.38.

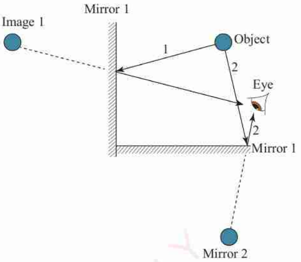


Figure 10.38: *Image formed in right-angle mirrors*

Note that the two plane mirrors each produce a left-right reversal of the images, i.e., 1 and 2. These two images are sometimes referred to as primary images.

Right-angle mirrors produce three images. Figure 10.39 shows the three images of a right-angle mirror system. If you look carefully, you see that a third image is formed by the rays that first reflect off mirror 1 and then off mirror 2 to your eyes. This third image is identical to the other two except that, it results from two reflections thus, it does not show right-left reversal. Image 3 is usually referred to as the secondary image. Secondary images are used to develop the locations of the three images using ray diagrams.

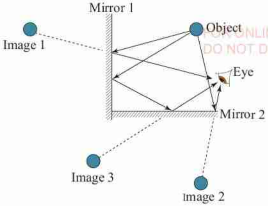


Figure 10.39: *Multiple images in right-angle mirrors*

Images in parallel mirrors

Suppose we set two mirrors parallel to each other and place an object between them. There will be a primary image formed in each mirror. In Figure 10.40, the mirrors are 2 m apart and the object is halfway between them. Remember that when mirrors are at 0° to each other the image distance equals the object distance, as shown in Figure 10.40.

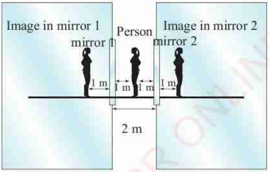


Figure 10.40: *Primary images in parallel mirrors*

Image 1 can be considered an object for mirror 2. It is 3 m from mirror 2 so its image will be 3 m behind mirror 2. This is a secondary image as shown in Figure 10.41 (a).

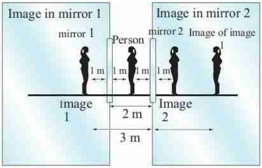


Figure 10.41 (a) *Secondary image in parallel mirrors*

In a similar fashion, there will be a secondary image of image 2 formed in mirror 1, as shown in Figure 10.41 (b).

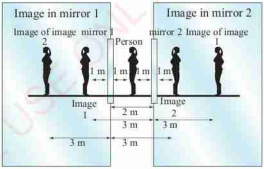


Figure 10.41 (b): *Secondary image in parallel mirrors*

These secondary images now act as objects and a third pair of images are formed and so on. The result is an infinite number of images in each mirror. The infinite images are not seen clearly when the mirrors are facing each other due to the following reasons.

(i) Due to successive reflections the images become very faint and are hardly visible.

(ii) The eyes cannot resolve very far off images as the angle subtended by them on the eye is very small.

Exercise 10.2

1. (a) What do you understand by the following terms
   (i) Light
   (ii) Diffused light

   (b) Giving one example and one use, explain
   (i) Regular reflection
   (ii) Irregular reflection

2. By drawing a neat diagram, explain the following:
   (i) Mirror
   (ii) Incident ray
   (iii) Reflected ray
   (iv) Angle of incidence
   (v) Angle of reflection
   (vi) Normal

3. A ray of light strikes a plane mirror, such that angle with the mirror is 20°. What is the value of angle of reflection? What is the angle between incident ray and reflected ray?

4. The Figure 10.42, the model, which shows how do we see object. Copy and complete the diagram by indicating the arrows showing the path of light.

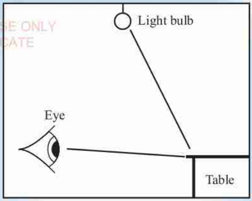


Figure 10.42

5. A girl in Figure 10.43, stands 80 cm away from plane mirror. If the girl moves 20 cm towards the mirror, what is the distance between the girl and his image? Give a reason for your answer.

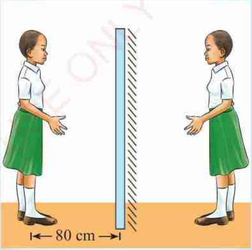


Figure 10.43

6. An object is placed 2 cm from a plane mirror. If the object is moved by 1 cm toward the mirror, what will be the new distance between object and image?

Activity 10.9

Aim: To determine the number of images formed by multiple mirrors.

Materials: Two plane mirrors, 1 optical pin, 4 drawing pins, an optical board, protractor, ruler, and plain paper

Procedure

1. Using drawing pins, fix a plane paper on an optical board.
2. Draw two lines which are at 90° to each other on a plain paper.
3. Place the two mirrors along the lines
4. Stick a pin in front of the mirrors as shown in Figure 10.44.

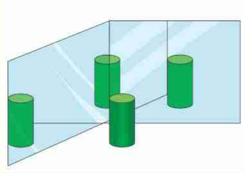


Figure 10.44: *Plane mirrors placed at right angle*

5. Observe and count the number of images formed.
6. Decrease the angle by closing the mirrors gradually onto each other such that the angle between them is 60°, 45°, 30°, and 0°. Note that at 0° mirrors are parallel to each other.
7. Record your results using a table as shown in Table 10.2.

Table 10.2 Number of images for various angles between the mirrors

Angle between the mirrors	Number of images
90°	
60°	
45°	
30°	
0°	

Questions

(a) What happens to the number of images when the angle is reduced?

(b) Account for the number of images formed in the mirror.

The number of images will increase as the angle between the mirrors becomes smaller. When the angle is 0°, the mirrors are parallel to each other and the number of images (n) is infinite. The number of images formed in multiple mirrors relates with the angle θ between two mirrors, as follows:

$$n = \frac{360^o}{\theta} - 1,$$

When $\theta = 90°$,

$$n = \frac{360^o}{90^o} - 1, n = 3$$

From the explanation above we can see that as the angle between the mirrors decreases, the number of images that can be seen increases. In fact, as the angle between the mirrors approaches zero degrees, the number of images approaches infinity. That is, there is a very large number of faint images. Parallel mirrors are commonly used in saloons and barbershops.

Differences between an image and a shadow

The image and shadow sometimes bring confusion. The following differences can help you to distinguish between image and shadow. The differences between the two. Image is formed by the intersection of rays while a shadow is formed when the light cannot reach behind the object. Image is seen when reflected rays enter the observer's eyes while no light enters the observer's eye to see the shadow. Image gives more information such as colour, structure, while shadow does not provide such information. Image can be straight or inverted while shadow can never be inverted.

Plane mirrors are used:
- (i) as looking glasses;
- (ii) for making periscope;
- (iii) in solar cookers; and
- (iv) for signaling purposes.

Applications of reflection of light

There are many applications of reflection of light either in the mirrors or on any other shiny surface. Many instruments such as periscope are formed using the knowledge and skills learnt in the reflection of light.

Simple periscope

A periscope is an instrument used to see over an obstacle from a concealed position. A periscope consists of a tube fitted with mirrors at each end. The mirrors are parallel and tilted at an angle of 45°. Light enters the upper end of the periscope, reflects off the first mirror, travels down the tube and then reflects off the second mirror to the observer's eye as in Figure 10.45.

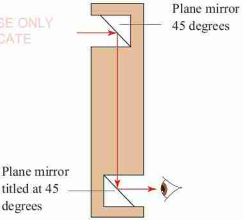


Figure 10.45: *Structure of a periscope*

Uses of the periscope

Periscopes are used in many aspects of everyday life, including the following:

1. When submarines are submerged at a shallow depth, periscopes are used to look for targets or threats in the surrounding sea and air;
2. Periscopes form part of modern telescopes as shown in Figure 10.46. Telescopes are instruments containing lenses that are used to make far away objects appear larger and nearer. Telescopes are often used for observing stars.

Figure 10.46: *A modern telescope*

3. It can be used by the soldiers in trench warfare.

Disadvantages of periscope

1. The final image is not brightly illuminated as some amount of light energy is absorbed by two successive reflections.
2. Any deposition of dust or moisture on mirrors reduces regular reflection almost to nil; hence, it stops working.

Project

Construct a simple periscope using the following steps.

1. Cut off the top of a carton of milk. About 2 cm from the top, cut out a rectangular hole. Cut out another hole on the opposite side about 2 cm from the bottom as in Figure 10.47.

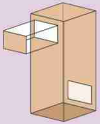


Figure 10.47

2. Lay the box on its side and measure the width of the top. Measure the same distance down the side and place a mark. Draw a line from the mark to the opposite corner of the top. Repeat at the bottom of the box.

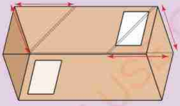


Figure 10.48

3. Cut slits along each line just long enough to fit the length of your two mirrors. Insert a mirror into each slit and fix it in place using sellotape, as shown in Figure 10.49.

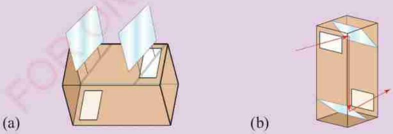


Figure 10.49

4. Use your periscope to observe objects above you and to see round corners.

Chapter summary

1. We see an object when the light from the object comes into our eyes.
2. Visible objects either emit their own light (luminous) or reflect light from other objects (non-luminous).
3. Incandescent objects emit light when they are hot.
4. Light travels in straight lines until it meets an obstacle. Light paths are represented by rays or beams.
5. Light can be transmitted through materials in different ways. A transparent material transmits most of the light which fall on it. Translucent materials transmit less light. Opaque materials transmit no light.
6. The dark area behind an obstacle is called shadow. When the light source is extended the shadow will have an umbra (total shadow) and penumbra (partial shadow).
7. Reflection is the bouncing back of light rays when they meet an obstacle in their path.
8. We see many things in our environment because they reflect light. There are two types of reflection, namely: regular reflection, diffuse reflection.
9. Regular reflection occurs on smooth polished surfaces. The reflected rays are parallel and they form a sharp image of an object.
10. Diffuse reflection occurs from rough uneven surfaces. The reflected rays are not parallel and they form distorted image or no image of an object.
11. Scattering occurs when light is reflected from small objects such as dust particles or molecules. Selective scattering of sunlight by the atmosphere causes us to see the blue sky and red sunrise and sunset.
12. If a mirror is rotated through an angle, the reflected ray is rotated through an angle twice as large.
13. If two mirrors are set perpendicular to each other they produce three images, with the image formed by two reflections not having right-left inversion. As the angle between the mirrors decreases, the number of images increases proportionally.
14. The number of images (n) formed between mirrors placed at $\theta°$, is given by the formula: $n = \frac{360^{\circ}}{\theta^{\circ}} - 1$.
15. Reflection of light is applicable in the manufacture of periscopes and telescopes. A periscope has its mirrors parallel to each other and tilted at 45°.

Revision exercise 10

Section A

Choose the most correct answer.

1. Light causes the
   (a) sensation of heat.
   (b) sensation of sound.
   (c) sensation of sight.
   (d) sensation of touch.
2. Objects which emit light on their own are called
   (a) non-luminous objects.
   (b) transparent objects.
   (c) translucent objects.
   (d) luminous objects.
3. Shadow is formed when light falls on
   (a) a transparent object.
   (b) a luminous object.
   (c) an opaque object.
   (d) a translucent object.
4. Angle of incidence is equal to the angle of reflection:
   (a) always.
   (b) sometimes.
   (c) under special conditions.
   (d) never.
5. Image formed by a plane mirror is:
   (a) virtual, behind the mirror and enlarged.
   (b) virtual, behind the mirror and of the same size as the object.
   (c) real at the surface of the mirror and enlarged.
   (d) real, behind the mirror and of the same size as the object.

6. Match each item from **Column A** with its corresponding item in **Column B**.

Column A	Column B
1. Bulb	A. Flat surface
2. Light	B. Luminous
3. Plane mirror	C. Translucent
4. Umbra	D. Periscope
5. Semi-transparent	E. Partial shadow
6. Right-angled mirror	F. Non-luminous
7. Diffuse	G. $3\times10^8 m/s$
8. Used in submarine	H. Full shadow
9. Eyes see image due to	I. Reflection of light
	J. Dark room
	K. Glow
	L. Incident
	M. Inverted images
	N. Images are infinite
	O. Upright images
	P. Telescope
	Q. Images are three
	R. Reflected ray
	S. Scattered

7. Fill in the blanks in the following statements:
   (a) We can see objects only in the presence of ______________.
   (b) A person 1 m in front of a plane mirror seems to be ______________ m away from his image.
   (c) If you touch your ____________ ear with right hand in front of a plane mirror it will be seen in the mirror that your right ear is touched with ____________.
   (d) Rectilinear propagation of light causes the formation of____________ and ______________.

(e) Charcoal and kerosene are _________at room temperature but when they are burnt they become_____________ .

8. Statements given (from a to e) are incorrect. Write the correct statement:

(a) A dark patch behind an opaque body when the opaque body is placed in the path of light is called image.

(b) When the light rays starting from a point travel in various directions, then, the collection of such rays is called convergent beam of light.

(c) A ray of light which bounces off the surface of a mirror is called incident ray.

(d) Reflecting periscope is used by a barber to show the back of head.

(e) A region of total darkness is called penumbra.

9. (a) Classify the following objects as natural or artificial source of light:
Wood fire, firefly, candle fluorescence light, stars, gas lamp, bulb, torch, charcoal.

(b) Differentiate between the following:

(i) Luminous and non-luminous objects.

(ii) Transparent and opaque objects.

(iii) Umbra and penumbra.

(iv) Image and shadow.

10. (a) Differentiate between regular and diffused reflection. Does diffused reflection mean the failure of the laws of reflection?

(b) Which of the following will produce regular or diffuse reflection when a beam of light strikes? Justify your answer in each case.

(i) Polished wooden table.

(ii) Chalk powder.

(iii) Cardboard surface.

(iv) Marble floor with water spread over it.

(v) Mirror.

(vi) Piece of paper.

11. (a) What is meant by the term image? Distinguish between real and virtual image.

(b) Give at least five (5) characteristics of the image formed by plane mirror.

(c) The distance and height of an object placed in front of a plane mirror are given in column A and B respectively. In column C and D the distance and heights of the images are given but not in same order. Correct the order.

Distance of object (A) (in cm)	**Height of object (B) (in cm)**	**Distance of image (C) (in cm)**	**Height of image (D) (in cm)**
10	5	10	10
5	10	5	8
6	8	6	5

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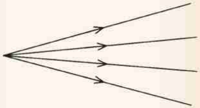
12. (a) What is meant by the term laterally inversion?
    (b) Find out the letters of English alphabet or any other languages that you know in which the image formed in a plane mirror appears exactly like the letter itself. Discuss your findings.
    (c) Write down the appearance of the word HEAT when viewed in a plane mirror. Explain why some letters appears differently?

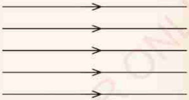
13. (a) Give the meaning of the following rays of light:
    (i) Parallel rays.
    (ii) Convergent rays.
    (iii) Divergent rays.

14. Name the rays drawn in Figure 10.50.

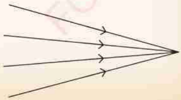
(a)



(b)



(c)



(d)

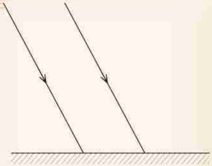


Figure 10.50

15. (a) State the laws of reflection of light.
    (b) Define the parameters labeled by the letters A, B, C, D, E and F, in the Figure 10.51.

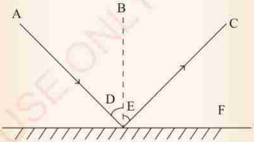


Figure 10.51

16. What is the difference between light from a fire and a firefly?
17. If you heat an iron rod it will begin to glow. What types of material does this represent?
18. Sekela, 148 cm tall stood at a distance of 2 m away from a plane mirror.
    (a) What is the distance between Sekela and her image?

(b) What is the height of Sekela's image?

(c) What will be the distance between Sekela and her image when she walks a distance of 1 m towards the mirror?

(d) How far Sekela has to walk to be only 1 m from her image?

19. (a) How many images will be formed if a candle is placed between two parallel plane mirrors separated by 40 cm?

(b) Using the letters given in the following box, make meaningful words related to the reflection of light by choosing the horizontal and vertical sequencing.

N	E	P	R	E	C	T
O	P	X	V	R	T	U
R	L	V	I	R	T	U
M	A	L	R	E	A	L
A	N	I	T	C	A	R
L	E	O	U	T	A	E
A	I	M	A	G	E	J
N	K	N	L	E	N	C

(c) When two mirrors meet at right angles, and a ray of light is incident on one mirror at an angle of 30°, as shown in Figure 10.52, draw the reflected ray from the second mirror.

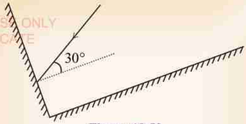


Figure 10.52

(d) If letter E is held in front of a plane mirror, how will its image look like?

(e) Is the image in (d) inverted or upright?

(f) State two differences between a real image and a virtual image.

20. Rays of light are incident on a mirror that is inclined at an angle of 30° as shown in Figure 10.51. What will be the angle of reflection?

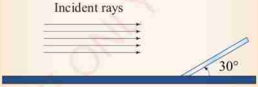


Figure 10.52

21. Two different incident rays a reflected off a mirror. The angle of incidence for ray 1 is 60° and 25° for ray 2, as shown in Figure 10.53. What is the angle between the two reflected rays?

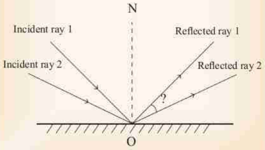


Figure 10.53

22. (a) Copy the diagram in Figure 10.54 and use the technique of multiple mirrors to locate all the images.

Figure 10.54

(b) Using your results in Question 22 (a), complete the following statement: As the angle between two mirrors decreases the number of images formed _______.

23. Figure 10.55 shows a person standing between two parallel mirrors. She is 1 m from mirror 1 and 2 m from mirror 2. How far behind mirror 2 is the third image in that mirror formed?

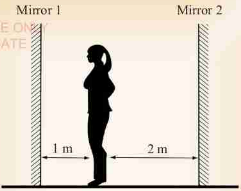


Figure 10.55

24. If we hold a burning candle on the other side of the following objects, state whether you would be able to see the flame clearly, hazy or not be able to see the flame at all.
    (a) Cardboard.
    (b) Stone.
    (c) Polythene sheet.
    (d) Cellophane paper.
    (e) Paraffin wax.
    (f) Glass.
    (g) Ground glass.

Glossary

Acceleration due to gravity	acceleration produced as a result of the attraction of the earth on an object
Accurate measurement	One that yields a result that is very close to the actual value
Action-at-a-distance force	force existing between two interacting objects which are not in physical contact with each other yet they to exert a push or pull upon each other. Examples are force of gravity, electrical, and magnetic forces
Actual weight	the weight of a body in the air
Adhesion	action of attraction between molecules of different substances to
Adhesive force	force of attraction that exists between molecules of different substances
Ammeter	a device for measuring electric current in a circuit. Electric current is measured in ampere
Aneroid barometer	an instrument for measuring pressure. It is an advanced Fortin barometer and contains no fluid
Apparatus	tools or equipment that are required in order to perform a particular activity or task effectively in the laboratory
Apparent loss in weight	the difference in weight when a body is totally or partially submerged in a fluid and the actual weight of an object in air
Apparent weight	the weight of a body in a fluid
Applied force	the push or pull exerted on an object, such as that exerted on a box when being pulled. It acts on a body
Archimedes' principle	describes the relationship between upthrust acting on a body and the weight of liquid it displaces
Astronomy	the scientific study of the moon, sun, stars, and the planets. It involves studying their sizes, motion, etc
Atmospheric pressure	the force or weight per unit area applied on all objects on the earth's surface due to the mass of the surrounding air. It is measured using barometers
Atom	the smallest unit of matter that forms a chemical element. Every solid, liquid and gas is composed of atom
Battery	two or more of electric cells connected together to produce current through the circuit
Beam of light	a collection of rays of light, for example from a torch or flashlight.

Bicycle pump	a type of force pump that consists of a hollow metal cylinder and a movable piston. It is specially designed for inflating bicycle tyres
Biology	the study of living organisms. It is divided into several specilised fields such as botany, zoology, and microbiology
Brownian motion	the random movement of tiny particles suspended in a liquid or gas that occurs as a result of collisions with molecules of the surrounding fluid
Buoyancy	the ability of an object to float in a fluid
Buoyant force	the upward force that causes immersed objects to float or rise to the surface of a liquid. It makes the object seem lighter
Burette	a glass tube with markings for measurement on the side and a tap at the bottom used for releasing an accurate amount of liquid. It is usually used in the laboratory
Chemical energy	energy obtained from food through chemical processes
Chemistry	is the scientific study of the properties and behaviour of matter. Chemistry and physics are both physical sciences and both study sciences and both study the structure and properties of matter
Cohesion	the action of molecules of a substance to attract each other, for example water molecules
Cohesive forces	molecular force that is exerted between molecules of the same kind
Compressional forces	forces applied to an object and results in a decrease in the size or volume of the object
Contact force	force which exists when two interacting objects are physically touching each other. Examples of contact forces are friction, tension and elastic forces
Density	the mass of an object per unit volume
Derived quantities	obtained by either multiplying or dividing two or more fundamental quantities. Examples are volume and speed
Digital balance	a very sensitive weighing balance, measuring masses to an accuracy of 0.001 g or better
Derived unit	obtained by combining two or more of the fundamental units. Examples are Newtons and Pascal

Diffuse reflection	a type of reflection that occurs on surfaces that are rough and uneven such as a wall. No image is formed or if formed it is normally distorted
Diffusion	the movement of particles from a region of high concentration to low concentration
Elastic energy	energy stored in objects like springs as a result of reversible deformation
Energy	the ability to do work
Evidence	information in the form of facts, figures or objects obtained from experiments used as a basis of drawing conclusions.
Elasticity	the ability of a deformed body to return to its original shape and size when the forces causing the deformation are withdrawn
Elastic limit	the maximum point of deformation that a body can undergo reversible deformation
Floating	the tendency of an object to be suspended in or remain on the surface of a fluid due to the forces exerted by the fluid
Force	a push or a pull that is experienced by an object
Fluid	a substance such as a liquid or a gas whose molecules flow freely, so that it has no fixed shape
Force of gravity	the pull by which the earth, moon and other very large bodies attract other objects towards them
Force pump	a pump that uses pressure to draw water to another surface
Free-fall	a motion of objects falling to the ground without air resistance due to the earth's gravitational pull
Frictional force	a force, normally resistive, arises from two objects in contact moving relative to one another
Fundamental force	the basic force in nature which cannot be explained by the action of another force
Hydrometer	an instrument used for determining the relative density of liquids. It consist of glass bulb and a cylindrical stem
Incident ray	a ray of light that strikes the surface an object, for example the shiny surface of a mirror.
Inclined plane	a smooth flat rigid surface slanted at an angle to the horizontal. It is an example of a simple machine

Insoluble granules	particles which do not dissolve in liquid
Instrumental error	an error that arises as a result of a defect or mishandling of an instrument. The defect could be from the manufacturing industry
Kinetic theory	theory which describes the physical properties of matter in terms of the behaviour of its component atoms and molecules
Laboratory	a special room that has been designed and equipped for carrying out scientific experiments for the purpose of study or research
Law of floatation	the relationship between a floating body and the weight of displaced fluid
Law of reflection	incident ray, reflected ray, and normal lie in the same plane and angle reflection equals angle of incidence
Least count	the difference between the main scale division and the vernier scale division of vernier caliper
Length	the distance or dimension between two points
Lift pump	a pump used to raise underground water to the surface and is mechanically operated
Light	an invisible form of energy that causes the sensation of vision to the eyes and makes seeing possible
Mass	the quantity of matter in an object. It is measured using a beam balance
Mathematics	the science of numbers and shapes. Branches of mathematics include arithmetic, algebra and trigonometry. It aids physics
Matter	any substance which has mass and occupies space
Measurement	the process of assigning numbers to observations or events.
Meteorology	the scientific study of the earth's atmosphere, especially its patterns of weather and climate
Metre rule	An instrument used for measuring length. It is calibrated in centimetres and millimetres. It spans from zero cm mark to 100 cm mark
Micrometer screw gauge	an instrument used to measure a diameter of thin object which gives more accurate readings. It measures to the nearest thousandth of a centimetre
Molecule	a chemical combination of two or more atoms. It is the smallest unit of a substance which can exist independently
Opaque material	materials that do not transit light, for example a wall

Osmosis	the movement of a solvent from a region of low concentration to high concentration through a semipermeable membrane
Parallax	apparent motion of one object relative to another when the position of the eye is varied
Parallax error	error which occurs when the observer changes position and takes measurement from a wrong position
Pascal's principle	any external pressure applied to an enclosed liquid transmitted equally throughout the liquid
Penumbra	the partial outer shadow which is usually lighter than the umbra (the darker inner shadow)
Period	the time taken by a pendulum to swing back and forth once
Ray	a line with arrow showing the direction of propagation of light
Record of result	a collection of related data or information which can be used for future reference as evidence of past experiments
Siphon	a bent tube or plastic pipe used for transferring liquid from one container to another by using atmospheric pressure to make it flow
Time	a limited period during which an event occurred, the order in which several events occurred or the rate at which an event happens as measured by a clock
Transparent material	materials which transmit light for example is glass
Triple beam balance	used to measure the mass of objects in grammes. It has three beams
Umbra	the area or region of complete shadow which is usually caused by an opaque object being in the path of light
Universe	the sum total of all matter and energy that exists in the vastness of space
Vernier calliper	an instrument used to measure small lengths more accurately than a ruler
Virtual image	an image which is not real and so cannot be formed on a screen.
Viscous force	the pull that resists the flow of a liquid
Work	work is said to be done when a force acts on a body and the body moves in the direction of force
Zero error	a condition when a measuring instrument registers a reading when there should not any reading. In case of vernier calipers it occurs when a zero on main scale does not coincide with a zero on a vernier scale.

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Answer to numeric questions

Chapter Three

Answers to exercise 3.1

2. (a) 3.74 cm
   (a) 3.46 cm
3. 6.44 cm

Answers to exercise 3.2

1. 3.88 mm
5. 0.728 cm

Answers to exercise 3.4

1. 8 cm^3
2. 2.5 cm
3. 37·68 cm^3
4. 50 cm^3
5. 23 cm^3
6. 7 cm^3

Answers to Revision exercise 3

7. (b) 1·84 cm
8. (b) 400 ml
9. (a) 2·9 cm
10. 0·35 mm
11. 10 cm^3

Chapter Four

Answer to Revision exercise 4

10. 3 kg
11. 33.3 kg
12. 1.5 kg
13. 2.5 N, 5 N

Chapter Five

Answers to exercise 5.1

2. 3 g/cm^3
3. 0.48 g/cm^3

Answer to revision exercise 5

6. (b) 10 cm^3
   (c) 30 g/cm^3
8. (b) 0·025 g/cm^3
9. 0·46 g/cm^3
12. 3·56 g/cm^3
15. 1·16 g/cm^3

Chapter Six

Answers to exercise 6.1

2. 21 600 N
3. 1.62 N
4. 60 cm^3

Answers to exercise 6.2

1. 976. 94 m^3
2. (a) 10 N
   (b) 10 N
   (c) 1 kg
   (d) 1 m^3
   (e) 4
   (f) 4000 kg/m^3
3. (a) 0.3 N
   (b) 0.86 g/cm^3
4. 1.7 N
6. 5 g/cm^3
11. 0.1 g/cm^3

Answer to revision exercise 6

13. (a) 0.3 N
    (b) 8333 kg/m^3
14. 978 m^3
15. 1.74 N
16. 0·72 g/cm^3
18. 0·5 g/cm^3
20. 152 m^3
23. (a) 51 %
    (b) 25 %
25. 89.6 %

Chapter 7

Answer to revision exercise 7

8. (a) 0.25 m
   (b) 0.07 kg
12. 24 N

Chapter 8

Exercise 8.1

1. (a) 250 N/m^2
   (b) 125 N/m^2
2. 27 375 N/m^2
3. 10 000 N/m^2
4. Maximum pressure is 105 000 N/m^2 and minimum pressure is 7 000 N/m^2.

Answers to revision exercise 8

13. (b) 0.26 cm
18. 106.3 kPa
19. (a) 2.52×10^{11} N
20. 3.265 cm, 153.125 N

Chapter 9

Exercise 9.1

1. 3 000 J
2. 600 J
3. 300 J
5. 1 800 J

Exercise 9.2

2. (a) 3.2 J
   (b) 4 000 J
3. (a) 2 000 J
   (b) 1 000 J

Exercise 9.3

1. 2 000 J
2. (a) 10 MJ
   (b) 2 MJ
3. 60 W
4. (a) 16 hp
   (b) 18 650 J
5. 1 000J or 1 kJ
   (a) 500J
   (b) 1 000J or 1 kJ

Answers to revision exercise 9

18. 2 000 J
19. (c) 9.25 hp
20. 112 500 J
21. 112 500 J, 1 012 500 J, 9
22. (a) 500 J
23. 2 250 J
25. 225 000 J
26. 2 025 000 J
27. 3 MJ
28. 4 MJ
30. 99 J
32. 600 000 J
33. 4 J

Chapter 10

Answers to exercise 10.1

1. 7 cm
2. 3.5 cm
5. 198 cm
6. 0.0000106
7. 8.3 cm
8. 350 cm

Answers to exercise 10.2

3. 70°
5. 120 cm
6. 2 cm

Answer to revision exercise 10

18. (a) 4 m
    (b) 148 cm
    (c) 2 m
    (d) 0. 5 m towards the mirror
19. (a) 1
20. 30°
21. 60° for ray 1 and 25° for ray 2
23. 1 m behind mirror 1 and 2 m behind mirror 2.

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