Physics

for Secondary Schools

Student's Book

Form Two

Tanzania Institute of Education

Physics

for Secondary Schools

Student's Book

Form Two

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Dr Lyabwene M. Mtahabwa
Commissioner for Education

Tanzania Institute of Education

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Tanzania Institute of Education
P. O. Box 35094
Dar es Salaam, Tanzania

Mobile numbers : + 255 735 041 168
+ 255 735 041 170
Email: director.general@tie.go.tz
Website: www.tie.go.tz

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Writers: Ms Auguster F. Kayombo, Mr Jonathan H. Paskali and Mr Shaban J. Baya (TIE)

Editors: Dr Yohana Msambwa (DUCE), Dr Mohamed Mazunga (UDSM), Dr Innocent J. Lugendo (UDSM), Dr Emmanuel D. Sulungu (UDOM), Dr Christian B. Uiso (MARUCO), Dr Talam E. Kibona (MUCE), Mr Elisante Maloda (DUCE) and Ms Debora J. Mahushi (MUCE).

Designer: Mr Frank P. Maridadi

Illustrators: Mr Fikiri A. Msimbe (TIE), Ms Rehema Maganga (TIE) and Alama Art and Media Production Co. Ltd.

Photographer: Mr Chrisant A. Ignas (TIE)

Coordinator: Ms Auguster F. Kayombo

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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 Two students in the United Republic of Tanzania. It is 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 nine chapters, namely Static electricity, Current electricity, Magnetism, Forces in equilibrium, Simple machines, Motion in a straight line, Newton's laws of motion, Temperature and Sustainable energy sources. Each chapter contains illustrations, activities and exercises. You 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

Static electricity

Introduction

Clothes containing nylon often crackle when they are taken off the body. Brushing a latex balloon against one's face results to the balloon trying to stick to the face. This is due to static electricity which is a result of an imbalance of electric charges within or on the surface of a material. The charge remains until an electric discharge happens, hence the name static electricity. In this chapter, you will learn the concept of static electricity, origin of charges, fundamental law of static electricity and detection of charges. You will also learn about conductors and insulators, capacitors, charge distribution along the surface of a conductor and lightning conductor. The competencies developed in this chapter will enable you to protect buildings from lightning and use electrostatic precipitators to easily remove unwanted particles from air.

Concept of static electricity

Have you ever noticed that a nylon garment produces a crackling sound as it is taken off the body? Sometimes, tiny sparks are seen when undressing in the dark. The crackling sound is caused by small electric sparks as a result of charge discharge. The charge is caused by friction between the nylon and your skin, giving rise to static electricity. Pens and combs made up of certain plastics could also attract tiny pieces of paper after being rubbed on the hair or on synthetic clothing material, as shown in Figure 1.1.

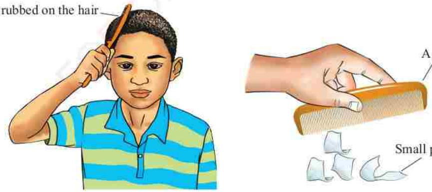


Figure 1.1: *Charged comb attracts pieces of paper*

Static electricity is the electricity resulting from the accumulation of stationary electric charges on a material that does not conduct electricity.

The effects of static electricity

The effects of static electricity are familiar to most people because you see, feel and even hear sparks as excess charge is neutralised by being brought close to a region with an excess of the opposite charge.

For example, when a dry cloth is used to clean a glass window, tiny pieces of cloth and dust adhere to the glass. When you rub feet on a carpet and then touch a metallic object, you experience a slight electrical shock. An aircraft in flight may accumulate charges on its outer surface because it rubs against the air. These effects of static electricity are pronounced under dry conditions because water conducts charges away.

All these examples and many others demonstrate static electricity. In each case, objects are electrically charged and therefore exert electrostatic force on each other. The charge acquired remains on the surface of the body, i.e. does not move, and so, it is called *electrostatic charge*. Electrostatic charges are stationary in nature. The rubbing only transfers, for example, negative charges from fur to an ebonite rod, leaving the fur with an equal amount of excess positive charge. Note that the rod initially has an equal number of positive and negative charges.

Electrostatics is the study of stationary electric charges.

Electrostatic force

The interaction between electric charges that are at rest (or nearly at rest) result to a force known as an *electrostatic force*. After charging plastic rods by rubbing them with a piece of fur, it is observed that the rods repel each other. Similarly, when glass rods are rubbed with silk, they become charged and repel each other. Furthermore, the plastic rods and the fur attract each other, and the glass rods and the silk attract each other.

A French physicist Charles Coulomb measured the force generated between two charged objects using a torsional balance. His work resulted in the development of a unit of electrical charge, named in his honour, the *coulomb*.

Activity 1.1

Aim: To demonstrate the existence of electrostatic force.

Materials: Plastic pen, plastic comb, tissue paper, human hair

Procedure

1. Tear a sheet of tissue paper into several small pieces and lay them on a table.
2. Rub a plastic pen or comb through your hair.
3. Bring the pen or comb near the pieces of paper but not touching them as shown in Figure 1.2.
4. Hold the pen or comb for 15 seconds.
5. Record your observations.

Questions

(a) What happens when the comb is brought near the pieces of paper?

(b) What happens to the pieces of paper on the comb or pen after a few seconds?

(c) Discuss your observations.

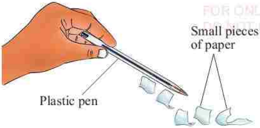


Figure 1.2: *Charged plastic pen attracts pieces of paper*

The comb picked up pieces of paper. The papers then dropped off after some time. The pen behaved in a similar manner. This shows that a plastic pen or comb rubbed with human hair acquires a charge that is able to attract other substances such as pieces of paper. After a few seconds pieces of paper fall off because they acquire similar charges as the comb or pen.

Origin of charges

When a glass rod is charged by rubbing it with fur or silk, no visible change in the appearance of the rod is observed. What happens to the rod when charging it? The answer to this question is obtained by understanding the structure of the atom, which is the building block of all matter.

All materials are made up of tiny particles of matter called *atoms*. The structure of the atom can be described in terms of the negatively charged particle (electron), the positively charged particle (proton), and the uncharged particle (neutron). The protons and neutrons in an atom make up a small, very dense core called *the nucleus.* Electrons surround the nucleus in shells. Figure 1.3 illustrates the structure of an atom.

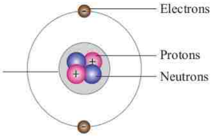


Figure 1.3: *Structure of a two-electron atom*

An atom has an equal number of electrons and protons. Such an atom is said to be electrically neutral. An atom with more protons than electrons is positively charged, whereas the atom with more electrons than protons is negatively charged. Figure 1.4 illustrates the neutral, positively charged and negatively charged atoms.

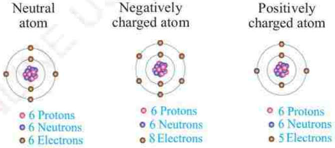


Figure 1.4: *Neutral atom, positively charged atom and negatively charged atom.*

The number of protons in the nucleus of an atom is called *the atomic number of an element.* If one or more electrons are removed from a neutral atom, what remains is called *a positive ion*. On the other hand, *a negative ion* is an atom that has gained one or more electrons. The gain or loss of electrons is called *ionisation.*

When the total number of protons in a body equals the total number of electrons, the total charge is zero, and the body is electrically neutral. To give a body an excess negative charge, you may add negative charge to a neutral body. Similarly, An excess positive charge can be created by removing negative charge. In most cases, because of their high mobility, negatively charged electrons are added or removed from an object. Thus, *a positively charged body* is one that has lost some of its electrons while *a negatively charged body* is the one that has gained excess electrons.

When speaking about the charge of a body, it always mean its net charge which is always a very small fraction of the total positive charge or negative charge in the body.

Electric charge is a property of matter that governs how matter behaves in an electric or magnetic field.

The SI unit of electric charge is the *coulomb (C).* The electron has the smallest amount of electric charge. The charge on the electron equals to -1.6×10^{-19} C. The proton has a charge of the same magnitude as that of the electron. Therefore, the charge on the proton is $+1.6 \times 10^{-19}$ C. Any other amount of charge is a multiple of 1.6×10^{-19} C.

A coulomb is a much larger quantity of charge than that normally produced by rubbing. Hence, it is more convenient to use micro-coulombs in measuring charge.

$1\ \mu C = 10^{-6}$ C

Charging objects

There are two types of charge, namely negative and positive charges. The total number of positive and negative charges within a neutral material is the same. Thus, the net charge on the material is zero. When two materials are rubbed against each other, electrons may be transferred from one material to the other. This upsets the balance between the opposite charges within each material, leaving each with a net negative or positive charge. For example, when rubbing an ebonite rod with fur, the electrons from the fur are transferred to the ebonite rod. This results to less electrons in the fur, which becomes positively charged. On the other hand, the ebonite rod gains excess electrons and hence becomes negatively charged. Similarly, when a glass rod is rubbed with silk cloth, glass loses electrons and becomes positively charged, and the silk cloth gains excess electrons to become negatively charged. Figure 1.5 shows charges on a glass rod and silk cloth before and after rubbing.

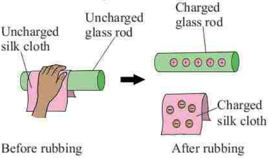


Figure 1.5: *Rubbing glass rod with silk*

Another example is when one rubs a balloon with a woollen cloth. Electrons are transferred from the woollen cloth to the balloon. This makes the balloon to have excess electrons and the woollen cloth to have less electrons. Thus, the balloon will have net negative charge while the woollen cloth will have net positive charge. Figure 1.6 shows charges on the balloon and woollen cloth before and after rubbing.

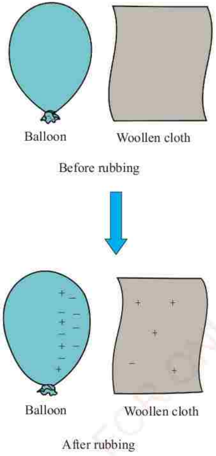


Figure 1.6: *Rubbing balloon with woollen cloth*

The summary of acquisition of charges by rubbing for some materials is given in Table 1.1

Table 1.1: *Acquisition of charges by different materials*

Material	Rubbed with	Charge acquired by the material
Ebonite	Fur/ woollen cloth	Negative
Glass	Silk	Positive
Polythene	Woollen cloth/fur	Negative
Polystyrene	Woollen cloth/fur	Negative
Perspex	Woollen cloth	Positive
Cellulose	Woollen cloth	Positive

In ancient times, experiments on static electricity involved the rubbing of a glass rod with silk to obtain a positive charge. Similarly, an ebonite rod was rubbed with fur so as to obtain a negative charge. Nowadays, scientists prefer cellulose and polythene for positive and negative charges respectively. This is because the materials are less affected by damp conditions.

Activity 1.2

Aim: To show the existence of opposite charge.

Materials: Water, plastic pen, plastic comb, human hair

Procedure

1. Take the pen or comb and rub it on your hair.
2. Bring it near a small slow stream of water coming from a tap as shown in Figure 1.7 (a).

Questions

(a) What did you observe?

(b) What types of charges were in water?

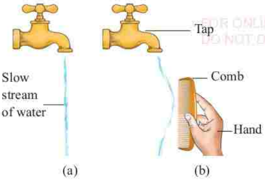


Figure 1.7: *Slow stream of water is attracted to the comb*

Electrostatic attraction between water and a charged comb causes water stream to bend as shown in Figure 1.7 (b). The water particles are attracted to the comb, causing the steady stream of water to bend. This means that the comb has charge that is opposite to that in the water.

Fundamental law of static electricity

The fundamental law of static electricity, also referred to as the first law of electrostatics, states that:

> Like charges repel, unlike charges attract.

Activity 1.3

Aim: To verify the fundamental law of static electricity.

Materials: 2 dry glass rods, 2 ebonite rods, thread, stand, silk cloth, fur (cotton cloth), stirrup wire (metal ring)

Procedure

1. Rub a dry glass rod with silk cloth and place it in a metal ring suspended by a piece of thread.
2. Bring a second charged glass rod close to the suspended one as shown in Figure 1.8.
3. Record your observations.
4. Repeat steps 1 and 2 but using ebonite rod rubbed with fur.
5. Now, repeat the activity by bringing a charged glass rod close to the suspended charged ebonite rod and the charged ebonite rod close to the suspended charged glass rod.
6. Record your observations.

Questions

(a) What did you observe?

(b) What conclusion can you make from the observation?

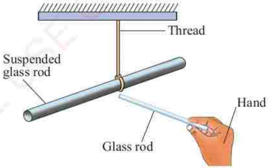


Figure 1.8: *Verification of the fundamental law of electrostatics*

If two negatively charged materials or two positively charged materials are brought near each other, they repel. However, if a positively charged object is placed near a negatively charged object, the objects attract each other.

This suggests that unlike charges exert an attractive force on each other and like charges exert a repulsive force on each other.

Activity 1.4

Aim: To show charge separation in materials.

Materials: Woollen cloth, glass rod, cotton fabric, plastic pen or comb, string, retort stand

Procedure

1. Take a pen or comb and hang it from a string tied to a retort stand.
2. Rub the comb with a piece of cotton fabric, then hang it.
3. Rub a glass rod with a piece of woollen fabric, then hang it.
4. Bring the charged glass rod near but not touching the hanging charged comb.
5. Bring the piece of woollen cloth that you used to rub the glass rod near but not touching the hanging comb.

Questions

(a) Which material will become positively or negatively charged in steps 2 and 3? (Refer to Table 1.1.)

(b) What do you observe in steps 4 and 5?

(c) Discuss your results.

The comb becomes negatively charged while the glass rod becomes positively charged. The comb and the glass rod attract each other. The woollen cloth and the comb repel each other. If objects are far apart, there is no interaction, or if any, very little.

It is worth noting that the presence of an excess charge induces a charge separation in nearby objects. Therefore, the strength of the attractive and repulsive forces decreases quite rapidly with increase in distance. This suggests that the electrostatic force weakens as the charges get far apart and grows strong as they get close to each other.

Methods of charging a body

A body consisting of an equal number of positive and negative charge is said to be electrically neutral. Such a body can become electrically charged by friction, contact and induction.

Charging by friction

This is also known as *electrification* by rubbing as illustrated by examples in page 4 and 5.

The examples show that, electrons can be exchanged between materials through friction as a result of rubbing. Materials whose electrons are weakly bound tend to lose them while those with sparsely filled outer shells tend to gain the electrons.

Charging by contact

Considering two metal plates X and Y, plate X is positively charged while plate Y is uncharged. Both plates are then placed on insulating blocks brought in contact and then separated as shown in Figure 1.9.

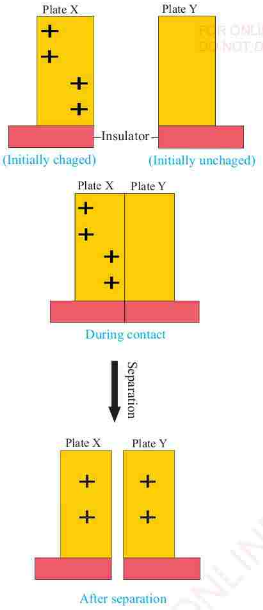


Figure 1.9: *Charging by contact*

Testing the metal plates after separation shows that, when a charged body is brought in contact with an uncharged body, the same electric charges distribute among the two bodies. As a result, the initially uncharged body acquires charges of the same sign as the charges of the initially charged body.

Charging by induction

Charging by induction is a method used to charge an object without actually touching the object with any other charged object. In order to obtain a charge of a given sign, the inducing charge must be of an opposite sign. Induction induces opposite charge to the uncharged body by bringing a charged body nearby an uncharged body. See Figure 1.10. Notice that in this example the negative charge in the body is repelled to one side. Connecting the body to the ground by a conducting wire allows the negative charge to drain to the ground. On removing the charging rod and the conducting wire, the body is left with net positive charge.

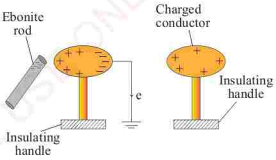


Figure 1.10: *Charging a body positively by induction*

It should be noted that, to charge a body negatively, a positively charged glass rod can be used.

Conductors and insulators

To fully understand the method of charging by induction, conductors and insulators must first be understood.

Conductors are materials that permit electrons to flow freely from one atom within the material to another. These free electrons are called *conduction* *electrons.* Conductors allow the charge transfer through the movement of free electrons. Moreover, an object made up of conducting material permits charge to be transferred across the entire surface of the object. Thus, charge transferred to a conductor is quickly distributed across the entire surface of the conductor. Metals like copper, steel, iron, silver and gold are examples of conductors.

Insulators on the other hand do not allow their electrons to flow freely from atom to atom. If a charge is transferred to an insulator at a given location, the excess charge will remain at that location. Thus, induced charge is not evenly distributed across the surface of an insulator. Rubber, glass, dry wood and plastic are examples of good insulators.

The ability of a material to conduct is measured in terms of conductivity. Thus, conductors have high conductivity while insulators have negligible conductivity. Figure 1.11 shows conducting abilities of different common materials.

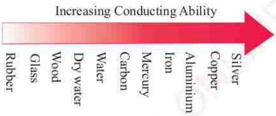


Figure 1.11: *Variation in conductivity of some insulators and conductors*

Activity 1.5

Aim: To demostrate movement of conduction electrons in a conductor by induction method.

Materials: Iron nail, string, plastic comb, cotton cloth, glass rod, woollen cloth

Procedure

1. Take an iron nail and hang it from a string as shown in Figure 1.12.
2. Rub the comb with a piece of cotton cloth.
3. Bring the comb near one end of the iron nail.
4. Rub the glass rod with a piece of woollen cloth.
5. Bring the glass rod near one end of the iron nail.

Figure 1.12

Questions

(a) What do you observe in steps 3 and 5?
(b) What type of charge does the comb acquire?
(c) Explain your results.
(d) Why is the iron nail suspended by a string?

When the plastic comb is rubbed with cotton, it becomes negatively charged. On placing the comb near the iron nail, the conduction electrons at the end of the iron nail near the negative charge on the comb are repelled and move to the opposite end of the iron nail. This leaves an excess positive charge at the end near the comb. The positive charges on the iron nail then attract the negative charges from the comb. Further observation reveals that the iron nail is slightly pulled towards the comb as shown in Figure 1.13.

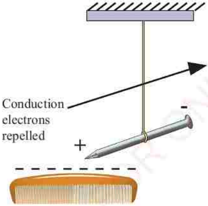


Figure 1.13: *Charging a conductor by induction using a negatively charged comb*

On the other hand, when the glass rod is rubbed with cotton, it becomes positively charged. On placing the rod near the iron nail, conduction electrons from the iron nail are attracted by the positive charge of the rod and move to the end of the iron nail near the glass rod. This leaves an excess of positive charge at the opposite end of the iron nail. Again, the iron nail is pulled slightly towards the glass rod as shown in Figure 1.14.

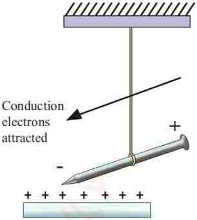


Figure 1.14: *Charging a conductor by induction using a positively charged rod*

If the charging object (comb or glass rod) is removed, the charges in the metal rod (iron nail) return to their normal distribution and the metal rod is no longer charged.

Detection of charges

Electroscopes are used to detect the presence of electric charges on a body. The commonly used type of this instrument is the leaf electroscope.

Structure of a leaf electroscope

In the past, a leaf electroscope was referred to as gold leaf electroscope. It is an instrument used to detect electric charge on an object.
It consists of a metal cap mounted on a metal rod, having at its lower end a small metal

plate with a thin metal leaf attached to it. The metal used for the cap, rod and plate is normally brass. The leaf is normally made up of gold, but any other metal like aluminium can be used. The metal rod and plate with attached metal leaf are enclosed in a metal or glass case to protect the leaf from air current. Figure 1.15 (a) shows an example of a leaf electroscope, and Figure 1.15 (b) is its schematic diagram.

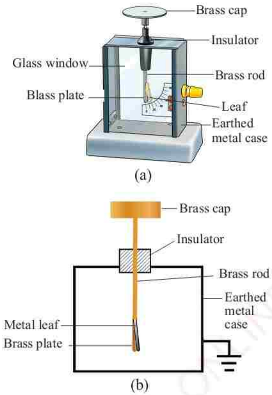


Figure 1.15: *Leaf electroscope*

Determining the sign of a charge

The true sign of a charge on a body can be determined in a number of ways; one among them is by using an electrophorus.

The electrophorus

It is a simple manual electrostatic generator used to produce unlimited number of electrostatic charges via the process of electrostatic induction.

An electrophorus consists of a circular slab of insulating material (polythene) together with a brass disc (conductor) on an insulating handle. Figure 1.16 (a) shows a picture of an electrophorus, and Figure 1.16 (b) is a schematic diagram of it.

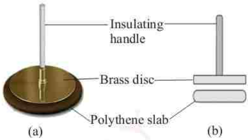
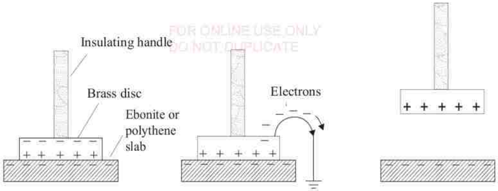


Figure 1.16: *The electrophorus*

Mode of action of an electrophorus

An electrophorus works by electrostatic induction and, hence, can be used to generate positive charges from a single negative charge. The polythene slab is first negatively charged by rubbing it vigorously with fur. The brass disc is then placed on it as shown in Figure 1.17 (a). Since the surfaces are only in contact at relatively few points, a positive charge is induced on the lower surface of the brass disc, and a corresponding negative charge is produced on its top surface. The top of the brass disc is then touched briefly using a wire that touches the ground, thereby carrying away the negative charges to the earth as shown in Figure 1.17 (b). This is known as earthing.



(a) Charges induced on the brass disc (b) Brass disc temporarily earthed (c) Brass disc removed

Figure 1.17: *Action of the electrophorus*

This leaves a net positive charge on the brass disc after separation as seen in Figure 1.17 (c). The electric force between the brass disc and the polythene base is fairly strong so that some mechanical work has to be done in order to overcome it. The top of the disc can be repeatedly charged in the same way. In principle, an unlimited amount of induced charge can be obtained from a single charge, but the insulated disc does slowly discharge to the surroundings. An electrophorus can be used to charge an electroscope through contact and induction.

Charging and discharging a leaf electroscope

A leaf electroscope can be charged or discharged either by contact or by induction.

If the metal cap is touched by a charged object, the metal leaf diverges from the plate. This is because same charge has been conducted through the metal cap and the metal rod to the metal plate and the leaf. This makes them repel each other, and, thus, the leaf diverges from the plate. This is charging by contact.

If you touch the brass cap with a conducting wire that touches the ground, the charge is transferred through the wire to the earth, and the leaf of the electroscope then collapses back. If the electroscope is brought near a charged object without touching it, the leaf also diverges from the plate. This is because charges on the metal cap with the same charge as the object are repelled to the leaf. This is charging by induction.

Charging by contact

If a positive or negative charged body is made to touch the brass cap of the neutral electroscope, the leaf diverges.

Activity 1.6

Aim: To charge a leaf electroscope by contact .

Materials: Charged ebonite rod, electroscope, silk cloth, glass rod

Procedure

1. Place the electroscope on a table and discharge it by earthing.
2. Bring the charged ebonite rod

in contact with the brass cap of the electroscope as shown in Figure 1.18.

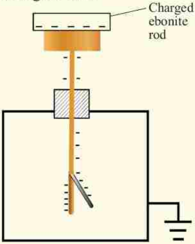


Figure 1.18

3. Observe the leaf of the electroscope.

Note: If the leaf does not stay diverged, bring the charged ebonite rod in contact with brass cap of the electroscope until the leaf stays diverged.

4. Remove the charged ebonite rod from the brass cap of the electroscope and observe what happens to the leaf of the electroscope.
5. Charge the glass rod by rubbing it with silk cloth.
6. Bring the charged glass rod close (not touching) to the brass cap of the electroscope.
7. Note your observations.

Questions

(a) Explain your observation.

(b) Why does the leaf collapse when a glass rod is brought near the cap.

When the negatively charged rod is brought into contact with the electroscope, the latter gets charged and the leaf diverges. It acquires a negative charge. The charge on the electroscope can be determined by testing using the charged glass rod. When a positively charged glass rod is brought near the brass cap, positive charges on the cap are repelled towards the brass plate. Therefore the plate becomes positively charged. This causes the leaf to collapse as shown in Figure 1.19.

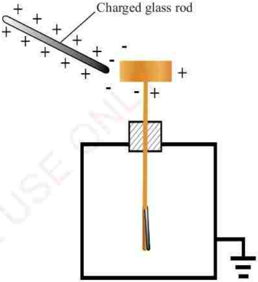


Figure 1.19: *Testing charged electroscope by using charged glass rod*

However, this method is unreliable since it could lead to wrong results.

Charging by induction

Having learnt how to charge an object by induction, the same method can be applied to charge a leaf electroscope. In this process, it is advised to use a positively charged electrophorus.

Activity 1.7

Aim: To charge an electroscope by induction using a positively charged electrophorus.

Materials: Electrophorus, glass rod, ebonite rod, silk cloth or fur, leaf electroscope

Procedure

1. Place the electroscope on a table and discharge it by touching with an earthed wire.
2. Charge the electrophorus by induction.
3. Hold the charged electrophorus close to the cap of the electroscope.
4. Earth the electroscope momentarily as shown in Figure 1.20.

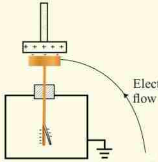


Figure 1.20

5. Remove the electrophorus and observe the leaf of the electroscope.
6. Test for charges on the electroscope using charged rods of glass and ebonite.

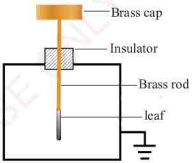
Question

Which charge does the electroscope acquire?

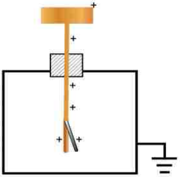
When the electroscope is charged in this manner, it acquires a negative charge. The charged glass rod, therefore, causes a collapse of the leaf while a charged ebonite rod causes a further leaf divergence. Recall that glass is positively charged while ebonite is negatively charged after being rubbed with silk and cloth respectively.

Discharging a leaf electroscope

Having charged a leaf electroscope by either contact or induction, the same can be effectively discharged through induction. Figures 1.21 (a) and (b) show uncharged and charged leaf electroscope respectively.



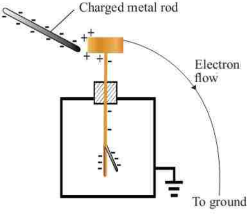
(a) Uncharged leaf electroscope



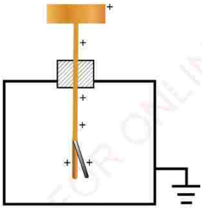
(b) Charged leaf electroscope

Figure 1.21: *Uncharged leaf electroscope and charged leaf electroscope*

If the brass cap is touched with an earthed wire while the electroscope is being charged by induction, as shown in Figure 1.22 (a), electrons will leave the electroscope through earthed wire into the ground. If the charged metal rod is removed, the electroscope will remain charged. The charge remaining on the electroscope will be the opposite of the charge on the rod (see Figure 1.22 (b)).



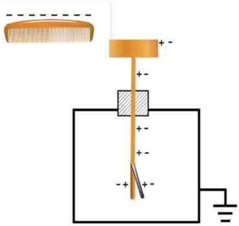
(a) Charging by induction



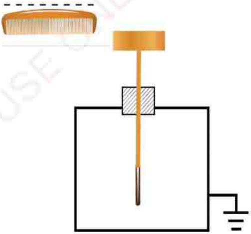
(b) Charged by induction

Figure 1.22: *Electroscope charged by induction*

If a negatively charged object is now brought near the brass cap, electrons in the brass cap are repelled and move down to the leaf as shown in Figure 1.23 (a). This cancels the positive charges. With no net charge, the leaf collapses back to the plate as shown in Figure 1.23 (b).



(a) Discharging by induction



(b) Discharged by induction

Figure 1.23: *Electroscope discharged by induction*

If the object is removed, the electrons return to the metal cap. They leave the leaf and plate of the electroscope with a net positive charge again, and the leaf diverges from the plate as shown in Figure 1.24.

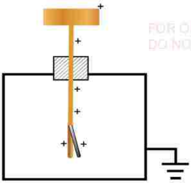


Figure 1.24: *Electroscope recharged*

Activity 1.8

Aim: To show charging and discharging of an electroscope by friction and contact.

Materials: Leaf electroscope, a glass rod, a cotton cloth

Procedure

1. Rub a glass rod with a piece of cotton cloth.
2. Roll the glass rod on the brass cap of an electroscope.
3. Record your observations.
4. Remove the rod.
5. Touch the metal cap of the electroscope with an earthed wire.
6. Record your observation.

Questions

(a) What happens to the electroscope? Why?

(b) Which type of charge is on the leaf of the electroscope? Why?

(c) What happened to the charge?

A leaf electroscope can also be discharged by induction.

Activity 1.9

Aim: To investigate charging and discharging of a leaf electroscope by induction.

Materials: Leaf electroscope, a piece of cotton cloth, a glass rod

Procedure

1. Rub a glass rod with a piece of cotton cloth.
2. Bring the rod near but not touching the brass cap of the electroscope.
3. Record your observations.
4. With the rod still near the cap, touch the cap with an earthed wire.
5. Note what happens.
6. Remove the rod.
7. Now rub the glass rod with a piece of wool, causing the rod to become positively charged.
8. Bring the positively charged glass rod near but not touching the brass cap of the electroscope.
9. Remove the glass rod.

Questions

(a) What happens to the electroscope? Why?

(b) Which type of charge is on the leaf of the electroscope?

Applications of the electroscope

An electroscope has a number of applications, among them are:

1. **Testing for the sign of charge on a body**
   If the leaf electroscope was initially charged negative, a negatively charged ebonite rod brought near the cap of the electroscope causes an increase in the leaf divergence. Now bring the material of unknown charge near the cap of the electroscope; a collapse of the leaf indicates that the material is positively charged.
   To test for a negative sign, the initial charge on the electroscope must be positive. If the material placed near the cap causes a collapse of the leaf, then this is a clear indication of the presence of a negative charge on the material. For example, if a glass rod is rubbed with silk and brought near the brass cap, there is a decrease in leaf divergence.

Note: A decrease in divergence, however does not necessarily mean that a charge of opposite kind is near the charged electroscope. An uncharged body has the same effect. Increase in divergence is therefore, a sure test. Table 1.2 summarises the effects of charges on a leaf electroscope.

Table 1.2: *Summary of charges and their effects on the leaf electroscope*

Charge on electroscope	Charge brought near cap	Effects on leaf divergence
+	+	increase
–	–	increase
+	–	decrease
–	+	decrease
+ or -	uncharged body	decrease

2. **Identifying the insulating properties of materials**
   An electroscope that is positively charged can be used to test for the insulating properties of materials. If the material that is placed near the cap of an electroscope is a conductor, then the metal leaf collapses. If the material being tested is an insulator, the leaf electroscope retains its charge, and the leaf remains raised.
3. **Detecting the presence of charge on a body**
   When a charge is induced on the leaf electroscope by a charged body, the leaf diverges. When the charged body is removed, the leaf collapses indicating that the induced charge on the electroscope is temporary, and it is due to the charged body.

Exercise 1.1

1. (a) What is static electricity?
   (b) Like charges_______, unlike charges ________. The law governing this is called ______.
   (c) A negatively charged object attracts a piece of paper because it ______ electrons away from the surface of the paper.
2. (a) Explain why:
   (i) nylon clothes crackle as you undress.
   (ii) petrol road tankers usually have a length of metal chain hanging down touching the ground.

(iii) some clothes tend to cling onto the body of a person.

(b) Why do TV screens become dusty after a while? Discuss.

3. State the functions of a leaf electroscope.
4. State and explain three methods through which an electroscope can be charged.

Potential difference

You have learnt that like charges repel each other, and unlike charges attract each other. Therefore, in moving a positive charge towards another positive charge, work must be done to overcome the repulsive force. Likewise, to move a negative charge away from a positive charge, work is done to overcome the attractive force. The above processes apply to all points in the region surrounding any charges. This means there exists an electrostatic force field around a charge.

The work required to move a unit charge from a reference point to a specific point against the electrostatic force field of another charge is called *the electrostatic potential* at the specific point. Therefore, there is a difference in electrostatic potential between any two points in the electrostatic force field.

Potential difference (p.d) is the work done to move a charge from one point to another when the points are at different potentials.

Potential and potential difference are measured in volts (V). The volt was named so in honour of an Italian physicist Alessandro Volta.

A volt is one joule of work per electric charge of one coulomb.

As a consequence, leaf divergence in a leaf electroscope occurs because there is a potential difference between the leaf and the cap. Also, when a negatively charged conductor is connected to the ground, negative charges flow from the conductor to the earth. Similarly, a positively charged conductor could receive electrons from the ground. These electrons flow because of a potential difference between the conductor and the earth.

Moreover, if two conductors at different potentials are joined by a conducting wire, electrons will flow from one to another until both are at the same potential. Free electrons in both conductors will have the same average potential energy. Usually, electrons flow from points of low potential to points of high potential as shown in Figure 1.25.

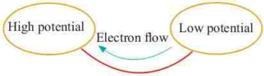


Figure 1.25: *Flow of electrons*

Capacitors

A capacitor is a device used to store electric charge. It consists of two electrically conductive plates, separated by an insulator material. The shape of a capacitor can be square, circular, rectangular or cylindrical. Insulator can be for example, ceramic, plastic film, air, paper, mica or liquid gel. The insulating material between the conductive plates is called a *dielectric* material.

Dielectric is an insulating medium used between the plates of a capacitor.

When a power source is connected across plates, one plate is charged negatively, and the other plate positively. Charge continues to accumulate on the plates with time until the capacitor is fully charged. Figure 1.26 (a) shows a capacitor, (b) its structure and (c) its circuit symbol.

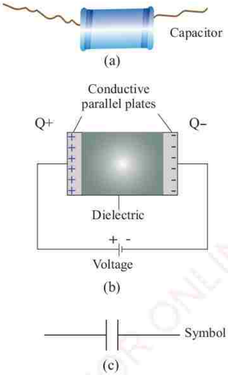


Figure 1.26: *Capacitor and its symbol*

Capacitors are used as parts of electrical circuits in many common electrical devices. They store energy in the electrostatic field created by the electric charges on their plates. Consider electric devices like the radio or stereo system, when power is switched off, the power lamp fades out slowly. On the other hand, the stereo system has its sound playing for some seconds after the power is switched off. This is because capacitors store electrical energy, and, as a result, the electronic appliances then continue being supplied with it. Capacitors are used in computers, televisions and other electronic circuits. Figure 1.27 shows mounted capacitors in a radio set.

Figure 1.27: *Capacitors in a radio set*

A fully charged capacitor has a positive charge on one plate and an equal amount of negative charge on the other. A voltmeter connected between the capacitor plates measures the potential difference between the plates.

Capacitance

When a capacitor is provided with more charge, the value of its positive and negative potential rises. Why does this happen? The reason is that the increased charge repels any incoming charge more strongly than before. Thus, more work has to be done to increase the charge on a capacitor. The ability of a system to store charge is called *capacitance*, *C*.

Capacitance is a measure of the amount of charge a capacitor (or any conductor) can hold for a given potential difference.

If Q is the charge stored by a capacitor, then:

$$Capacitance,\ C = \frac{Amount\ of\ charge\ stored\ by\ a\ capacitor,\ Q}{Potential\ difference\ between\ plates,\ V}$$

$$C = \frac{Q}{V}$$

Since $Q \propto V$, the ratio of $\frac{Q}{V}$ is constant for a given capacitor.

$$\text{Also, } Q = CV$$

The SI unit of capacitance, C is farad, F. Normally, the value of C is a very small number, therefore, the millifarad (mF), microfarad (μF), picofarad (pF) and nanofarad (nF) are also used, where:

$$1\ \text{mF} = 10^{-3}\ \text{F}$$

$$1\ \mu\text{F} = 10^{-6}\ \text{F}$$

$$1\ \text{nF} = 10^{-9}\ \text{F}$$

$$1\ \text{pF} = 10^{-12}\ \text{F.}$$

A farad is defined as the capacitance of a capacitor when a charge of one coulomb changes its potential difference by one volt.

One farad is the capacitance of a very large capacitor. In practice, radio receivers for example have the capacitance of their capacitors expressed in microfarads. Capacitors in most modern electrical circuits, like those in hi-fi systems, have their capacitance expressed in picofarads.

Example 1.1

A capacitor of capacitance 200 μF is being charged. The potential difference (p.d) between its plates is 10 V. How much charge will accumulate on the plates during the period of charging?

Solution

Given, p.d = 10 V

capacitance = 200 μF

$$C = \frac{Q}{V}$$

$$Q = CV$$

But $C = 200\ \mu\text{F} = 200 \times 10^{-6}\ \text{F}$

$= 2 \times 10^{-4}\ \text{F}$

Therefore, $Q = 2 \times 10^{-4}\ \text{F} \times 10\ \text{V}$

$= 2 \times 10^{-3}\ \text{C}$

$= 2\ \text{mC}$.

Therefore, one plate has a charge of −2 mC, and the other has + 2 mC.

Exercise 1.2

1. A capacitor with a capacitance of 50 pF is charged to 30 V. What is the charge on its plates?
2. Briefly explain the following:
   (a) capacitor
   (b) capacitance
3. A 3 μF capacitor has a p.d of 12 V. Determine the total charge on the capacitor.

4. If a cell of voltage 1.5 V is used to charge a capacitor, calculate the capacitance of the capacitor when the charge is 90 C.

Types of capacitors

There are different types of capacitors depending on the dielectric materials used to make them. These are as follows:

1. **Paper or plastic capacitors**

A paper or plastic capacitor has metal foil strips as their conductor plates. Waxed paper or plastic forms the insulating material. Polyester film can also be used as a separating or insulating material. See Figure 1.28. Insulating materials are rolled up and sealed inside a metal box so as to prevent moisture from entering. Moisture dampens the insulation.

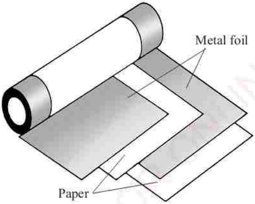


Figure 1.28: *Paper capacitor*

2. **Mica capacitor**

Note that any arrangement of two conductors separated from one another by an insulator forms a capacitor. In an ordinary laboratory, this could be two sheets of metal foil isolated by small pieces of plastic in between, with air as the insulating material.

In a mica capacitor, the sheets of metal foil are separated by strips of mica as shown in Figure 1.29. Mica is preferred because it is a natural mineral and splits easily into very thin sheets.

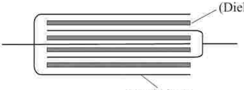


Figure 1.29: *Mica capacitor*

3. **Electrolytic capacitor**

Metal sheets are separated by paper previously soaked in a chemical compound (see Figure 1.30). The soaked paper is not an insulating material. As the capacitor charges, a thin layer of aluminium oxide is formed on the positive plate thereby providing a thin insulating layer between the plates. The thinner the layer the higher the capacitance.

Electrolytic capacitors are connected with great care. Their ends are labelled positive or negative as a safety precaution because a wrong connection can lead to an explosion.

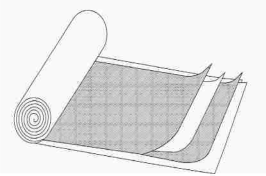


Figure 1.30: *Electrolytic capacitor*

4. **Air filled capacitors**

In an air filled capacitor, air forms the insulating material (see Figure 1.31). The capacitance of such devices is altered by changing the overlapping area between the plates.

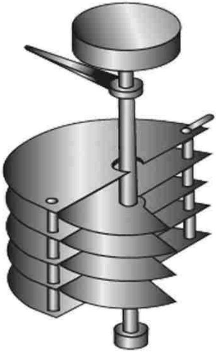


Figure 1.31: *Air filled capacitor*

An air filled capacitor is a good example of a variable capacitor. The semicircular plates are separated by air. Variable capacitors are mainly used for tuning radio sets. One set of the plates is fixed while the other one can be rotated by means of a knob. Rotation changes the area of the plates. Generally, the capacitor whose capacitance can be varied is termed a variable capacitor. On the other hand, the capacitor whose capacitance cannot be changed is a fixed capacitor.

Charging a capacitor

Consider the circuit in Figure 1.32 for charging a capacitor.

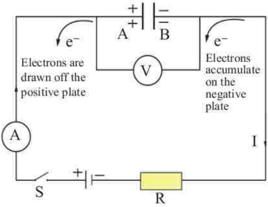


Figure 1.32: *Charging a capacitor*

An uncharged capacitor has no potential difference between its plates. It does not resist the current from arriving at one plate or leaving the other. This is due to the fact that the initial current in the circuit is determined by the resistance of the connecting wires only. Due to the presence of the insulation between the plates of the capacitor, electrons tend to accumulate on the plate connected to the negative terminal of the charging cell. This is partly due to the attraction of the positive side of the cell or repulsion from the nearby negative charge.

Current flows until the p.d across the capacitor is equal to the voltage of the charging cells. Charging of the capacitor then stops. Figure 1.33 shows a graph of charge against time for a charging capacitor.

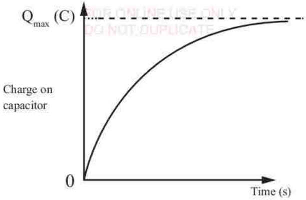


Figure 1.33: *Graph of charge against time for a charging capacitor*

The current in the circuit is controlled by the resistance, *R*.

$$\textit{Initial charging current} = \frac{\textit{Potential difference across a cell}}{\textit{Resistance in the circuit}}$$

The gradient of the charging curve gives the current. Therefore, the initial current is the gradient of the graph at the origin (Time = 0).

Activity 1.10

Aim: To demonstrate the charging of a capacitor.

Materials: A cell, uncharged capacitor, high-resistance voltmeter, resistor, switch, connecting wires and ammeter

Procedure

1. Connect the circuit as in Figure 1.32, keeping the switch open.
2. Close the switch and then record the values of current at different time intervals.
3. Tabulate your results as follows:

Time (s)	0	20	30	40	50	60	70	80	90
Current (mA)									

Questions

(a) Plot a graph of current against time.

(b) What does the area under the graph represent?

The area under the graph of current, I against time, t represents charge, Q.

When a cell is connected to the circuit, the charge starts to flow immediately. Electrons accumulate on the plate connected to the negative terminal of the cell. The other side experiences low accumulation, partly due to the attraction from the positive side of the cell.

Charging stops when the p.d between the plates is equal to the total p.d. across the cell. The current drops as the charge on the plates increases.

Note: Electrons flow from the negative terminal of the battery to plate B of the capacitor. At the same rate, electrons flow from the other plate A of the capacitor towards the positive terminal of the battery. Hence, there is an equal positive and negative charge on the plates (refer Figure 1.32).

As the charge accumulates, the p.d between the plates increases, and the charging current falls to zero the moment the p.d equals that of the battery. At any moment, the charges on the plates are equal but with opposite signs, $+Q$ and $-Q$. The capacitor is said to have stored charge Q.

Discharging a capacitor

Theoretically, an isolated but charged capacitor should hold its charge indefinitely. However, due to leakage between the plates, the capacitor is eventually discharged. A capacitor can also be discharged by connecting its plates together via a resistor.

Figure 1.34 shows a circuit used for discharging a capacitor.

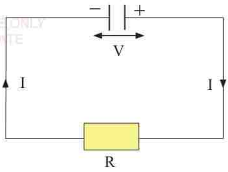


Figure 1.34: *Discharging a capacitor*

Figure 1.35 shows a graph of charge against time for a discharging capacitor.

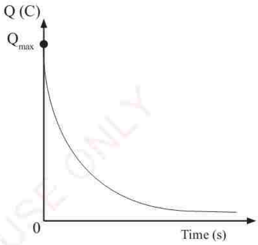


Figure 1.35: *Graph of discharging capacitor*

Note:

At $t = 0$, $Q = Q_{Max}$

A graph of charge against time gives a decay exponential curve. The discharging current is given by the gradient of the curve.

$$Discharging\ current = \frac{Charge}{Time}$$

$$I = \frac{Q}{t}$$

But, $Q = CV$

Therefore, $I = \frac{CV}{t}$

Construction of an air-filled capacitor

Project 1.1

Any arrangement of two parallel conductors such as metal plates placed close together but at suitable fixed distance make up a capacitor. When air forms the insulating medium between the plates, the dielectric here is air.

In groups, construct an air-filled capacitor.

Combination of capacitors

Capacitors have voltage ratings that should not be exceeded. Continuous charging by using a large voltage can result in an explosion as the potential difference between the plates can break the insulation. To adjust voltage rating and consequently capacitance, capacitors are connected either in series or in parallel in a circuit.

Capacitors in series

Figure 1.36 shows a series connection of capacitors, where C_1, C_2, and C_3 are respective capacitances.

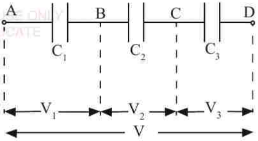


Figure 1.36: *Capacitors in series*

If V_1, V_2 and V_3 are the potential differences developed between the various plates, then the total potential difference, V across AD is:

$$V = V_1 + V_2 + V_3.$$

When capacitors are in series, there is equal distribution of charge on the plates.

Charge Q on C_1 is transferred to C_2 and C_3 by induction.

Then,

$$V_1 = \frac{Q}{C_1},\ V_2 = \frac{Q}{C_2} \text{ and } V_3 = \frac{Q}{C_3}$$

Substituting for V_1, V_2 and V_3 in the above equation, you obtain:

$$V = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$

$$V = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right) \quad \text{But } V = \frac{Q}{C}$$

Where C is the combined or equivalent capacitance.

Then, $\frac{Q}{C} = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$ which simplifies to:

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Note: If two capacitors are in series, then their total capacitance, C, is given by:

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\boxed{C = \frac{C_1 C_2}{C_1 + C_2}}$$

This is the combined capacitance for two capacitors in series.

Example 1.2

Three capacitors, A, B and C, are arranged in series. Their capacitances are given as 10 µF, 20 µF and 30 µF, respectively. Calculate the value of a single capacitor that could replace them.

Solution

Let C be the total capacitance.

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$= \frac{1}{10\ \mu\text{F}} + \frac{1}{20\ \mu\text{F}} + \frac{1}{30\ \mu\text{F}}$$

$$= \frac{(20\ \mu\text{F} \times 30\ \mu\text{F}) + (10\ \mu\text{F} \times 30\ \mu\text{F}) + (10\ \mu\text{F} \times 20\ \mu\text{F})}{(10\ \mu\text{F} \times 20\ \mu\text{F} \times 30\ \mu\text{F})}$$

$$C = \frac{6\ 000}{1\ 100}\ \mu\text{F} = 5.45\ \mu\text{F}$$

The value of an equivalent single capacitor is $5.45\ \mu\text{F}$.

The value from the answer is smaller than any of the individual capacitors.

Capacitors in parallel

In a parallel arrangement, all capacitors have the same potential difference across them as shown in Figure 1.37. But the charges for all the capacitors are different.

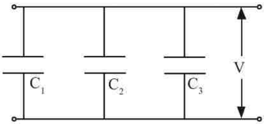


Figure 1.37: *Capacitors in parallel*

Therefore, total charge,

$$Q = Q_1 + Q_2 + Q_3$$

But

$$Q_1 = C_1 V,\ Q_2 = C_2 V \text{ and } Q_3 = C_3 V$$

$$Q = C_1 V + C_2 V + C_3 V$$

But $Q = CV$ where C is the total capacitance.

Then, $CV = C_1 V + C_2 V + C_3 V$ which simplifies to:

$$\boxed{C = C_1 + C_2 + C_3}$$

This is the combined capacitance for the three capacitors in parallel.

Example 1.3

An electric circuit has three capacitors arranged in parallel to a cell. If the p.d, V across each plate is the same, calculate the total capacitance.

Solution

$$\frac{Q_1}{C_1} = \frac{Q_2}{C_2} = \frac{Q_3}{C_3} = V$$

If an equivalent circuit consists of one capacitor of value C_T, the charge drawn from the cell Q must be the same as the total charge on the plates of the other capacitors.

$$Q = Q_1 + Q_2 + Q_3$$

$$C_T V = C_1 V + C_2 V + C_3 V$$

$$C_T = C_1 + C_2 + C_3$$

Exercise 1.3

1. A 1 000 μF capacitor has been charged to a p.d of 25 V. What is the charge on the plate of the capacitor?
2. A capacitor of capacitance 250 μF is allowed to charge until the potential difference between its plates is 10 V. How much charge accumulates on the plates during the charging process?
3. What value of capacitor could be used to replace a set of 5 μF, 10 μF and 15 μF capacitors connected in series?
4. Three capacitors of values 2 μF, 3 μF and 6 μF are connected in series and then in parallel. What is the equivalent capacitance in each case?

Factors affecting capacitance

Capacitance of a parallel plate capacitor is affected by three major factors, namely:

(a) the area of the plates;

(b) the insulating property of the medium; and

(c) the distance between the plates.

(a) Area of the plates

An increase in the area of the plates causes a decrease in potential difference between the plates, hence an increase in capacitance.

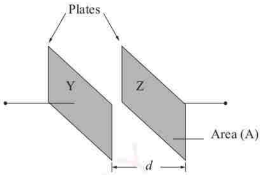


Figure 1.38: *Area of plates of a capacitor*

From experiments, $C \propto A$ where C is the capacitance, and A is the effective area between the plates Y and Z as shown in Figure 1.38. They are separated by a distance, d. If d is kept constant, and Z is moved parallel to Y, the overlapping area is varied.

(b) Insulating property of the medium

If the air that is in between the plates of a capacitor is replaced with another insulating medium such as glass or book or polythene when the area A and the distance d remain constant, the capacitance increases. From experiments, capacitance, C is directly proportional to the insulating property of the medium between plates Y and Z (Figure 1.39).

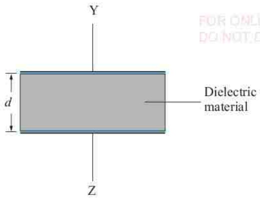


Figure 1.39: *Insulating property of materials*

(c) Distance between plates

A charged capacitor is connected such that one plate is earthed while the other is connected to an electroscope as shown in Figure 1.40. The distance between the plates is varied and its effect on the leaf divergence is noted. It is observed that the closer the plates are to each other, the smaller the divergence and the lower the potential. In conclusion, capacitance increases with closeness of the plates. Thus, $C \propto \frac{1}{d}$ where C is the capacitance, and d is the distance between plates.

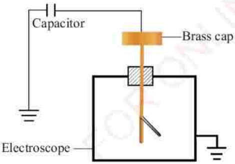


Figure 1.40: *Capacitor connected to an electroscope*

Charge distribution on a conductor

Induced charge resides on the surface of a conductor. Conductors appear in many different shapes such as spherical, pear-shaped and cylindrical surfaces. Charge distribution on conductors depends on the shape of a conductor.

Charge distribution on the surface of a conductor

Given a net charge, the charges repel each other. As a result, the charges will distribute themselves to reduce the force of repulsion as much as possible.

Charge distribution on the surface of a conductor can be investigated by connecting an originally neutral electroscope to several parts on the surface.

The deflection of the leaf indicates the quantity of charge transferred from one area of the conductor to the electroscope. Figure 1.41 shows distribution of charges on spherical conductors.

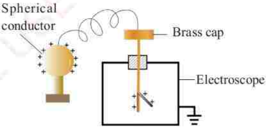


Figure 1.41: *Charge distribution on a conductor*

The spherical conductor can then be replaced with a pear-shaped one.

> Charge distribution on a conductor is mostly concentrated at sharply curved surfaces.

A proof plane and a leaf electroscope are useful in such an investigation. A proof plane is a metal disc with an insulated handle though its disc is smaller than that of an electrophorus (see Figure 1.42). It is used to transfer small amounts of charge from one body to another.

A proof plane is touched to the surface of a conductor at various points in turn. The charge on the proof plane is then transferred to an electroscope which indicates the charge distribution on the conductor.

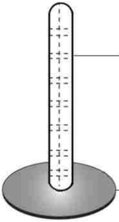


Figure 1.42: *Proof plane*

Activity 1.11

Aim: To show the distribution of charges on the surface of a conductor.

Materials: Aluminium foil, proof plane, rugby ball, leaf electroscope, football

Procedure

1. Cover separately a football and a rugby ball with aluminium foil. Keep the foil as smooth as possible (see Figure 1.43).

Figure 1.43

2. Construct a proof plane. This is similar to an electrophorus but with a much smaller metal disc as shown in Figure 1.42.
3. Charge the proof plane and touch it to the foil-covered rugby ball. The metal sphere now has the same charge as the proof plane.
4. Touch the proof plane to some other region on the ball. Be sure to test the ends of the cap as well as points near the centre. The proof plane will acquire a charge proportional to the amount of charge on the touched region of the sphere (see Figure 1.44).

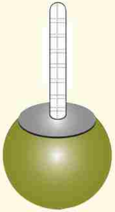


Figure 1.44

5. Now, transfer the proof plane to the cap of a leaf electroscope as shown in Figure 1.45, and note how far the leaf diverges according to the scale shown on the leaf electroscope. Record your reading.

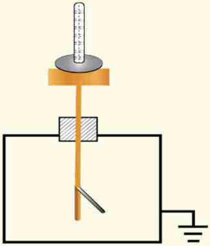


Figure 1.45

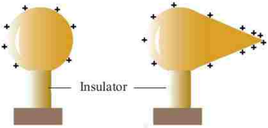
6. Discharge the electroscope by touching the cap with earthed wire. Also discharge the conductor.
7. Recharge the conductor. Test other regions of the sphere for charge and note your observations.
8. Repeat this experiment with the foil-covered football.

Questions

(a) Is the amount of charge the same at the different regions you tested?

(b) Sketch the charge distribution on each conductor.

Spherical conductors have equal distribution of charges. So, leaf divergence is the same throughout. For others, leaf divergence is larger when charge is transferred from points within sharp bending or pointed regions. This also means that charge accumulates more at these points. Therefore, charge distribution on a conductor depends on the shape of the conductor surface as shown in Figure 1.46.



(a) Spherical conductor (b) Pear-shaped conductor

Figure 1.46: *Charge distribution on conductors*

The electroscope leaf deflection is maximum at the sharpest part of a conductor.

The charged body in Figure 1.46 (b) discharges faster than the one in Figure 1.46 (a). Charge concentration at the sharpest part causes leakages which are important in the construction of lightning conductors.

Charge distribution on hollow conductors

Hollow conductors have their own distribution of charge.

Activity 1.12

Aim: To investigate charge distribution on a hollow conductor.

Materials: A metal can or an insulated hollow glass sphere, charged cap, brass sphere, proof plane, an electroscope

Procedure

1. Place a metal can on an electroscope as shown in Figure 1.47.

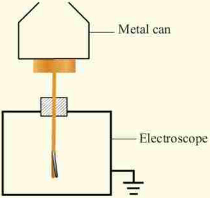


Figure 1.47

2. Insert a charged ball into the can as shown in Figure 1.48 (a) and observe.

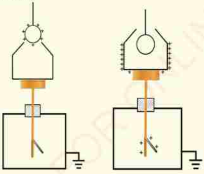


Figure 1.48

3. Record your observations.

Question

What conclusion do you make?

In step 1, the charged ball is not yet inserted in the metal can. So, the leaf of the electroscope is not diverged. In step 2, a charged ball repels the charges on the surface of the metal can onto the electroscope's cap. The leaf diverges as an indication of repulsion due to the presence of like charges.

It is found that charge distribution in a hollow conductor is concentrated on the outside. The inside of the can has no charges.

Lightning and lightning conductor

Lightning is a large spark due to electrostatic discharge within a cloud, between two clouds or between a cloud and the ground. Interaction between updrafts and downdrafts in the cloud produces static charge by friction. The lower portion of the cloud becomes negatively charged and the upper part positively charged. The ground beneath the cloud can become positively charged by induction. Figure 1.49 shows positively and negatively charged clouds.

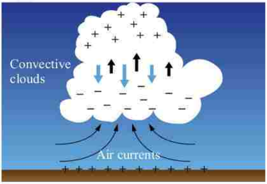


Figure 1.49: *Positively and negatively charged cloud*

As charge builds up beyond a certain limit, the insulating property of the medium between positive and negative charge centres breaks down. Hence, a large current suddenly passes, ionising the air molecules on its way, accompanied by sudden expansion of the air. Ionisation of air results in the observed flush of light (lightning) as shown in Figure 1.50. Sudden expansion results into the booming sound (thunder) that is heard a few seconds after the flash is seen.

Thunderstorm is severe weather associated with lightning and thunder, heavy rainfall and strong winds.

The current flow and heating effect of lightning can cause immense destruction of property and life.

Figure 1.50: *Lightning*

A single discharge of lightning can lead to temperatures as high as 30 000°C. Objects on the ground that are struck by lightning can be severely damaged. Sharp or pointed objects on the earth's surface such as mountains, trees and tall houses are highly charged and are therefore prone to lightning strikes.

Lightning conductor

Lightning cannot be prevented but protection of the destruction is possible by using *lightning conductors*. A lightning conductor works on the fact that charge concentrates more at sharp points.

A lightning conductor is a sharp ended metal rod attached to a building and connected to a thick copper strip that leads into the ground. Its tip has sharp spikes.

Lightning conductors can help protect buildings and other structures from lightning strikes. Since lightning tends to hit the highest objects within its region or path, the lightning conductor extends above the highest point of a tall building as shown in Figure 1.51. When lightning strikes the conductor, electric charges flow along the wire and are dissipated to the ground where they cause no harm, thereby protecting the building.

Figure 1.51: *Lightning conductor installed on the house*

Mode of action of lightning conductor

A negatively charged cloud passing overhead causes the sharp spikes of the conductor to become positively charged by induction. Acquired charge on the spikes is safely conducted to the ground, hence, no lightning occurs, and, therefore, no harm is caused to the building.

Task

Depending on your environment, your teacher shall organise for an excursion for the whole class to observe installed lightning conductors on different buildings. Be motivated to observe and gather as much data as possible to discuss with others.

Project 1.2

Use the information gathered during the excursion to construct a simple lightning conductor for your Physics laboratory.

Chapter summary

1. Static electricity is the accumulation of excess electric charges in a region which does not conduct electricity such that the charge remains in place.
2. Every atom contains a positively charged central part known as the nucleus which attracts all the electrons firmly to itself. There are two types of charge, negative and positive charges.
3. An ebonite rod rubbed with fur becomes negatively charged. A glass rod rubbed with silk becomes positively charged.
4. The fundamental law of static electricity states that like charges repel, unlike charges attract.
5. Objects can be charged by friction, contact or by induction.
6. Repulsion is the only sure way of determining the sign of charges by the electroscope.
7. Conductors are materials with electrons that flow freely from atom to atom. Any excess charge on a metallic conductor will distribute itself over the surface of the metal.
8. Insulators are materials that hinder the free flow of charge.
9. Excess charge on an insulator will remain in the location where it was introduced.
10. An electroscope is a device used to detect the presence of an electric charge and determine the type of charge present on a material.
11. An electroscope can be charged and discharged by contact and by induction.
12. Electrophorus comprises of a circular disc of insulating material together with a metal (conductor) disc on an insulating handle.
13. An electrophorus is charged by induction and can in turn be used to charge a leaf electroscope.
14. Capacitors are devices for storing charge. They are used in computers, radios and other electronics.
15. There are several types of capacitors, such as paper capacitors, mica capacitors, electrolytic capacitors and air filled capacitors.
16. The SI unit of capacitance is the Farad.

$$Capacitance,\ C = \frac{Amount\ of\ charge\ on\ plate,\ Q}{p.d\ between\ plates,\ V}$$

17. Capacitance depends on the area of the plate, the insulating property of the medium between the plates and the distance between the plates.
18. Capacitors can be connected either in series or in parallel.
19. Charge is normally concentrated on the sharp points of conductors.
20. Charges on a conductor will distribute themselves to reduce as much as possible the force of repulsion.
21. Hollow conductors have their excess electrostatic charge distributed on their outer surfaces.
22. Lightning is a large discharge of static electric charge within a cloud, between two clouds or between a cloud and the ground. The resulting sound heard after lightning is called thunder.
23. Lightning conductors protect buildings and other structures against lightning strikes.
24. Lightning conductors function due to the action of sharp points. Electric charges accumulate at these points and lead to the ground so as to prevent the dangers of lightning.

Revision exercise 1

Choose the most correct answer in items 1-6.

1. Capacitors of 1 µF, 4 µF and 2 µF are connected in series. Calculate the capacitance that could replace them (equivalent capacitance).

   (a) $\frac{9}{4}$ µF (b) $\frac{4}{7}$ µF

   (c) $\frac{7}{4}$ µF (d) $\frac{7}{4}$ F

2. The SI unit for capacitance is ______________.
   (a) farad
   (b) joules
   (c) volts seconds
   (d) coulombs

3. For each of the following pairs of materials being rubbed together, identify the one that could become negatively charged.
   (a) Glass and silk
   (b) Comb and hair
   (c) Fur and glass
   (d) Fur and hard rubber

4. If the positively charged rod in Figure 1.52 moved near the neutral solid metal sphere and then removed, which diagram correctly shows the resulting charge distribution on the metal sphere?

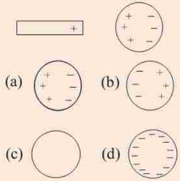


Figure 1.52

5. If you are caught outside during a severe thunderstorm, you should:
   (a) take shelter under the nearest tree.
   (b) stand under power lines.
   (c) move to higher ground.
   (d) hide in a ditch.

6. A negatively charged metal rod is brought near side P of a neutral metal sphere PS. Which diagram in Figure 1.53 correctly shows the resulting charge distribution on the metal sphere?

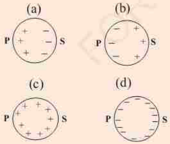


Figure 1.53

7. Match each item in **column A** against its corresponding item in **column B** by writing the correct response in the space provided.

Column A	Answer	Column B
(a) Stores charge		(i) Repel
(b) $C=C_1+C_2$		(ii) Capacitor
(c) Glass		(iii) Metal cap
(d) Similar charges		(iv) Positive charge
(e) Detect charges		(v) Leaf electroscope
		(vi) Insulator
		(vii) Attracts
		(viiii) Capacitors in parallel
		(ix) Capacitors in series
		(x) Negative charge

8. Fill in the following blanks.
   (a) A glass rod rubbed with ________ becomes ________ charged.
   (b) An ________ rod rubbed with ________ becomes negatively charged.
   (c) When a charged electroscope is touched by a finger it ________. This is called ________.

9.(a) Explain the two types of charges.
(b) State the fundamental law of static electricity.
(c) Explain how a balloon rubbed against your hair can be attracted to small pieces of paper.

10. (a) Draw a well labelled sketch of a gold-leaf electroscope.
(b) How is the electroscope used for testing the types of charges?

11. If a metal rod is given a negative charge and brought near another metal rod that is neutral,
(a) will there be an electric force between them?
(b) if there is a force, will it be attractive or repulsive? Why?
(d) what could happen if the first rod were given a positive charge instead of a negative one? Explain your answer.

12. Two rubber balloons are rubbed with hair.
(a) Will the electric force between one of the balloons and the hair be attractive or repulsive?
(b) Will the electric force between the two balloons be attractive or repulsive?
(c) Explain your answers.

13. State what happens in the following conditions.
(a) An ebonite rod is rubbed with fur.
(b) A negatively charged electroscope's cap is touched by a neutral glass rod.
(c) A proof plane is inserted in a hollow sphere and tested for charge.

14. An insulating rod A is charged and brought near an electroscope as shown in Figure 1.54.

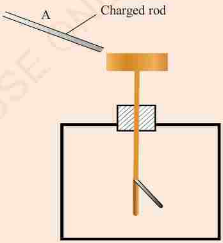


Figure 1.54

With rod A still near the cap of the electroscope, the cap is briefly touched and rod A is removed.
It is observed that the leaf of the electroscope remains diverged as shown in Figure 1.55.

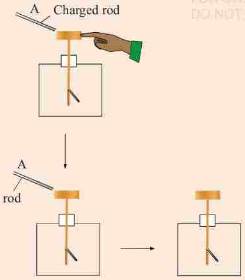


Figure 1.55

Is the charge on the electroscope now the same as the charge that was on rod A or the opposite charge? Explain your answer.

15. (a) Distinguish between capacitor and capacitance.
    (b) List the types of capacitors that you know and their uses.
    (c) Mention appliances that use capacitors.

16. A capacitor of two parallel plates separated by air has a capacitance of 15 pF. A potential difference of 18 volts is applied across the plates.
    (a) Determine the charge on the capacitor.
    (b) If the space between is filled with mica, the capacitance now increases to 240 pF. How much more charge can be put on the capacitor using the 18 V supply?

17. A sharp needle was brought close to the cap of a charged leaf electroscope. Explain why the leaf collapsed.

18. (a) Determine the effective capacitance of the circuit shown in Figure 1.56.
    (b) How much charge is stored?

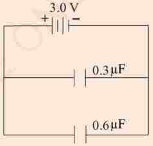


Figure 1.56

(c) After walking across a carpeted floor, you sometimes get a mild electric shock when you touch a metal door knob. Explain how this happens.

Chapter Two

Current electricity

Introduction

In Chapter One, you learnt the concept of electric charge which was stationary or static. In this chapter, you will learn the concept of current electricity and simple electric circuits. Also, you will learn about the relationship between current, voltage and resistance. The competencies developed will enable you to make simple electric circuits, operate electrical appliances in homes and efficiently use some commercial and industrial facilities such as refrigerators.

Concept of current electricity

Current electricity is the flow of electric charges along a conductor. To maintain a steady flow of electric charges, two things are required. First, there must be a source of electric charges that is capable of moving and a way of causing it to move. Secondly, there must be a closed conducting path in which the charges move ultimately returning to the source. This closed path is called an electric circuit (see Figure 2.1). Copper wires are normally used as conducting pathways for the electric charges to flow. If focus is put on one point in the electric circuit for the purpose of determining the amount of electric charges passing that point in a given period of time, then the electric current has been determined.

Figure 2.1: *Electric circuit*

The amount of the electric current in a material depends on the number of charges taking part and the speed at which they are moving. In a simple electric circuit, the charges that flow are the electrons.

Electric current is the amount of charge passing a given point in a circuit in one second. It is a fundamental quantity.

Mathematically,

$$\textit{Electric current, } I = \frac{\textit{Quantity of charge, } Q}{\textit{Time, } t}$$

$$I = \frac{Q}{t}$$

But, $Q = ne$

Where: $n = \textit{number of charges}$

$e = \textit{charge of single electron}$

Therefore, $I = \dfrac{ne}{t}$

Thus, from the formula:

Electric current = Rate of flow of charge
= (the number of charge carriers per second) × (charge of a single electron)

From this definition, the SI unit of an electric current is coulomb per second (C/s) where, 1 C/s = 1 ampere (A).

Other units are milliamperes (mA), kiloamperes (kA) and microamperes, (μA). Their equivalence to the ampere are as follows:

1 A = 10^3 mA

1 A = 10^6 μA

1 kA = 1 000 A.

When a steady electric current of 1 A is flowing in a circuit, a coulomb of charge passes a given point in the circuit per second. Coulomb is the SI unit of the number of charges flowing in a circuit.

A coulomb is the quantity of electricity which passes a given point in a circuit in one second when a steady current of one ampere is flowing.

Charge movement in an electric circuit

During the 18th century, Benjamin Franklin, American scientist and statesman, extensively studied both static and current electricity. He believed that in an electric circuit, it was the positive charges (the protons) that were moving, and his belief still defines the conventional direction of the electric current by the direction in which protons are thought to move.

In most electric circuits the electric current flows through conductors in which only negative charges (the electrons) can move freely. This implies that in most circuits, electric current is made up of moving electrons. Just as in a bicycle (see Figure 2.2), the chain allows energy to be transferred from the rider to the rear wheel; the chain does not carry energy. It is the motion of the chain that allows energy to be transferred. Likewise, the motion of the charges carried through a circuit transfers energy from one point to another. This means that the actual direction of an electric current is opposite to the conventional direction of electron flow.

Figure 2.2: *Transfer of energy in a bicycle*

Sources of electricity

All sources of electric current work by converting some form of energy into electrical energy. The two basic sources are batteries and generators. Batteries convert chemical energy into electrical energy while generators and alternators convert mechanical energy into electrical energy. Figure 2.3 shows some sources of electric current.

Figure 2.3: *Some sources of electric current*

Other sources of electric energy include water (hydroelectric power, water currents, ocean waves), sun, geothermal and wind. These sources are discussed in detail in chapter nine of this book.

Task 2.1

What are the 10 sources of electricity? How reliable are they? How do they produce electricity for use? Discuss.

Simple electric circuits

An electric circuit contains a source of moving charge (battery or generator), connecting wires made of a conducting material (usually copper metal) and various electrical devices such as bulbs, switches and resistors. The circuit may also contain devices for controlling the amount of current; these include rheostat, fuses and circuit-breakers, as well as devices such as ammeters for measuring current and voltmeters for measuring potential difference. Table 2.1 shows the list of some common circuit components, their purpose and the symbols used to represent them.

Table 2.1: *Electric circuit components*

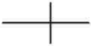
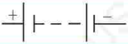
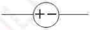
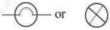
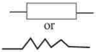
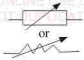
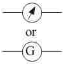
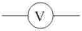
Circuit device	Symbol	Purpose
Connecting wire		Carry current from one point to another point in a circuit
Joined wires		
Crossing wires (not connected)		
Cell		Source of moving charge
Battery (more than 2 cells)		
Alternating current (AC) supply		
Direct current (DC) supply		
Lamp/bulb		Converts electrical energy to heat and light
Resistor		Opposes the flow of current
Switch		Opens and closes a circuit

Table 2.1: *(Continued)*

Rheostat (variable resistor)		Controls the amount of current (For example, the brightness of a lamp)
Galvanometer		Detects the presence of current
Ammeter		Measures current
Voltmeter		Measures potential difference (voltage)*
Capacitor		Stores charge
Fuse		Breaks the circuit if excessive current flows

* Potential difference or voltage is the difference in the amount of electrical energy that charge carriers have between two points in a circuit.

The potential difference between the positive and the negative terminals of a battery causes a current to flow along any conducting path that links them. Figure 2.4 shows two bulbs connected to a battery of two cells using copper wires. This combination of the battery, bulbs, switch and the conducting path formed by the copper wires make up a simple circuit.

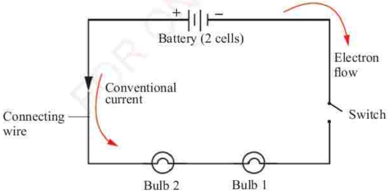


Figure 2.4: *Simple electric circuit*

Task 2.2

In groups, list the circuit components that you know. Draw a chart and indicate the use of each component and the electric symbol used to represent it. The best chart will be hung in the Physics laboratory.

Relationship between current, voltage and resistance

In an electrical circuit, there is a close relationship between current, voltage and resistance.

Current

An electric current is the rate of flow of charge through the material. In metals such as aluminium, gold, silver and copper, the charge is carried by free electrons. In solutions, such as sodium chloride, charge is carried by charged particles known as ions.

Insulators like wood, plastic and rubber do not have free electrons since every electron is firmly bound in their atoms or molecules.

Detection and measurement of electric current

Since the electric current cannot be seen, it can however be detected by observing some of its visible effects. Such effects include the deflection of a galvanometer when connected to a circuit as shown in Figure 2.5. Galvanometers can detect very small currents of a few hundred microamperes.

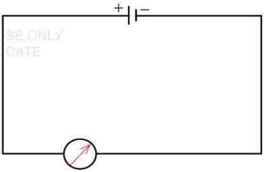


Figure 2.5: *Deflection of a galvanometer pointer in a circuit*

The rate of flow of electrons in a material is called electric current, and it is measured in amperes (A) using an ammeter shown in Figure 2.6. An ammeter is a calibrated galvanometer constructed with a known low resistance connected in parallel with galvanometer circuit. The pointer on the ammeter indicates the amount of current passing through it.

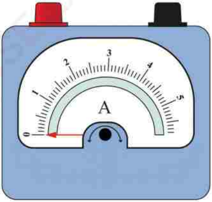


Figure 2.6: *Ammeter for measuring electric current*

The ammeter is connected to a circuit in such a way that all the current flows through it. It is designed in such a way that its presence has little effect on the current. In essence, the ammeter acts like another connecting wire.

Ammeters are sensitive to the direction of the current implying that a wrong connection can damage them. Therefore, when connecting to a circuit, the red terminal (+) should be connected to the side of the circuit which leads to the positive terminal of the battery. The black terminal (–) should be connected to the side of the circuit which leads to the negative terminal of the battery.

With reference to Figure 2.4, the current in a simple circuit is the same at all points, or else the electrons could accumulate somewhere within the circuit or even leak away. The electrons leave the negative terminal of the battery towards the positive terminal via the connecting wires as in Figure 2.4. These electrons do so at the same rate as they flow into the positive terminal.

Note that, it is not necessary to change the direction of conventional current since the flow of electrons is effectively equivalent to a transfer of positive charge from the positive terminal to the negative terminal of the battery. In other words, the flow of negative charge to the right is algebraically equivalent to the flow of positive charge to the left.

Once the circuit is complete, electric charges inside cells start to flow out into the circuit. The cells provide the driving energy for the electrons. The electrons in turn lose all potential energy as they flow round to the other terminal. Energy lost to the bulbs is normally given out as light and heat.

The amount of electric current required to run various electric appliances varies depending on the intended use. For example, a car headlamp requires a current of about 4 A passing through it while a small torch uses about 0.2 A.

Activity 2.1

Aim: To measure current in a simple circuit.

Materials: Connecting wires, ammeter, battery, bulb and a switch

Procedure

1. Using a battery, a bulb, a switch and connecting wires, construct a circuit that allows you to turn the bulb on and off as shown in Figure 2.7.

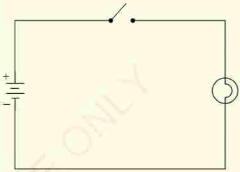


Figure 2.7

2. Connect an ammeter in the circuit as shown in Figure 2.8

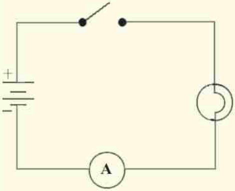


Figure 2.8

3. With the switch open, measure and record the current in amperes.

4. Close the switch, then measure and record the current as shown in Figure 2.9.

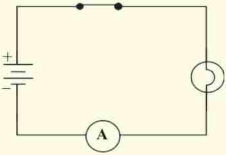


Figure 2.9

Question

Explain your observations and measurements.

In measuring electric current in the circuit, the ammeter must be connected in series with the battery and the bulb. This arrangement enables the ammeter to experience the same amount of current in the circuit as the bulb. When the switch is opened, no current flows, light goes off and no reading is observed on the ammeter. When the switch is closed, current flows, light goes on and the ammeter reading is observed.

Example 2.1

An electric current of 0.12 A passes a certain point along a conducting wire. How much electric charge is flowing past this point in a minute?

Solution

Current = 0.12 A

Time = 1 min = 60 s

Required: Electric charge

$$Charge = current \times time$$

$$Q = I \times t$$

$$0.12 \text{ A} \times 60 \text{ s}$$

$$= 7.2 \text{ C}$$

Therefore, the electric charge flowing past the point is 7.2 C

Voltage

Every cell has a voltage, commonly referred to as potential difference across its terminals. It is this potential difference (p.d) that causes the flow of electrons (charges) in a circuit. For example, a dry cell shown in Figure 2.10 has a voltage of 1.5 V. This voltage is normally marked on the cell.

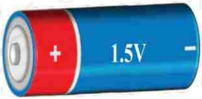


Figure 2.10: *Dry cell*

The larger the voltage, the higher the flow of electric current through a conducting medium and vice versa. Thus, voltage is defined as the difference in electric potential between two points. Voltage is measured using a voltmeter, as shown in Figure 2.11 (a). The SI unit for voltage is the volt (V).

A volt is the energy given to each coulomb of charge.

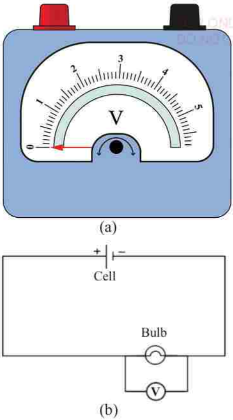


Figure 2.11: *Voltmeter and its connection in a circuit*

Voltmeter is connected across a component in a circuit, so that its positive terminal is connected towards the positive terminal of the battery and its negative terminal is connected towards the negative terminal of the battery. For such connection, a voltmeter draws very little current from the battery, and its overall effect on the current in the main circuit is almost negligible. The potential difference (p.d) between the ends of a connecting wire is zero volts since there is almost no loss of potential energy over the section. Note that if 1 joule of potential energy is changed into other forms of energy when 1 coulomb of charge passes between the points in a circuit, then the p.d between the two points is 1 volt.

Sum of p.d around a conducting path = p.d across the battery terminals.

Resistance

As current flows through the circuit, it encounters some opposition. This opposition determines the amount of current flowing in an electric device. All materials offer some resistance to the flow of electric current. Insulators offer high resistance while conductors offer low resistance. Amount of current flow depends on the voltage (p.d) across a material and the nature of the material. The higher the resistance the lower the current for a given voltage.

George Ohm observed that voltage across a conductor was directly proportional to the electric current flowing through it provided that temperature and other physical conditions of the conductor were kept constant.

Hence, $V \propto I$

$$V = IR$$

where R is the constant of proportionality. This constant is called *resistance* and the above relationship is known as Ohm's law.

Ohm's law states that at constant temperature and other physical factors, a current passing through a wire (conductor) is proportional to the potential difference across its ends.

This implies that,

$$\textit{Resistance, } R = \frac{\textit{p.d across the conductor, } V}{\textit{current through the conductor, } I}$$

Therefore, a resistance of 1 ohm is obtained when a p.d of 1 V causes a current of 1 A to flow in a circuit.

Resistance is measured in ohms (Ω). Other multiples of the unit are kiloohm (kΩ) = 10^3 Ω, megaohm (MΩ) = 10^6 Ω, milliohm (mΩ) = 10^{-3} Ω and microohm (μΩ) = 10^{-6} Ω.

Resistors

Resistors are the most commonly used electronic components that play a vital role in a circuit. These components are designed to offer specific resistance to the flow of an electric current in a circuit. They can maintain currents and potential differences at the levels needed for other circuit components to function properly.

A resistor whose value does not change with the change in voltage is called *fixed resistor* or *standard resistor*. Standard resistor values can be checked from a resistor colour-code chart. Resistors whose values can be changed by the experimenter are called *variable resistors*. The rheostat in Figure 2.12 (a) is an example of the variable resistor. Figure 2.12 (b) shows a fixed resistor with colour codes.

Figure 2.12: *Resistors*

Materials through which current flow is directly proportional to the p.d across them, at a steady temperature, are said to obey Ohm's law. They are referred to as Ohmic conductors.

A graph of voltage against current for an ohmic conductor is shown in Figure 2.13.

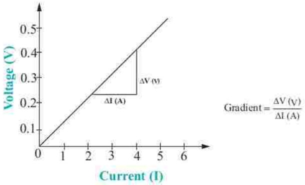


Figure 2.13: *Graphical representation of Ohm's law*

The gradient of the graph represents resistance. The gradient is constant. The resistance of a particular wire or conductor is constant. If the voltage is doubled, so will the current. The graph of voltage against current passes through the origin. The results obtained from various experiments have shown that the resistance of a conductor is affected by several factors. These include;

1. **Length of the conductor**
   A short length of a wire has small resistance while a long wire of the same material and thickness has a large resistance.
2. **Temperature**
   The higher the temperature of the conductor the higher the resistance and vice versa. The resistance of most metal conductors increases with increase in temperature, though this is much less in some cases than in others. In such a case the conductor does not obey Ohm's law. Hence:
   (a) Constantan (copper – nickel alloy) is used in standard resistors since its resistance changes to a very small extent in a wide range of temperature.
   (b) Connecting wires used in circuits have a very low resistance to keep the energy that is wasted as heat to a minimum. Heating elements of electric kettles and cooker are made from wires of known large resistance to ensure that heat (thermal energy) is released at a specific rate.
3. **Nature of material**
   The conducting ability of a material has to be considered. A nichrome wire has higher resistance than a copper wire of the same dimension. This is why nichrome wires are used in heating elements of electric heaters. Also, due to its low resistance, copper is mostly used for connecting wires in circuits, including wiring in houses.
4. **Cross-sectional area**
   A thin wire has higher resistance than a thick wire of the same length and material. The filament of a bulb is made up of a very thin tungsten wire. It therefore has a high resistance necessary to produce large amount of heat to light the bulb.

Comparing copper and nichrome wires, these factors can be summarised as shown in Figure 2.14.

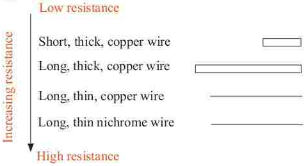


Figure 2.14: *Comparison of copper and nichrome wires basing on their cross-sectional area and resistance*

With all other factors being kept constant, a long wire has a higher resistance than a short wire, and a thin wire has a higher resistance than a thick one.

Construction of simple electric circuits

Figure 2.15 shows a circuit consisting of a battery, a switch and 2 bulbs.

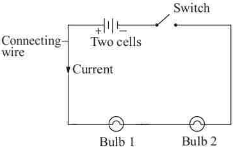


Figure 2.15: *Simple electric circuit diagram*

When the switch is closed, the current flows through the circuit, and the bulbs light up. The circuit is said to be complete. When the switch is opened, no current flows through the wire as the path carrying the current is broken. The circuit is said to be incomplete.

When constructing an electric circuit, we must be certain that there is a complete path for the current to flow from the battery through any external devices and back to the battery. It is a good idea to first sketch a schematic diagram of the circuit. On the diagram, use a pencil to trace the path the current will follow. You should be able to do this without lifting the pencil. Also, remember that the conventional current is the flow of positive charge, so the current leaves the positive terminal of the battery and returns to the negative terminal.

Consider a simple circuit containing two dry cells, a lamp and connecting wires as shown in Figure 2.16 (a). Figure 2.16 (b) is the schematic diagram showing the direction of the conventional current of this circuit.

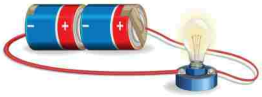


Figure 2.16 (a): *Simple circuit diagram*

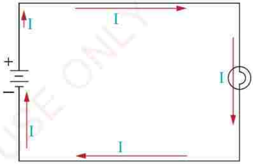


Figure 2.16 (b): *Schematic diagram of a circuit*

A switch can be added to the circuit so that the light can be turned on and off as shown in Figure 2.16 (c).

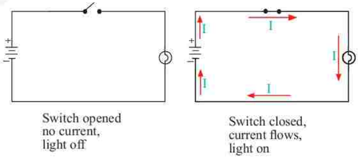


Figure 2.16 (c): *Schematic diagram of circuits with switches*

In order to control the brightness of the lamp, a rheostat has to be included in the circuit as shown in Figure 2.16 (d).

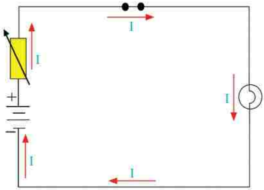


Figure 2.16 (d): *Circuit with rheostat to control the lamp's brightness*

To determine the amount of current flowing in the circuit, an ammeter is inserted as shown in Figure 2.16 (e).

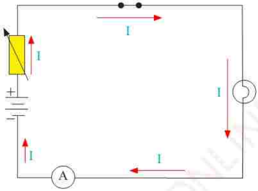


Figure 2.16 (e): *Circuit with ammeter*

In a circuit, an ammeter is always connected in series to the battery. The current has to pass through the ammeter if it is to be measured. Unlike the ammeter, a voltmeter is connected in parallel to a component so as to measure the voltage drop across it. Figure 2.17 shows a simple electric circuit in which the ammeter and voltmeter are connected in series and parallel to a bulb, respectively.

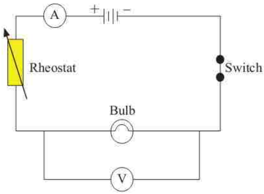


Figure 2.17: *Voltmeter, ammeter and a rheostat in circuit*

As already learnt, resistance is the ratio of the potential difference across the ends of a conductor to the current flowing through the conductor. Radio and television sets contain large number of resistors, ranging from few ohms to millions of ohms. Some are made by winding wire while others are made from carbon or graphite. For connection purposes, resistors are provided with wire ends or terminals as shown in Figure 2.18.

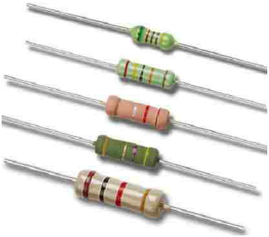


Figure 2.18: *Carbon resistors*

Activity 2.2

Aim: To verify Ohm's law.

Materials: Voltmeter, ammeter, connecting wires, cell, variable resistor, unknown resistor, switch

Procedure

1. Connect a switch, an ammeter, unknown resistor and the variable resistor to the battery in series as shown in Figure 2.19.

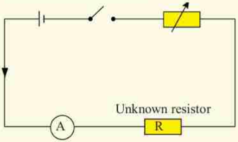


Figure 2.19

2. Connect a voltmeter parallel to the unknown resistor as shown in Figure 2.20.

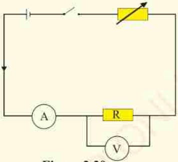


Figure 2.20

3. Close the switch, then record the ammeter and voltmeter readings.
4. Adjust the rheostat so that the lowest possible current and corresponding voltage are obtained.
5. Move the sliding terminal of the rheostat to increase the current gradually. Record the values of current, I and potential difference, V in Table 2.2.

Table 2.2: *Observation Table for V, I and R*

No.	p.d (V)	Current (A)	Resistance (Ω)
1.			
2.			
3.			
4.			
5.			

Question

Calculate the resistance of the unknown resistor.

The resistance of the unknown resistor, R is calculated using the formula: $R = \frac{V}{I}$ The average of the values in the third column of Table 2.2 gives a value for the resistance of the unknown resistor. In the above activity, the rheostat (variable resistor) has been used for varying the current in a circuit. Note that, as the sliding terminal of rheostat moves, it varies the length of the conductor being used in making the rheostat.

Note: For a single loop or simple circuit:

1. Current is the same at all points around the circuit.
2. The sum of the potential differences around a conducting path from one battery terminal to the other terminal within the circuit is the same as the p.d across the battery.

Example 2.2

A resistance wire of 20 Ω is connected across a battery of 5 V. Calculate the current in the circuit.

Solution

Resistance, $R = 20\ \Omega$

Potential difference, p.d $= 5$ V

Required: Current, $I = ?$

From;
$$I = \frac{V}{R}$$
$$= \frac{5\ \text{V}}{20\ \Omega}$$
$$= 0.25\ \text{A}$$

Therefore, the amount of current is 0.25 A.

Example 2.3

An ohmic conductor has a voltage drop of 9 V measured across it. The current flowing in the conductor is 3 mA. What is its resistance?

Solution

Voltage drop, $V = 9$ V

Current, $I = 3\ \text{mA} = 3 \times 10^{-3}\ \text{A}$

Required: Resistance, $R = ?$

From; $V = IR$
$$R = \frac{V}{I}$$
$$= \frac{9\ \text{V}}{3\times10^{-3}\ \text{A}}$$
$$= 3000\ \Omega$$

Therefore, the resistance is $3\,000\ \Omega$.

Example 2.4

Calculate the readings of the voltmeter P and the ammeter Q in the electric circuit in Figure 2.21 when the switch is closed.

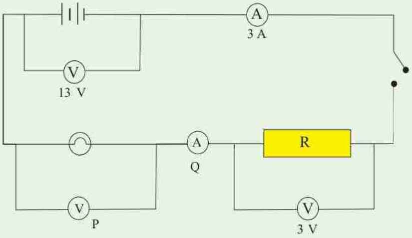


Figure 2.21

Solution

Being a single loop circuit, the current is the same at all points.

Therefore, the reading of ammeter Q is 3 A.

Sum of p.d in external circuit = p.d across battery

$$3\text{ V} + P = 13\text{ V}$$

$$P = 10\text{ V}$$

Therefore, the reading of Voltmeter P is 10 V.

Exercise 2.1

1. In an experiment to determine the value of resistance, the following results were obtained.

Voltage (mV)	0.04	0.08	0.2	0.21	0.22
Current (mA)	5.5	10.5	20.3	28.9	30

From the experimental results:

(a) draw a graph of V against I

(b) determine the resistance R

2. A current of 0.25 A flows through a circuit of voltage 10 V across a bulb. What is the resistance of the bulb?

3. Describe factors that affect the resistance of a conductor.

4. (a) What do you understand by an ohmic conductor?

   (b) A resistor has a resistance of 500 Ω. How could this resistance be measured experimentally?

   (c) Which has a greater resistance; a long, thin, hot nichrome wire or a short, thick, cool copper wire?

   (d) If a p.d of 6.0 V is measured across the ends of a wire of resistance 12 Ω,

   (i) determine the current that flows through it.

   (ii) calculate the p.d that is required to produce a current of 1.5 A flowing through it.

Task 2.3

In groups, collect wires of different thicknesses (cross-sectional areas) and carry out the following tasks inside the Physics laboratory.

1. Measure and record the lengths and thicknesses of the wires.
2. Use Figure 2.22 to construct a simple circuit that can compare the current passing through each of the wires connected between A and B.

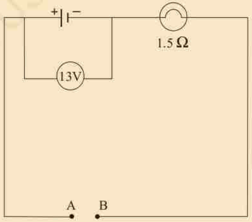


Figure 2.22

3. List the wires in their order of increasing resistance.

Connection of resistors

Resistors can be connected either in series or in parallel depending on the desired output.

(a) Series connection

In series connection, the resistors are connected end to end as shown in Figure 2.23. In this case, voltages are additive. The total potential difference (V_T) is given by;

$$V_T = V_1 + V_2$$

This means that the sum of the p.d across the resistors is the same as the p.d across the battery. The current is the same at all points around the circuit. That is;

$$I_1 = I_2 = I$$

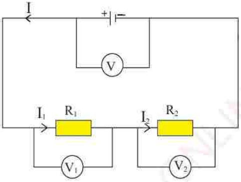


Figure 2.23: *Resistors in series*

From Ohms' law,

$$V = IR$$

Then,

$$V_1 = I_1R_1 \text{ and } V_2 = I_2R_2$$

$$V_T = I_1R_1 + I_2R_2 = IR_T$$

Since the current flowing through the resistors is the same;

$$IR_T = IR_1 + IR_2$$

$$R_T = R_1 + R_2$$

Therefore, total resistance or equivalent resistance for resistors in series is equal to the sum of individual resistances.

(b) Parallel connection

Resistors are connected across two common points in a parallel arrangement as shown in Figure 2.24.

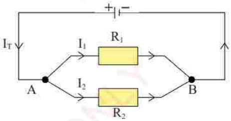


Figure 2.24: *Resistors in parallel*

In parallel connection, potential difference is from a single source; so, it is the same for all the branches. However, the current is different in each branch.

From Figure 2.24:

Total current $I_T = I_1 + I_2$

From Ohm's law;

$$V = IR$$

$$I = \frac{V}{R}$$

Then, $I_T = I_1 + I_2$

$$\frac{V}{R_T} = \frac{V}{R_1} + \frac{V}{R_2}$$

$$V\left(\frac{1}{R_T}\right) = V\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$R_T = \frac{R_1 R_2}{R_1 + R_2}$$

Therefore, total resistance for two resistors connected in parallel is given by;

$$Total\ resistance = \frac{Product\ of\ resistances}{Sum\ of\ resistances}$$

When resistors are connected in series, they give larger resistance than when connected in parallel. In parallel connection, each resistor has the same potential drop across it, and the currents through each resistor may be different depending on the resistance of a given resistor.

Note that, where bulbs have to be powered by a single source of electric current, the bulbs are connected in parallel (see Figure 2.25). This is practised in cars and home lighting systems. The advantages of a parallel connection over a series connection are:

1. The full p.d of source is applied across each bulb irrespective of the number of bulbs.
2. Switching one bulb on or off does not affect the others.

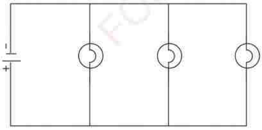


Figure 2.25: *Parallel arrangement of bulbs*

Activity 2.3

Aim: To study the flow of current through bulbs connected in series and parallel.

Materials: Bulbs, bulb holders, ammeters, battery of 2 cells, switch, connecting wires

Procedure

1. Connect a battery to two bulbs arranged in series as shown in Figure 2.26.

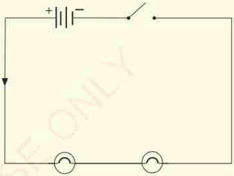


Figure 2.26

2. Add a suitable ammeter by connecting it to the circuit as shown in Figure 2.27.

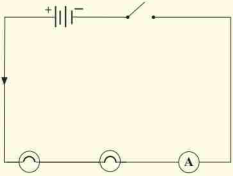


Figure 2.27

3. Switch on the circuit and note the ammeter reading.

4. Record your observations.
5. Open the switch, then move the ammeter to different positions within the circuit as shown in Figure 2.28.

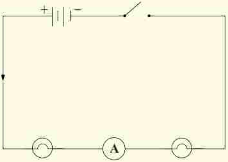


Figure 2.28

6. Switch on the circuit and record your observations.
7. Remove one bulb from the series circuit and record the ammeter reading.
8. Now, connect the two bulbs in parallel as shown in Figure 2.29.

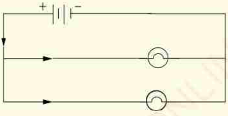


Figure 2.29

9. Add switches by connecting them to your circuit as shown in Figure 2.30.

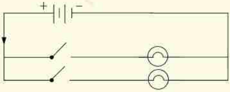


Figure 2.30

10. Switch on the circuit and record your observation.
11. Connect three ammeters to the circuit as shown in Figure 2.31, close the switches and record the readings.

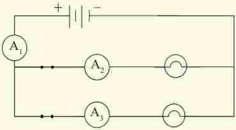


Figure 2.31

Questions

(a) What can you conclude about the current in steps 3, 6 and 11?

(b) How are the light bulbs in your home connected?

Example 2.4

Consider the circuit shown in Figure 2.32. If the p.d across the battery is 24 V, calculate the p.d across the 4 Ω and 6 Ω resistors.

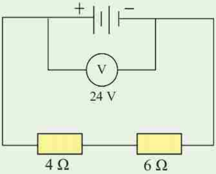


Figure 2.32

Solution

Total resistance in the circuit = 4 Ω + 6 Ω = 10 Ω

Using Ohm's law,

$$I = \frac{V}{R}$$

Current in the circuit,

$$= \frac{24\text{ V}}{10\ \Omega}$$

$$= 2.4\text{ A}$$

Voltage across 6 Ω and 4 Ω

p.d across 6 Ω	p.d across 4 Ω
$V = IR$	$V = IR$
$= 2.4 \times 6$	$= 2.4 \times 4$
$= 14.4$ V	$= 9.6$ V

Therefore, p.d across 6 Ω and 4 Ω are 14.4 V and 9.6 V, respectively.

Exercise 2.2

1. Use information in Figure 2.33 to calculate:
   (a) the p.d across the 5 Ω resistor.
   (b) the current value across the resistor of 3 Ω.

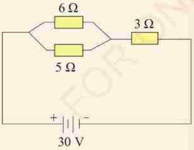


Figure 2.33

2. What is the difference between series and parallel circuit connection?

3. What is the p.d across the 2 Ω resistor in Figure 2.34?

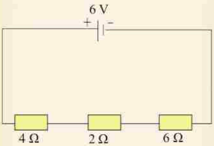


Figure 2.34

4. Calculate the combined resistance in Figure 2.35 (a), (b) and (c).

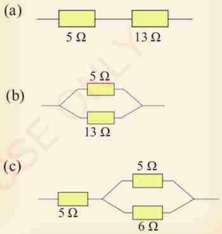


Figure 2.35

Chapter summary

1. Electric current is the amount of charge passing through a given point in a circuit per second.
2. Electric current is expressed as the rate of flow of electric charge, $I = \frac{Q}{t}$.

3. Electric current is one of the fundamental quantities and is measured in units of coulombs (C) per seconds (s) called amperes (A).

4. The direction of conventional current is opposite to the flow of electrons.

5. Electric current flows in all complete paths that allow it to return to its source. Electric circuits contain a source of moving electric charges such as a battery or a generator.

6. Resistors are used to control the flow of current and voltage in a circuit while obeying Ohm's law.

7. Ohm's law states that "at a constant temperature and other physical factors, voltage across the ends of a conductor is directly proportional to the current flowing through that conductor".

8. Resistance is the ratio of the potential difference across the ends of a conductor to the current flowing through that conductor.

9. The voltage is the amount of potential difference in an electric circuit.

10. Ammeters are connected in series to the source of electric charge while voltmeters are connected in parallel to the load and battery.

11. Total resistance for resistors in series is equal to the sum of individual resistances.

12. For any two resistors connected in parallel;

$$\textit{Total resistance} = \frac{\textit{Product of resistances}}{\textit{Sum of resistances}}$$

That is;

$$R_T = \frac{R_1 R_2}{R_2 + R_1}$$

13. The amount of current in a circuit can be measured by using an ammeter.

Revision exercise 2

Choose the most correct answer in items 1-3.

1. For a device in an electric circuit to work, the current must flow through it. Using Figure 2.36, select the circuit in which the bulb will light.

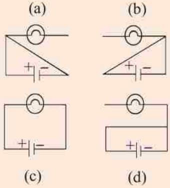


Figure 2.36

2. A current of 1.0 A passes in the circuit shown in Figure 2.37. What is the resistance of P?

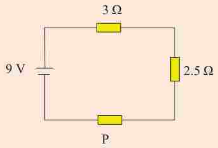


Figure 2.37

(a) 1.5 Ω (b) 3.5 Ω

(c) 4.5 Ω (d) 2.5 Ω

3. The resistance of most metal conductors:
   (a) increases with increasing temperature.
   (b) increases with decreasing temperature.
   (c) decreases with increasing temperature.
   (d) decreases with decreasing temperature.

4. Match each item in **column A** against its corresponding item from **column B** by writing the correct response in the answer column provided.

Column A	Answer	Column B
(a) Ammeter (b) Voltage is proportional to current (c) Rheostat (d) Series connection (e) Charge		(i) Measures p.d (ii) Measures current (iii) Ohm (iv) Controls current (v) Ohm's law (vi) Controls p.d (vii) Coulomb (viii) Constant current (ix) Galvanometer (x) Constant p.d

5. (a) Explain the following concepts:
   (i) electric current.
   (ii) resistance.
   (iii) voltage.

   (b) Convert these currents into amperes:
   (i) 500 μA.
   (ii) 250 μA.

6. In an electric circuit, the current will flow along any complete path that allows the current to return to its source. In the circuit shown in Figure 2.38:
   (a) Which bulb will light? why?

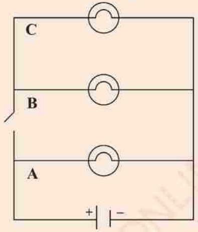


Figure 2.38

   (b) Sketch the circuit in (a) and use arrows to show the direction in which the current flows.

7. Consider the circuit in Figure 2.39;
   (a) If bulb A burnt out, will bulbs B and C light up? Explain your answer.

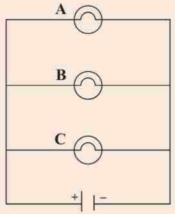


Figure 2.39

   (b) Sketch the circuit in (a) and use arrows to show how the current will flow after bulb A burns out.

8. (a) Differentiate between potential difference and current.
   (b) Using a diagram, show how an ammeter is connected to measure the current flowing through resistor, *R*.
   (c) Draw a circuit diagram to show how a voltmeter is used to measure the potential difference of load, *R*.

9. (a) State Ohm's law.
   (b) What is the SI unit of resistance ?

10. What could be the effect on the resistance of a conductor if:
   (a) its length was increased?
   (b) its temperature was increased?
   (c) its cross-sectional area was reduced?

11. A current of 100 mA flows through a 5 kΩ resistor. Determine the p.d across the resistor.

12. Three resistors of 2 Ω, 3 Ω and 6 Ω are connected in series to a 3 V battery. What is the current in the circuit?

13. (a) Two resistors of 6 Ω and 12 Ω are connected in parallel. Calculate their total resistance.

    (b) Two resistors of 3 Ω and 6 Ω are connected in parallel.

    (i) Draw the schematic diagram of the circuit.

    (ii) Determine the total resistance of the circuit.

    (iii) Calculate the p.d of the circuit when the current across it is 5 A.

14. Consider the circuit in Figure 2.40.

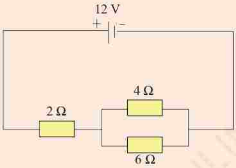


Figure 2.40

(a) Find the equivalent resistance.

(b) Determine the current in the circuit.

15. Suppose an additional 2 Ω resistor is connected in parallel to the cell in Question 14.

    (a) Draw the circuit diagram.

    (b) Calculate the resistance of the circuit.

16. Basing on your observations in Activity 2.1, does adding an ammeter to a circuit affect the amount of current flowing? Explain your answer.

17. Two resistors of resistances 2 Ω and 4 Ω are connected to a circuit. Calculate the resistance of the circuit when:

    (a) resistors are connected in parallel.

    (b) resistors are connected in series.

18. Considering Figure 2.41, which one has a lower combined resistance?

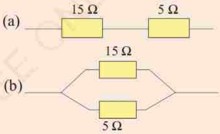


Figure 2.41

19. Calculate the combined resistance for each in Figure 2.42 (a) and (b).

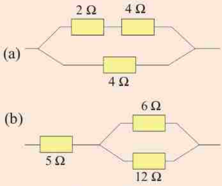


Figure 2.42

20. Given two resistors, 4 Ω and 6 Ω, and a battery, explain how you can connect them in a circuit.

21. If the p.d between points A and B in Figure 2.43 is 22 V, calculate the current between the points.

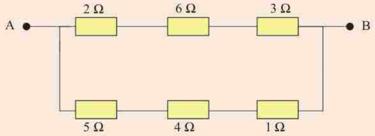


Figure 2.43

Chapter Three

Magnetism

Introduction

Knowledge of magnetism has triggered a number of useful applications in daily life, dating from the historical navigation by the Greeks to the present day digital world. In this chapter, you will learn the concept of magnetism and how materials can be magnetised or demagnetised. You will also learn about magnetic fields including the Earth's magnetic field. The competencies developed will enable you to make magnets, design methods of storing them and apply magnetic shielding. You will also be able to apply the knowledge of magnetism to lift loads.

Concept of magnetism

Magnetism is a phenomenon produced by the motion of electric charge that results in attractive and repulsive force between objects. The earliest observation of magnetism was recorded in the 600 BC by a Greek philosopher Thales. He observed that pieces of iron were attracted to a natural mineral iron ore called magnetite or triiron tetraoxide. The lodestone is an example of magnetised piece of a mineral magnetite. Figure 3.1 shows an iron ore.

Figure 3.1: *Iron ore*

The lodestone has a tendency to attract certain metals more strongly at specific points on its surface than others. Any material that has properties similar to those of the lodestone is called a *magnet*. When magnets attract or repel each other they exert a force called *magnetic force*.

Magnetism arises from two types of electron motion as shown in Figure 3.2. The first is the motion of electrons around the nucleus of an atom. The second type of motion is the spin of electrons about their own axes. These motions of charged particles independently impart a magnetic effect, causing an atom to behave like a tiny magnet.

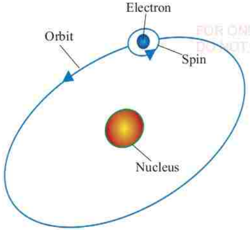


Figure 3.2: *Orbit of a spinning electron around the nucleus of an atom*

In many atoms, these magnetic effects cancel each other while in other atoms they do not cancel completely.

Magnetic and non-magnetic materials

When a magnet is brought near different objects, some will be attracted or repelled, and for others they will not. Objects that are attracted are said to possess *induced magnetism*. The process by which a material becomes a magnet due to its closeness or contact with a magnet is called *induction*.

The induced magnetism can be *temporary* or *permanent* upon the removal of the magnet in contact. The nature of the material being magnetised determines how long the induced magnetism lasts. For example, iron exhibits temporary magnetism while materials like steel tend to retain their magnetism for a long time. Materials which are not affected by a magnet are called non-magnetic materials.

Activity 3.1

Aim: To identify magnetic and non-magnetic materials.

Materials: Bar magnet, knife, blade, copper rod, paper, glass rod, iron nail, water, wooden toothpick, chalk, aluminium foil, lead (graphite) pencil, sand

Procedure

1. Place in turn each of the materials close to a bar magnet.
2. Note down your observations.

Questions

(a) List the magnetic and non magnetic materials.

(b) State whether the magnetic materials have anything in common.

(c) What about the non-magnetic materials?

Metallic materials like iron, nickel and cobalt become magnetised when exposed to the influence of a magnet. They are thus, magnetic in nature. Magnetic materials are those which can be magnetised by even weak magnets. Materials that are attracted to a magnet and can be strongly magnetised, are called *ferromagnetic materials.*

Ferromagnetic materials contain either iron, nickel or cobalt. These materials are grouped as magnetically hard or soft depending on how well they retain their magnetism when magnetised.

Magnetically hard materials such as steel do not readily lose their magnetism though they are difficult to be magnetised. They are used to make permanent magnets. On the other hand, soft magnetic materials like iron can be easily magnetised, but they tend to lose their magnetism easily. As a result, they are used in the cores of electromagnets and transformers.

Brass, copper, tin, zinc and aluminium are non-magnetic materials. These materials are not attracted by a magnet. Non-metals, for example plastic, rubber, water, wood and ceramics are also non-magnetic. These materials cannot be magnetised.

Types of magnets

Magnets are categorised according to their sources of magnetism as follows:

Temporary magnets acquire magnetism due to an applied external magnetic field but lose their magnetism when the external field is removed. These magnets retain magnetism in a short time (i.e the time during which the magnetising field is present). For example, the magnetism that is induced in iron is temporary and is lost once the external magnet is withdrawn. Iron nails and paper clips shown in Figure 3.3 (a) are good examples of objects that can be temporarily magnetised. An electromagnet used in magnetic cranes as shown in Figure 3.3 (b) is an example of a temporary magnet.

(a) Iron paper clips and nails

(b) Magnetic crane

Figure 3.3: *Temporary magnets*

Permanent magnets retain some magnetism even after the external magnetic field is removed. Such materials include an alloy composed of aluminium, nickel and cobalt (Alnico), or ceramic like material made from a mixture of iron oxides with nickel, strontium, or cobalt (ferrites) that become magnetised in a magnetic field. These magnets may be naturally occurring "rare-earth" elements or chemical compounds. An example of a permanent magnet is the bar magnet shown in Figure 3.4.

Figure 3.4: *Bar magnet*

Electromagnets are temporary magnets whose magnetism is generated by an electric current. An energised coil creates a magnetic field. A solenoid with a piece of iron core is an example of an electromagnet. An electromagnet can be quickly switched on and off, and its strength can be varied by adjusting the electric current.

Electromagnets, however, have the disadvantage that they require a continuous supply of electrical energy to maintain the magnetic field. When the current is switched off, the magnetic field disappears.

Electromagnets are preferred for applications that require strength including rail road tracks, motor engines, microphones, hard drives, Magnetic Resonance Imaging (MRI) machines, home security systems and cranes. They are also used in computer and television hardware, as well as in alarm systems. Figure 3.5 shows a magnetic disc as an example of an electromagnet.

Figure 3.5: *Magnetic disc*

Properties of magnets

When you closely examine a bar magnet, you see one end marked N and the other end marked S. Every magnet regardless of its shape and size, has two poles. N represents a North pole and S represents a South pole as shown in Figure 3.6.

Figure 3.6: *Bar magnet showing the N and S poles*

These poles are always marked during the process of manufacturing for easy identification. Colouring is also used to mark the poles as shown in the Figure 3.6.

Activity 3.2

Aim: To investigate the properties of magnets.

Materials: Bar magnets, block of wood, iron filings, water, string, compass needle, retort stand

Procedure

1. Place the north pole of one bar magnet near the south pole of another bar magnet.
2. Bring the two north poles together and then do the same for the two south poles.
3. Record your observations.
4. Pour some iron filings onto a sheet of paper and bring the north pole of one magnet near but not touching them.

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5. Now bring the south pole near the filings but not touching.
6. Finally, bring the middle of the magnet near but not touching the filings.
7. Note your observations.
8. Tie a string around the middle of a bar magnet and suspend it in the air as shown in Figure 3.7.

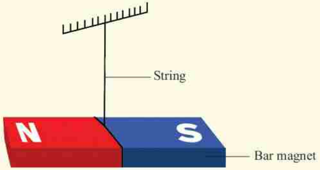


Figure 3.7

9. Gently push one end of the magnet so that it slowly spins and comes to rest.
10. Note the direction in which the magnet's north pole is pointing.
11. Push the magnet again and wait for it to come to rest.
12. Place a block of wood in a pan of water and lay the bar magnet on top as shown in Figure 3.8. Note what happens.

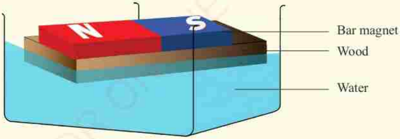


Figure 3.8

Questions

(a) Did the iron filings stuck to the magnet while picking up more filings?
(b) Does a magnet always point in the same direction?
(c) Compare the direction of the suspended magnet with that of a compass needle. Does the magnet line up with the compass needle?
(d) Explain your observations and identify some of the properties of a magnet.

Some of the properties of magnets and magnetism can be summarised as follows:

1. All magnets have two poles, the north and south poles.
2. Magnets exert a force on some materials and do not on others.
3. Magnets attract ferromagnetic materials such as iron, nickel and cobalt.
4. The magnetic force is an action-at-a-distance force.
5. In a bar magnet more iron filings stick to the poles, meaning that the magnetic force is the strongest near the poles of a magnet, and that the poles have equal strength.
6. When two magnets are brought together, like poles repel each other while unlike poles attract as shown in Figure 3.9. This is the basic law of magnetism.

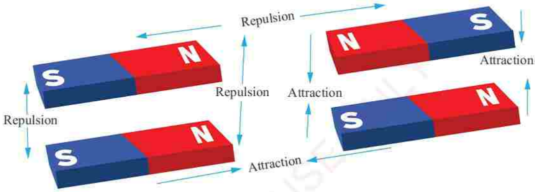


Figure 3.9: *Attraction and repulsion of magnetic poles*

7. A freely suspended bar magnet always points in a north – south direction. The north pole of a freely suspended magnet points in the north direction, and the south pole points in the south direction of the earth. Likewise, the arrow of a compass needle points towards the north direction.

Shapes of magnets

Magnets are of different types and they work in different ways. They differ in materials, shapes, sizes, functions, forces and applications. For example, magnets can have different shapes, which include bar, horseshoe and disc as shown in Figure 3.10. Magnets also vary in size from tiny discs used in speakers to large magnets used in commercial power-generating plants. One of the largest magnets is perhaps the earth itself.

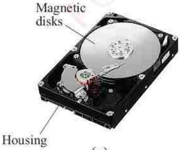
Figure 3.10: *Types of magnets according to their shapes*

Applications of magnets

Magnets are widely used in various electronic devices as explained in the following examples:

1. **Magnetic recording media**

   Magnetic recording is a technology that stores information on a magnetic medium. Examples of magnetic recording media include computer hard discs and magnetic tapes as shown in Figure 3.11. In the hard disc the magnetic material is coated with aluminium or glass. The magnetic tape is a plastic strip coated with a ferromagnetic material. The recorded information can be retrieved by playing back, using a special head.



(a)

(b)

Figure 3.11: *Magnetic recording media*

2. **Credit, debit and ATM cards**

   These have a magnetic strip on one of their sides. This strip contains the necessary information to contact an individual's financial institution and connect with their account. These automatic cash cards also use magnetic ink to store information. Figure 3.12 shows an example of an automatic cash card.

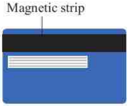


Figure 3.12: *ATM card*

3. **Common television and computer monitors**

   These employ an electromagnet in their inputs so as to assist in producing an image on the screen (see Figure 3.13).

Figure 3.13: *Image as observed on a TV screen*

4. **Speakers and Microphones**

   These use permanent magnets and current-carrying coils to convert electric energy into sound and sound energy to electrical energy respectively. For example, hi-fi stereo speakers (see Figure 3.14) have very powerful magnets in order to produce high-quality sound and sufficient volume.

Figure 3.14: *Speaker*

5. **Electric generators**

   These use permanent magnets to convert mechanical energy to electrical energy.

6. **Transformers**

   These are used in power transmission and in many electronic devices as shown in Figure 3.15 (a) and (b).

Figure 3.15 (a): *Transformer for power transmission*

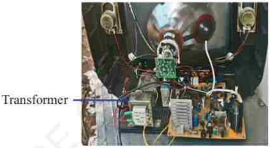


Figure 3.15 (b): *Small transformer in a television set*

   Transformers used in electronic devices have the purpose of getting low voltages from the 240 V AC mains for use in radios, hi-fi systems, computers, TV and door bells.

7. **Electromagnets**

   These are used in hospitals when dealing with eye injuries caused by iron or steel splinters. They are also used in Magnetic Resonance Imaging (MRI) to diagnose brain tumours, haemorrhage, nerve injury and stroke injury. Electromagnets are also applicable in steel works and on cranes.

8. **Moving coil meters**

   A horseshoe magnet is used in voltmeters and ammeters. It is an inbuilt part of these devices that enables the pointers to move in a direction of increasing voltage or current.

Task 3.1

In groups, use books and the internet to identify other ways in which magnets are used. Write a report on your findings and present it to the rest of the class.

Magnetisation and demagnetisation

Magnets are manufactured by aligning the tiny atomic magnets of a material. The process of making a magnet is called *magnetisation.* Likewise, *demagnetisation* is the process of destroying or removing the magnetism in a magnetised material.

Magnetisation

The atoms of most materials act like tiny magnets called atomic dipoles. If the material is not yet magnetised its atomic dipoles randomly align forming magnetic domains as shown in Figure 3.16.

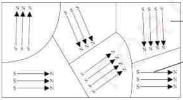


Figure 3.16: *Random alignment of atomic dipoles in unmagnetised material*

If atomic dipoles arrange in such a way that N poles of all the dipoles face in one common direction, the material is said to be magnetised.

Magnetisation is the process of aligning the atomic dipoles in a material in one direction so as to produce a net effect of attraction or repulsion.

The domains may exhibit a net magnetic behaviour in the absence of an external magnetic field. On applying external magnetic field, all dipoles align themselves in the direction of the applied field. In this way the material is strongly magnetised in the direction parallel to the magnetising field as shown in Figure 3.17.

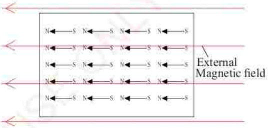


Figure 3.17: *Aligned atomic dipoles in a magnetised material*

Materials in which it is possible to cause this alignment are either ferromagnetic or paramagnetic. *Ferromagnetic* materials such as steel, nickel and cobalt can form permanent magnets while *paramagnetic* materials such as aluminium and chromium can only be weakly magnetised.

The alignment of domains in these materials can be achieved through one of the following methods:

1. Heating or vibration method
2. Stroking method
3. Electric method

In the first method of magnetisation, an external magnetic field is required. Placing an object in an external magnetic field will result in some degree of alignment. Vibrating or heating the object can increase the amount of alignment by causing the atomic dipoles to move and eventually become aligned.

Many natural magnetic materials start out as part of lava (molten rock). If the lava contains ferromagnetic minerals, the atoms align with the earth's magnetic field that is subject to vibration while the rock is still liquid. As the rock cools and solidifies, the alignment becomes permanent.

Activity 3.3

Aim: To demonstrate magnetic alignment.

Materials: A small glass or plastic jar, iron filings, magnifying glass, bar magnet

Procedure

1. Fill in the small glass or plastic jar with iron filings.
2. Examine the filings with a magnifying glass.
3. Now place the jar of filings alongside a strong bar magnet and gently shake the jar for a few seconds.
4. Observe the filings again using a magnifying glass as shown in Figure 3.18.

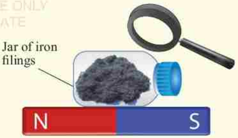


Figure 3.18

Questions

(a) What did you observe?

(b) Explain your observations.

In the second method of magnetisation, a piece of unmagnetised material is stroked using a magnet. An existing magnet is moved from one end of the material to the other in the same direction. This process is repeated several times. The pole produced at the end of the stroke is always the opposite of that at the end of the magnet used for stroking. For example, if the north pole of the magnet is used for stroking, then the rod will be magnetised such that its starting end will act as the north pole and other end as the south pole as shown in Figure 3.19.

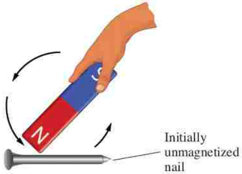


Figure 3.19: *Single-touch method*

After completing stroking, care has to be taken not to move the magnet close to the nail because this is taken as a repeat stroke. It disorganises the already aligned dipoles. The stroking method whereby only one magnetising magnet is used is called *a single-touch method*.

When two magnetising magnets are used in the stroking, the method is called *a double-touch method*. In this process an iron nail can be magnetised by using two permanent magnets. The ends of two magnets of different polarities are positioned at the middle of the iron nail. The two magnets are then moved in a curved motion in the opposite directions as shown in Figure 3.20. The iron nail is stroked a few times along its length. It is important that this procedure is done with care to ensure the proper magnetisation of the iron nail.

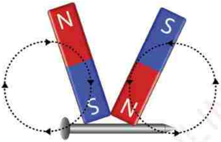


Figure 3.20: *Double touch method*

Activity 3.4

Aim: To magnetise a steel rod by single-touch method.

Materials: Steel rod, bar magnet, pins

Procedure

1. Place the steel rod on a flat surface.
2. Drag the pole of a bar magnet from one end of the rod to the other.
3. When the other end is reached, lift away the magnet from the rod and bring back to the starting end.
4. Repeat step 2 ten times. The stroking should involve wide loops.
5. Test for the magnetism using the pins (load them one below the other).

Questions

(a) Why must step 2 be repeated?

(b) Why are wide loops necessary when stroking?

(c) State the significance of loading the pins one below the other.

For each stroke, a number of dipoles align themselves in one direction. Stroking is repeated to ensure that a maximum number of dipoles have aligned themselves to such a level that the end product is a magnet. A state when no further alignment takes place is known as *saturation.* A load of pins placed one after the other is used to test for saturation. If the magnet can hold the pins, then it has reached its saturation. During stroking, a wide loop is advised so that the alignment of the dipoles is not disturbed.

The third method of magnitisation relies on the fact that an electric current produces a magnetic field. A long wire is wrapped around an object such as a nail and connected to a battery as shown in

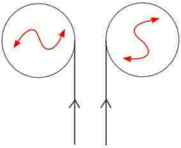
Figure 3.21. The direct current supplied in the wire produces a magnetic field that magnetises the nail. The combined effect of all the turns of wire produces a field similar to that of a bar magnet.

A wire coil of several turns is called *a solenoid*. In order to increase the field strength of the magnet formed by solenoid, a soft iron core is inserted in the solenoid, and a large current is passed through the wire. The number of turns of the wire is also increased. This is an industrial way of making a magnet. The solenoid produces an electromagnet that acts like a bar magnet.

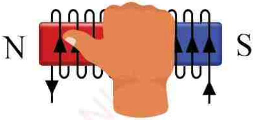
Figure 3.21: *Electric method of magnetization*

Polarity of a magnet can be determined by the direction of the current. When looking at the nail, the end that has current flowing in a clockwise direction is the S pole. If it flows anticlockwise, the end acts as the N pole. See Figure 3.22 (a). This is the rule for magnetic polarity.

Also, a right hand grip rule can be used to indicate the polarity of the magnetised material. The rule states that "if the fingers of the right hand grip the solenoid in the direction of the current, then the thumb points to the N pole of the solenoid" as shown in Figure 3.22 (b).



(a) Rule of magnetic polarity



(b) Right hand grip rule

Figure 3.22: *Rules of polarity*

Activity 3.5

Aim: To magnetise a steel bar.

Materials: Steel bar, battery, switch, solenoid of copper wire, iron filings

Procedure

1. Test the steel bar for magnetism using iron filings.
2. Connect the battery to the solenoid and the switch.
3. Place the steel bar inside the solenoid as shown in Figure 3.23.

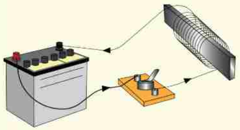


Figure 3.23: *Making a steel based permanent magnet*

4. Switch on the current for 10 seconds and then switch off.
5. Remove the bar from the solenoid and test it again for magnetism using the iron filings.

Questions

(a) Why is the current switched on for only a few seconds?

(b) What is observed when the steel bar is brought near the iron filings?

The current is switched on for a short time only because overheating can damage the coil. Moreover, the bar does not become more strongly magnetised if the current is left on for a long time. The steel bar attracts the iron filings, showing that it has been magnetised.

In each of the methods mentioned, if the object is composed of ferromagnetic materials, it will remain magnetised even after the external field is removed. However, if it is composed of paramagnetic materials, it will lose its magnetism when the magnetising field is switched off.

Demagnetisation

Demagnetisation is the process of destroying the magnetic property of a material. The process involves the destruction of the dipole alignment in the magnetised material. This process can be done in the following ways:

1. If a permanent magnet is heated or vibrated in the absence of an external field, the magnetisation can be destroyed.
2. Randomly stroking one magnet with another can demagnetise the magnet being stroked.
3. Wrapping a wire coil around the magnet and connecting the coil to a source of alternating current will eliminate the magnetic alignment.
4. Repeated hammering or dropping down the magnet can also distort dipoles alignment.

Activity 3.6

Aim: To demagnetise a bar magnet.

Materials: Bar magnet, solenoid wire, rheostat, iron filings

Procedure

1. Test a bar magnet for magnetism using iron filings.
2. Set up an electric circuit by connecting the solenoid wire with

an AC mains voltage.

3. Connect the rheostat in series with the mains voltage.
4. Place the solenoid with its axis pointing in an east–west direction as shown in Figure 3.24.

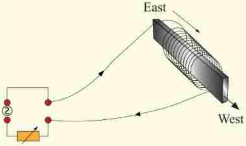


Figure 3.24

5. Place the bar magnet inside the solenoid and switch on the current.
6. After 10 seconds, slowly withdraw the bar magnet from the solenoid in the east-west direction with alternating current still flowing in the solenoid.
7. Using the iron filings, test whether the bar magnet still has magnetic ability.

Questions

(a) Why is the solenoid and bar magnet placed in an east-west direction?

(b) What is observed when the bar magnet is brought near the iron filings?

The magnet is placed in an east-west direction so that it is not left with any magnetism due to the induction in the earth's magnetic field. When this bar is brought near some iron filings, it does not attract them. This proves that a bar magnet has been demagnetised.

Storage of magnets

Magnets become weaker with time because free poles near the ends repel each other and upset the alignment of the tiny magnets. Other external factors may also cause magnets to lose their magnetism. For these reasons, it is advisable to consider the storage of magnets for them to remain effective for long.

Task 3.2

Do library search to find out ways in which magnets should be stored and handled so that they do not lose their magnetic strength. Write a report and present it to the rest of the class. Use your findings to design ways of storing magnets in your laboratory.

In order to maintain the magnetism in magnets for a long period of time, the following practices have to be observed:

1. Avoid storing magnets in places where they may come into contact with ferrous objects such as steel shelves and tools.
2. Store magnets in pairs with the unlike poles facing each other. Pieces of magnetic keepers are used at the ends to preserve the strength of the magnets.

Note:

A magnetic keeper is a ferromagnetic bar placed across the poles of a permanent magnet. It preserves the strength of the magnet by completing the magnetic loop as shown in Figure 3.25.

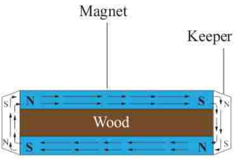


Figure 3.25: *Magnetic keeper*

3. Do not overheat magnets. This may cause harmful structural changes in the magnet.
4. Do not store or keep magnets near strong magnetic or electric fields.
5. Do not subject magnets to any form of severe stress such as vibrations or mechanical impacts. These can physically damage the magnet. Permanent magnets are hard but brittle at the same time.

Exercise 3.1

1. (a) Briefly explain the origin of magnetism.
   (b) State the basic law of magnetism.
2. (a) Explain the concept of ferromagnetic materials.
   (b) Explain three materials which are classified as ferromagnetic.
3. (a) Differentiate between magnetisation and demagnetisation.
   (b) Describe three methods through which a magnetic material can be magnetised.
4. (a) Explain four ways in which magnets are used in daily life.
   (b) In which part of a fridge or a microwave oven do magnetic strips installed? Why?
5. How can you store magnets for effective and durable use of their magnetism?

Magnetic field of a magnet

A magnetic field exerts a force on a magnetic material placed in it. Physicists use magnetic field patterns to describe the action of magnetic forces from a distance.

If a magnet is dipped in iron filings, the filings tend to cling around its ends. Similarly, if the filings are sprinkled on a paper over a bar magnet, they will be pulled to the poles of the magnet. The filings thus become magnetised and aligned, forming a magnetic field pattern as shown in Figure 3.26.

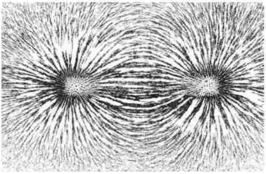


Figure 3.26: *Magnetic field pattern*

A magnetic field is the region around a magnet in which magnetic force can be experienced by magnetic materials.

Magnetic field is thus an indication of the strength and direction of the force a magnet exerts on magnetic materials. If the magnetic field is stationary, it is referred to as a magnetostatic field. At any given point its magnitude and direction remain the same.

One application of a magnetic field is in the banking industry. Banks use magnetic ink on cheques and cheque deposit slips so that the cheques are sorted out automatically by machines. These machines can detect the magnetic field around each number on a cheque and cheque deposit slips. Figure 3.27 shows a cheque and a cheque deposit slip containing magnetic field.

Magnetic ink characters

(a) Cheque

Magnetic ink characters

(b) Cheque deposit slip

Figure 3.27: *Magnetic ink on a cheque and cheque deposit slip*

Activity 3.7

Aim: To demonstrate existence of a magnetic field using iron filings.

Materials: Magnifying glass, bar magnet, iron filings, cylindrical magnet, plastic bottle, test tube, masking tape, sheet of paper

Procedure

Part I

1. Lay a strong bar magnet on a table as shown in Figure 3.28.

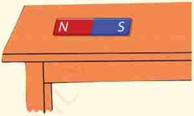


Figure 3.28

2. Cover the magnet with a sheet of white paper and trace the magnet.
3. Label the north and south poles as shown in Figure 3.29.

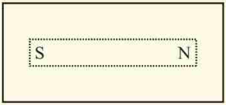


Figure 3.29

4. Sprinkle iron filings onto the paper in the area around the outline.
5. Gently blow any loose filings aside.
6. Examine the pattern formed by the filings with a magnifying glass as shown in Figure 3.30.

Figure 3.30

Part II

1. Fill in a plastic bottle to about one-fifth with iron filings.
2. Take a test tube that will fit the mouth of the bottle and is about $\frac{3}{4}$ the length of the bottle.
3. Wrap the top part of the test tube with masking tape so that the tube fits tightly into the mouth of the bottle.
4. Fit the test tube into the mouth of the bottle and slide the cylindrical magnet into the test tube as shown in Figure 3.31.
5. Put the bottle cap on. Turn the bottle on its side and rotate it.

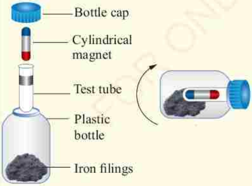


Figure 3.31

Questions

(a) What did you observe in procedure of part I above? Sketch the pattern.

(b) What is your observation in procedure of part II?

(c) Explain your observations.

Magnetic lines of force

Recall that iron filings become aligned in the presence of a magnetic field. This alignment displays the lines of force in a magnetic field. The magnetic lines of force emerge from the north (N) pole to the south (S) pole of a magnet. They are crowded together or become denser at the poles of a magnet, showing that the magnetic field is strong at the poles. Away from the poles, the field is weak, hence magnetic lines formed are less dense. Magnetic lines of force show the direction of the magnetic force. The direction of the magnetic lines of force at any point is the direction in which the north pole of a small magnet points when located at that point as illustrated using arrows in Figure 3.32.

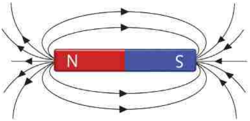


Figure 3.32: *Magnetic field lines around a bar magnet*

The lines of force point away from the north pole of a magnet and towards the south pole. The direction at any point along a line of force is therefore defined as the path that a magnetic north pole would tend to take. The north end of a compass needle could also point in the same direction as shown in Figure 3.33.

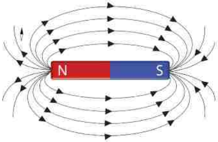


Figure 3.33: *Compass needle direction around a bar magnet*

Properties of magnetic lines of force

Some of the properties of magnetic lines of force are as follows:

1. Magnetic lines of force are continuous and always form closed loops.
2. Lines of force from the bar magnet leave the north pole and enter the south pole and back to the north pole forming a closed loop.
3. Magnetic lines of force are close together where the magnetic force is stronger, and they are far apart where the magnetic force is weaker.
4. Magnetic lines of force never cross one another.
5. Parallel magnetic lines of force in the same direction repel one another. Parallel magnetic lines of force in the opposite directions attract one another (See Figure 3.34).

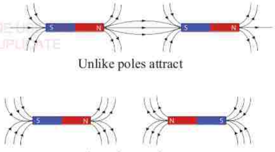


Figure 3.34: *Unlike poles attract and like poles repel*

6. Magnetic lines of force pass through magnetic and non-magnetic materials.
7. Magnetic lines of force always enter or leave a magnetic material at right angles to the surface.

Neutral points in a magnetic field

At any point where two different magnetic fields exist, a stronger field is created if they are in the same direction but a weaker field arises if they are in opposite directions.

It is possible for the two fields to balance each other at one point. A point where the net magnetic field is zero is called *neutral point.* For example, when two bar magnets are placed near each other as shown in Figure 3.35, their magnetic fields repel each other such that at one point they completely cancel each other, forming a neutral point. Therefore, there is no magnetic force at neutral points.

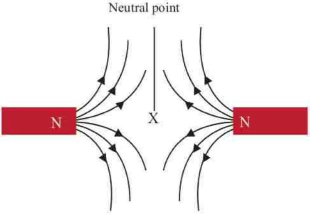


Figure 3.35: *Neutral point*

Activity 3.8

Aim: To locate the magnetic neutral points.

Materials: A large sheet of cardboard, tape, two bar magnets, compass

Procedure

1. On the large sheet of cardboard, draw a line along the N-S direction as indicated by a compass needle.
2. Tape the bar magnets on the board with their axis along the N-S line as shown in Figure 3.36.
3. Place a compass at point A near the bar magnet.
4. Record your observations.

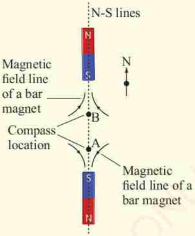


Figure 3.36

5. Slowly slide the compass along the N–S line toward point B until the compass needle spins to point in the opposite direction.
6. Record your observations.
7. Use your compass to locate a neutral point.
8. Repeat the above activity with the bar magnets aligned in the W-E direction (in a line perpendicular to the drawn N-S line).

Questions

(a) Why does the compass change direction?

(b) Did you locate any neutral point on the N–S or E–W lines? Explain.

Magnetic shielding

Magnetic shielding is the process of limiting the flow of magnetic fields between two locations by separating them with a barrier made of conductive ferromagnetic material. Suppose the rain water flowing off the roof of a house finds its way undirected to the ground (see Figure 3.37 (a)). The flow of water from the roof to the ground cannot be stopped but can be redirected to a specific location such as a special well. If a channel (gutter) is put along the roofline and connected to downspouts at each corner of the house as shown in Figure 3.37 (b), the rainwater will flow along the channel to the specified location.

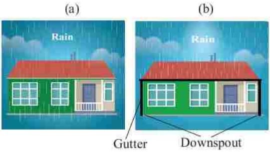


Figure 3.37: *Using channels to redirect rainwater*

The same thing can be done with magnetic field lines. Field lines from the north pole cannot be stopped from moving to the south pole of a magnet, but they can be redirected. In this case, the channel is a length of ferromagnetic material such as soft iron. When magnetic field lines reach the iron, they flow along it rather than through the magnet itself. Materials that can redirect magnetic field lines are said to be *permeable*.

Suppose a region is to be shielded from magnetic effects; it could be enclosed with ring made up of soft iron. The field lines could follow the iron ring around the shielded region as shown in Figure 3.38.

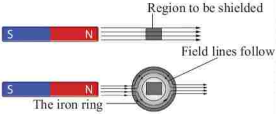


Figure 3.38: *Magnetic shielding redirects field lines*

Activity 3.9

Aim: To demonstrate magnetic shielding.

Materials: Two pencils, bar magnets, index cards, sellotape, paper clips, drinking straws, iron nails

Procedure

1. Stick the two pencils along the sides of an index card.
2. Stick a second index card on top of the pencils as shown in Figure 3.39.

Figure 3.39

3. Tape a strong bar magnet to the top index card as shown in 3.40.

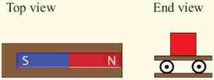


Figure 3.40

4. Use the assembly to pick up several small paper clips with the bottom card as shown in Figure 3.41.

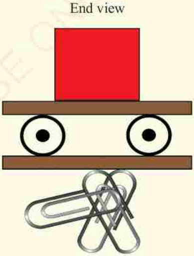


Figure 3.41

5. Tape several drinking straws together side by side and insert them into the space between the two index cards as shown in Figure 3.42, then repeat step 4.

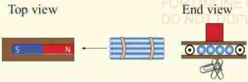


Figure 3.42

6. Tape several iron nails side by side and insert them into the space between the two index cards as shown in Figure 3.43, then repeat step 4.

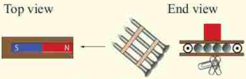


Figure 3.43

Questions

(a) For each case, what happens to the paper clips? Why?

(b) Explain your results using the concept of magnetic shielding.

Earth's magnetic field

The earth behaves as if it has a short bar magnet inside it (See Figure 3.44). This apparent magnet is inclined at a small angle to the earth's axis of rotation, with its south pole pointing in the northern hemisphere. This is inferred from the fact that the compass needle points towards the true north only at certain locations.

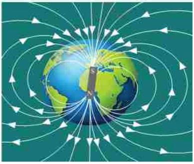


Figure 3.44: *Earth's imaginary magnet*

The origin of the earth's magnetism is still not clear and does not have a simple answer. However, it is believed that the generation of the magnetic field is linked to the rotation of the earth. This leads to the rotation of the metallic iron fluid that makes up a large portion of the interior of the earth. The earth has two sets of poles, the north and south geographic poles as defined by its axis of rotation, and the north and south magnetic poles that are defined by its magnetic field. The magnetic pole in the Northern Hemisphere is magnetically a south pole called the Magnetic South Pole (MSP) and in the Southern Hemisphere the magnetic pole is called the Magnetic North Pole (MNP) as shown in Figure 3.45.

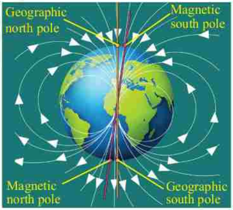


Figure 3.45: *Earth's geographic and magnetic poles*

Direction of the earth's magnetic field

Magnetic fields have both magnitude and direction. The SI unit for magnitude of a magnetic field is the

Tesla, T. The magnitude of the earth's field varies from one location to another, ranging from 25 μT to 65 μT. A compass may be used to determine the direction of the earth's magnetic field.

A compass is a device with a magnetised needle that is free to rotate in a horizontal plane and align itself with the horizontal component of the earth's magnetic field. The head of a compass needle is a magnetic north pole, and the tail is a magnetic south pole. The compass needle points toward a north pole which means it will point toward the earth's MSP. Therefore, a compass needle points in the general north direction of the earth as shown in Figure 3.46. For this reason, the magnetic north pole of the compass needle is referred to as a north-seeking pole. For this reason, the general direction indicated by the needle is often referred to as the "magnetic north".

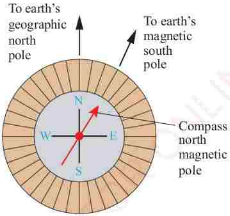


Figure 3.46: *Magnetic compass*

If you suspend a magnet to swing in a horizontal plane as shown in Figure 3.47, it will oscillate to and fro for a short time before it comes to rest in an approximate N–S direction. The magnet comes to rest with its axis in a vertical plane called the magnetic meridian.

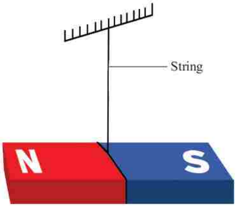


Figure 3.47: *Freely suspended magnet*

Just as with the compass needle, the pole which points towards the north is the north-seeking pole (N pole), and the other is the south-seeking pole (S pole).

Activity 3.10

Aim: To demonstrate existence of the earth's magnetic field.

Materials: A nail or pin, water, a bar magnet, stopper (cork), water dish

Procedure

1. Using the north pole of a bar magnet, stroke a nail or straight pin from head to tip 10 to 15 times. This magnetises the nail with a south pole (SP) at the tip and a north pole (NP) at its head as shown in Figure 3.48.

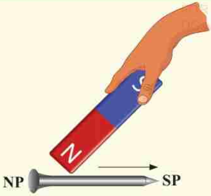


Figure 3.48

2. Float a cork or rubber stopper in a dish with shallow water. Place the nail on the cork as shown in Figure 3.49.

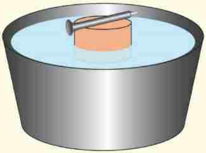


Figure 3.49

3. Give one end of the nail a slight horizontal push so that it rotates slowly. When the nail comes to rest, its tip will be pointing toward the earth's MSP.
4. Place a piece of tape on the edge of the dish to mark this direction.
5. Give the nail another slight push and observe its orientation when it stops moving. Repeat this several times.

Question

Does the needle always point in one direction? Why?

If a bar magnet is suspended horizontally from its centre, it will point to the north-south direction. The bar magnet is free to turn and lines up along the field lines of the earth's magnetic field.

Earth's magnetic lines of force about a bar magnet

The earth's field around the equator consists of parallel lines that point towards the north as shown in Figure 3.50. This forms a 'uniform field' in which the direction and strength of the lines of force is constant.

Figure 3.50: *Earth's field*

The earth's magnetic lines of force about a bar magnet is a resultant of two magnetic fields, one due to the bar magnet and the other due to the earth. Figures 3.51 illustrates the resulting field when the two fields combine. At certain location, the earth's field neutralises the field due to the bar magnet. This results into neutral points (x).

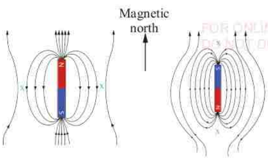


Figure 3.51: *Fields of a bar magnet against the earth's magnetic field*

Angle of declination

As mentioned earlier, the earth's Magnetic North Pole (MNP) and Geographic North Pole (GNP) are not in the same plane. Generally, the earth's axis of rotation does not coincide with the magnetic axis. The angle between the two axes is called the *angle of declination, D or angle of deviation,* and is shown in Figure 3.52.

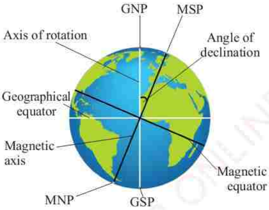


Figure 3.52: *Angle of declination*

Additionally, the earth's magnetic field changes slowly over time so that the MNP moves. There have been times through the earth's 4.5-billion-year history that the earth's magnetic field was completely reversed.

Table 1 shows a list of the latitude and longitude of the MSP for some years from 2001.

Table 3.1: *Location of MSP for some years*

Year	Latitude	Longitude
2001	81.3 N	110.8W
2002	81.6 N	111.6W
2003	82.0 N	112.4W
2004	82. 3 N	113.4W
2005	82. 7 N	114.4W
2020	86.50 N	164.0 E

The angle of declination also indicates whether the magnetic south is east or west of the geographic north.

Angle of inclination (dip angle)

If we turn a compass on its side so that the needle is free to rotate in a vertical plane, it will align itself with the earth's magnetic field. The angle between the resultant magnetic field direction and the horizontal component of the field is called the *angle of inclination*, *I*, or *dip angle*. The angle of inclination is positive if the magnetic field vector points down (northern hemisphere) and negative if it points up (southern hemisphere). The angle of inclination varies from 0° at the magnetic equator to 90° at the magnetic poles. It is measured using a dip needle shown in Figure 3.53. A dip needle consists of a magnetised needle pivoted to rotate freely in a vertical plane.

(a) *Compass showing angle of declination*

Figure 3.53: *Dip needle*

In practice, a compass is used to align the dip needle with the horizontal component of the magnetic field, and the dip needle rotates vertically to align with the total field.

The magnetic dip produces a vertical moment causing the needle in a compass to rotate vertically. This produces friction in the pivot which impedes the free rotation of the needle. To compensate for the dip, a small mass is added to one end of the needle to produce an opposite gravitational moment so as to maintain the needle in vertical equilibrium. A compass to be used in the northern hemisphere whereby the vertical component points down has the mass added to the tail end of the needle. A compass to be used in the southern hemisphere whereby the vertical component points up has the mass added to the head end of the needle. Figure 3.54 (b) shows the various magnetic field components in the northern and southern hemispheres.

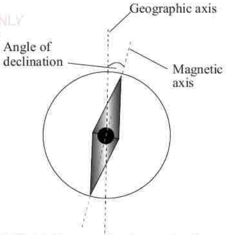


Figure 3.54: (a) *Compass showing angle of declination*

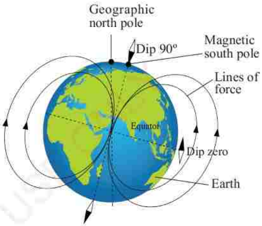


Figure 3.54: (b) *Compass showing dip angle*

Task 3.3

Use a compass and dip needle to determine the angles of declination and inclination at your location.

Applications of the earth's magnetic field

The earth's magnetic field has very important applications in our daily life.

1. It is used by map-readers to find locations of different places.

2. It gives useful information in the search for minerals.

3. Reversals of the earth's magnetic field provide the basis for dating rocks and sediments.

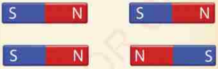
4. Map-readers with a magnetic compass can locate the direction of the magnetic north using the compass.

5. It protects the earth from cosmic radiation (potentially damaging high energy particles from the sun).

Exercise 3.2

1. Briefly explain the following terms as applied in magnetism.
   (a) A magnetic field.
   (b) A magnetic line of force.

2. (a) Draw a magnetic field around a bar magnet using magnetic lines of force.
   (b) Draw magnetic fields around the pairs of magnets shown in Figure 3.55:



(i) (ii)

Figure 3.55

3. The earth is a magnet. Explain.

4. State the applications of the earth's magnetic field.

Chapter summary

1. Magnetism was known to the early Greeks since the 600 BCE.

2. Some materials have magnetic properties and can be made into permanent (ferromagnetic) magnets or temporary (paramagnetic) magnets. All magnets have a north pole and a south pole.

3. Magnets exert a force on some materials but not on others. The force is strongest at the poles of the magnets, and it can act from a distance.

4. Like poles repel and unlike poles attract.

5. Magnets are categorised into:
   - temporary magnets
   - permanent magnets
   - electromagnets

6. Magnets can be applied in:
   - magnetic recording media
   - credit cards
   - speakers and microphones
   - computers and televisions
   - transformers
   - electric motors
   - generators.

7. The 'tiny magnets' in a material are called dipoles. A group of dipoles form a domain.

8. Magnetic materials can be magnetised by:

- heating or vibrating in the presence of an external field
- stroking
- electric method

9. A magnet can be demagnetised through:
   - hammering, heating or vibrating in the absence of an external field.
   - random stroking.
   - the electric method by using alternating current.

10. Magnets should be stored:
    - away from ferrous materials
    - in pairs and using magnetic keepers
    - away from heat
    - away from strong electric and magnetic fields
    - away from strong vibrations

11. A magnetic field is the region around a magnet within which magnetic force can be experienced. Magnetic fields are represented by lines of action of magnetic force called field lines.

12. Magnetic lines of force:
    - run from the north pole towards the south pole.
    - are continuous and always form closed loops.
    - never cross each other.
    - repel each other if pointing in the same direction and attract each other if pointing in the opposite direction.
    - pass through magnetic and non - magnetic materials.
    - always enter or leave a magnetic material at right angles to the surface.

13. Points at which the net magnetic field is zero are called neutral points.

14. Materials that can redirect field lines are called permeable materials.

15. A magnetic field has magnitude and direction and has horizontal and vertical components. A compass needle points in the general north direction of the earth. Thus, the magnetic North pole of the compass needle is referred to as a north-seeking pole. The general direction indicated by the needle is often referred to as the "magnetic north".

16. The angle between the resultant magnetic field direction and horizontal component of the field is called *the angle of inclination*, *I*, or dip angle.

Revision exercise 3

Choose the most correct answer in items 1-2.

1. Why are magnets often fitted to the doors of refrigerators and some of the cupboards?
   (a) To keep away heat.
   (b) To keep the inside environment warm.
   (c) To keep the door tightly closed.
   (d) To keep iron away.

2. The following are applications of magnetism in daily life, EXCEPT:
   (a) Magnets are used to trap non-metallic objects during flour packing.
   (b) VHS tapes are manufactured as a result of magnetism.
   (c) Banks make use of magnetic ink on cheques.
   (d Magnets are used to lift scrap metals.

3. Match each item in **column A** against its corresponding item from **column B** by writing the correct response in the space provided.

Column A	Answer	Column B
(a) Magnetic materials		(i) Like poles attract, unlike poles repel
(b) Law of polarity		(ii) Magnetic field is zero
(c) Magnetic shielding		(iii) Redirects magnetic lines of force
(d) Neutral point		(iv) Strong magnet
(e) Aluminium		(v) Iron nail
		(vi) Paramagnetic
		(vii)Direct neutral point

4. Why is the core of an electromagnet made of ferromagnetic material?

5. Where on the surface of the earth is the earth's magnetic field perpendicular to the surface of the earth?

6. Differentiate between a force due to a magnet from the force due to gravity on the earth.

7. (a) How do you know that a certain material is magnetic in nature?
   (b) State the law of polarity and illustrate it using sketch diagrams.
   (c) Suppose you are in the physics laboratory and you are given a bar magnet whose poles are not labelled. Describe how you could determine which end of the bar is the north pole.

8. (a) State three applications of magnets.
   (b) Draw the following sketch diagrams:
      (i) Arrangement of domains of dipoles in unmagnetised iron bar.
      (ii) Arrangement of domains of dipoles in a magnetised iron bar.

(c) Explain what would happen if you cut a bar magnet into half.

9. (a) Describe the magnetisation process.

(b) How can a permanent magnet be demagnetised?

(c) Explain the type of force that a magnet experiences.

10. (a) What are magnetic lines of force?

(b) Analyse the properties of lines of force.

(c) Describe the process of magnetic shielding.

11. Suppose you mount a bar magnet on a set of rubber wheels as shown in Figure 3.56.

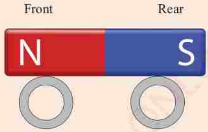


Figure 3.56

If you place the 'magnetic car' on the magnetic N–S line with the front of the car pointing to the geographic north, would it roll towards the north or towards the south? Explain your answer.

12. (a) You are given 4 strong bar magnets; is it possible to build the objects shown in Figure 3.57?

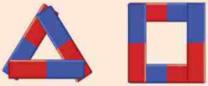


Figure 3.57

(b) Draw diagrams indicating each magnet's north and south poles.

13 You are given two iron bars, A and B, that look identical as shown in Figure 3.58. One of them is a strong permanent magnet.

Figure 3.58

Explain how you can determine which bar is a strong permanent magnet.

14. Bar magnet P is twice as strong as bar magnet Q.

(a) The two magnets are arranged with the N-pole of P 1m from the S-pole of Q as shown in Figure 3.59.

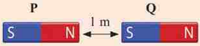


Figure 3.59

Is there a neutral point between the two magnets? If there is, how far from magnet P is it located?

If there is no neutral point, explain why.

(b) Magnet Q in Figure 3.59 is flipped so that the two north poles are 1 m apart as shown in Figure 3.60.

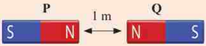


Figure 3.60

Is there a neutral point between the two magnets? If there is, how far from magnet P is it located? If there is no neutral point, explain why not.

15. The two magnets described in Question 14 are placed parallel to each other as shown in Figure 3.61.

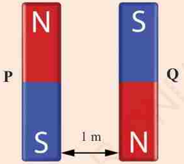


Figure 3.61

Is there a neutral point between the two magnets? If there is, how far is it from magnet P? If there is no neutral point, explain why.

16. Copy the image of a horseshoe magnet shown in Figure 3.62 and sketch 8 to 10 field lines.

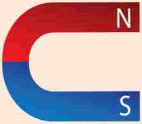


Figure 3.62

17. Compasses designed to be used in cars are equipped with a suction cup so that they can be mounted on the dashboard. Why?

18. Suppose that in Figure 3.63 (a) the nail becomes magnetised, with the head of the nail becoming a north magnetic pole. What could happen if the battery was reversed as in Figure 3.63 (b)?

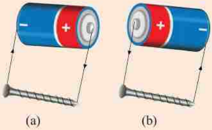


Figure 3.63

Chapter Four

Forces in equilibrium

Introduction

Force is any interaction that when unopposed, will change the motion of an object. When the forces that act upon an object are balanced, the object is said to be in a state of equilibrium and the total force acting upon the object is zero. In this chapter, you will learn the effects of turning forces, moment of force, centre of gravity and types of equilibrium. The competencies developed will enable you to apply the concept of equilibrium in opening a door, turning on a tap, steering a car, tightening up a nut on a bolt with a spanner, driving a screw into a piece of wood with a screw driver and measuring masses of various objects.

Effects of turning forces

A force produces different effects when applied on a body, depending on the way it is applied. Some of these effects include stretching, compressing and rotating or turning. When you push an object to turn, you say that you are applying a '*turning force*'. Application of this force is different from that of a regular force. This is because, instead of moving an object along a straight line, it rotates the object. In fact, the object turns about an axis or a fixed point, hence the term 'turning effect of a force'.

The turning effect of a force is called *a moment of force*, whereas the fixed point is known as a *turning point* or *pivot* or *fulcrum*.

Moment of a force

In Figure 4.1, Rebecca and Abdul are pushing against a hinged classroom door with forces 480 N and 600 N respectively. Rebecca is pushing from outside the classroom and close to the knob of the door while Abdul is pushing from the inside but near the hinges. Who will succeed to close or open the door, and why?

Figure 4.1: *Students pushing a door from different positions*

The hinges of the door represent a turning point called the *pivot* or *fulcrum*.

Activity 4.1

Aim: To observe the turning effect of a force.

Materials: Metal rod, mass *m*, ruler, string, piece of wood

Procedure

1. Hold the rod horizontally at one end.
2. Tie the mass, *m* with a string, and hang it on the rod near your hand.
3. Measure the length from your hand to the loading position and record.
4. Hang the mass, *m* at different positions from your hand while the rod is in the same horizontal position, and record the distance from your hand.
5. Repeat step 1 to 4 using the piece of wood.

Question

What happens when the mass is moved to different positions?

The feeling in your hand is a result of the turning effect of force; the turning force is the weight of the object. Due to this observation, the moment (turning effect) of a force depends on the size of the force and the perpendicular distance from the pivot to the line of action of the force. Moment of force has both magnitude and direction.

Task 4.1

Your teacher will guide you through activities that involve turning forces. These include opening or closing of doors, turning a water tap and tightening or loosening of nuts on a bolt using a spanner. Carefully, observe the resulting motion. Discuss your observations in the class.

The direction of rotational motion is best described using the terms clockwise and anticlockwise as shown in Figure 4.2.

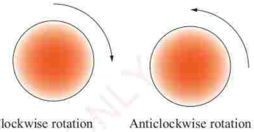


Figure 4.2: *Clockwise and anticlockwise rotation*

When a force is applied on an object, its effect is felt through a line of action. The line of action of the force is the line drawn from the point where the force is applied and through the object on which the force acts as shown in Figure 4.3.

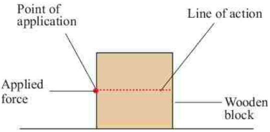


Figure 4.3: *Force acting on the wooden block*

When the line of action passes through the centre of gravity of an object, a linear motion occurs. If it does not pass through the centre of gravity, then a rotational motion occurs. On the other hand, if the lines of action of some forces pass through the object's centre of gravity while others do not, then the object will undergo a combination of linear and rotational motion.

Consider a case of opening a door or turning a water tap. Factors involved in effecting these actions are the magnitude of the force applied and the distance of its line of action from the axis or pivot about which turning takes place. A large turning effect can be produced by a small force provided that the perpendicular distance from the pivot is long. Consider Figure 4.4 in which a person is loosening a nut using a wheel spanner.

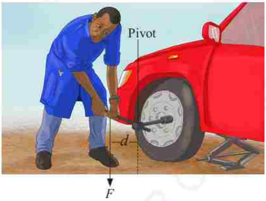


Figure 4.4: *Loosening a nut using a wheel spanner*

The applied force is at the far end of the spanner, leaving a wide gap between the hand and the turning point (pivot). The combined effect of force, F and the perpendicular distance, d is what determines the magnitude of the turning force and is referred to as the *moment of force*.

Moment of a force about a point is the product of the force and the perpendicular distance of its line of action from the point.

Hence,

Moment of a force = applied force (in newtons) × perpendicular distance from a pivot (in metres)

Moment of a force is measured in newton metre (Nm).

Linear and rotational motion

A force can cause different kinds of motion depending on how it is applied. That is, when a force is applied on an object, it can cause either linear or rotational motion as shown in Figure 4.5. In translational motion, the object moves along a line so that there is a net displacement of its fixed point referred to as *centre of mass* (c.m). The centre of mass coincides with centre of gravity for a body with uniform mass distribution.

The centre of mass of an object is the point on the object at which the whole mass of the object appears to be concentrated.

In rotational motion, all points in a body move in circles around a single line called the *axis of rotation.* The linear velocity of a point depends on its distance from the axis of rotation. If the axis of rotation passes through the centre of mass, there will be no net displacement.

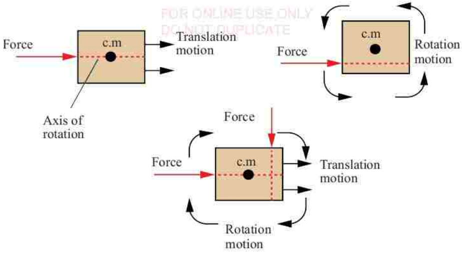


Figure 4.5: *Linear and rotational motion*

The linear acceleration caused by a force acting through an object's centre of mass depends only on the magnitude of the force and the object's mass.

In rotational motion, acceleration depends on the magnitude of a force and location of the axis of rotation.

Activity 4.2

Aim: To determine the moment of a force.

Materials: Metre rule, masses, table

Procedure

1. Lay a metre rule on the bench with its 70 cm mark coinciding with edge of the bench as shown in Figure 4.6.

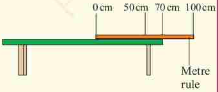


Figure 4.6

2. Place a 100 g mass on the 70 cm mark.
3. Slowly move the mass from the 70 cm mark towards the 100 cm mark until the rule begins to tilt.
4. Record the mass and its distance from the axis of rotation (70 cm mark) when the metre rule first begins to tilt.
5. Repeat steps 2 to 4 using the 120 g, 150 g and 200 g masses.
6. Record all your observations in Table 4.1.

Table 4.1: Results

Mass (g)	Force (N)	Distance from axis of rotation (cm)	Distance from axis of rotation (m)	Force x distance (Nm)
100				
120				
150				
300				

Questions

(a) Calculate and record the force exerted by the mass on the metre rule.

(b) Does the metre rule rotate? Explain your answer.

(c) Calculate and record the product of the force and distance.

(d) What do you observe about the product of force and distance?

(e) If you had used a mass of 170 g, where could it be placed to make the metre rule tilt?

If a mass of 100 g is placed beyond the 70 cm mark, the rule will tend to rotate clockwise with the pivot at the 70 cm mark.

The product of the magnitude of an applied force and the distance between the force's line of action and axis of rotation can be expressed as:

Moment of force, M = force, F × perpendicular distance, d applied

$$M = F \times d$$

From this definition, the SI unit of moment of force is the newton metre (Nm).

The distance, d is measured as the length of the perpendicular line segment between the force's line of action and the object's axis of rotation as shown in Figure 4.7.

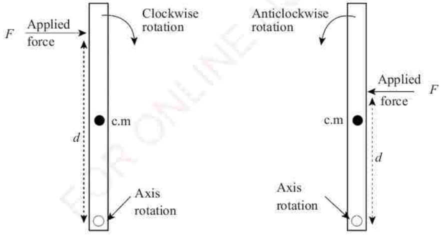


Figure 4.7: *Force's line of action, axis of rotation and the distance between them*

If a force is applied at the pivot, its distance and moment could be zero. The location of the pivot is arbitrary and can be chosen anywhere on the object.

Principle of moments

The **principle of moments** states that, for a system to be in rotational balance, the sum of clockwise moments must be equal to the sum of anticlockwise moments about a fixed axis of rotation.

Alternatively, if an object is in equilibrium, then the algebraic sum of the moments about any point is zero.

$$\textit{Sum of clockwise moments} = \textit{Sum of anticlockwise moments}$$

If you use the sign convention that clockwise moments are negative and anticlockwise moments are positive, the principle of moments can be expressed as:

$$\textit{Sum of clockwise moments} + \textit{Sum of anticlockwise moments} = 0$$

This means that, for a system in rotational balance, the sum of all moments about a fixed axis of rotation is zero.

Activity 4.3

Aim: To verify the principle of moments.

Materials: Metre rule, knife edge, masses of 20 g and 50 g

Procedure

1. Balance a metre rule with its zero mark to the left of a pivot, using a knife edge and choose the point O as the pivot.
2. Place 20 g masses at the 10 cm and 20 cm marks respectively.
3. Place a 50 g mass somewhere to the right of O. Adjust its position until the rule is balanced. Ensure that the metre rule remains at its point of balance O. Note that the two 20 g masses produce anticlockwise moments while the 50 g mass produces clockwise moments (see Figure 4.8).

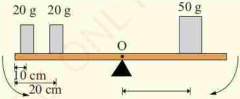


Figure 4.8

4. Measure and record the distance of each mass from the pivot in Table 4.2 (a) and (b) respectively.

Results: I

Table 4.2 (a): *Clockwise moment*

Mass (g)	Force, (N)	Distance in metre (m) from the pivot	Moment (Nm)
50	0.5		
Total clockwise moment			

Table 4.2 (b): *Anticlockwise moment*

Mass (g)	Force (N)	Distance in metre (m) from the pivot	Moment (Nm)
20	0.2		
20	0.2		
Total anticlockwise moment			

5. Place the two 20 g masses at the 20 cm and 30 cm marks and repeat the measurements. Measure and record the distance of each mass from the axis of rotation in (c) and (d).

Results: II

Table 4.2 (c): *Clockwise moment*

Mass (g)	Force (N)	Distance in metre (m) from the pivot	Moment (Nm)
50	0.5		
Total clockwise moment			

Table 4.2 (d): *Anticlockwise moment*

Mass (g)	Force (N)	Distance in metre (m) from the pivot	Moment (Nm)
20	0.2		
20	0.2		
Total anticlockwise moment			

Questions

(a) Calculate the moment of each force.

(b) In results I, compare the total clockwise moment with the total anticlockwise moment.

(c) In results II, compare the total clockwise moment with the total anticlockwise moment.

If a system is in a state of balance, what can be said about the total clockwise moment and the total anticlockwise moment? For a system to be in a condition of rotational balance, the total clockwise moments must be equal to the total anticlockwise moments.

Example 4.1

A uniform metre rule is pivoted at its centre O with a knife edge. A 20 g mass is placed at the 10 cm mark and a 50 g mass at the 40 cm mark as shown in Figure 4.9. At what mark must a second 50 g mass be placed for the system to be in rotational balance?

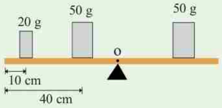


Figure 4.9

Solution

Since the metre rule is uniform, its centre is at its midpoint (the 50 cm mark) which is chosen as the pivot. Since the metre rule's weight can be considered concentrated at the centre, which is the pivot along the axis of rotation, the rule's weight does not produce a moment. The 20 g (w = 0.2 N) and 50 g (w = 0.5 N) masses that are to the left of the axis of rotation produce anticlockwise moment. So, the 50 g (w = 0.5 N) mass must be placed to the right of the axis of rotation so as to produce a clockwise moment as shown in Figure 4.10.

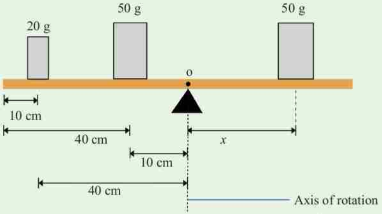


Figure 4.10

The 20 g mass is 40 cm (0.4 m) from the axis of rotation, and the 50 g mass is 10 cm (0.1 m) from the axis of rotation. The total anticlockwise moment is then:

$$(0.2\,\text{N} \times 0.4\,\text{m}) + (0.5\,\text{N} \times 0.1\,\text{m}) = 0.13\ \text{Nm}$$

The 50 g mass must produce an equal but clockwise moment. Using the principle of moment:

Sum of clockwise moments = Sum of anticlockwise moments

Let x be the distance from the axis of rotation of the 50 g mass.

$$0.5\ \text{N} \times x\ \text{m} = 0.13\ \text{Nm}$$

$$x = \frac{0.13\ \text{Nm}}{0.5\ \text{N}}$$

$$x = 0.26\ \text{m}$$

So, the second 50 g mass must be placed 26 cm to the right of the axis of rotation. That is at the 76 cm mark (50 cm + 26 cm = 76 cm), on the rule.

Concurrent and non-concurrent forces

Consider four forces illustrated in Figure 4.11. The net force, F_{net}, is given by:

$$F_{net} = F_1 + F_2 + F_3 + F_4$$

For an object to be in translational balance, all of the forces acting on it must be concurrent. Concurrent forces are forces which intersect at a point resulting to a net force of zero. Concurrent forces have their lines of action passing through the same point in the object. Non-concurrent forces cause rotation and must obey the condition of rotational balance. Also, the net force must be equal to zero.

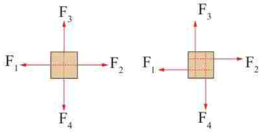


Figure 4.11: *Concurrent and non-concurrent forces*

Example 4.2

A uniform rod with a mass of 120 g and a length of 130 cm is suspended by a wire at a point of 80 cm from one end as shown in Figure 4.12.

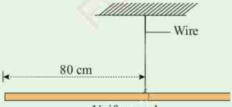


Figure 4.12

What mass must be hung on the rod for it to be in equilibrium? What will be the tension (T) in the wire?

Solution

You will choose the point where the wire is attached to be the axis of rotation so that the tension in the wire does not produce a moment. The two forces that produce moments could be the weight (W) of the rod. This can be considered to act at the rod's centre of mass (its midpoint), and the weight (w) hung from the other end as shown in Figure 4.13.

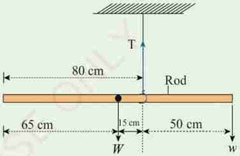


Figure 4.13

The rod's weight (W) of 1.2 N acts at the centre of gravity, which is 15 cm (0.15 m) from the axis of rotation and produces an anticlockwise moment. The unknown mass hung from the right end is 50 cm (0.5 m) from the axis of rotation and produces a clockwise moment. For the rod to be in rotational equilibrium, the clockwise and anticlockwise moments must be equal.

Let w be the unknown weight and d_1 be its distance from the axis of rotation, and d_2 is the distance of the centre of gravity from the axis of rotation.

$$M_{clockwise} = M_{anticlockwise}$$

$$wd_1 = Wd_2$$

$$w = \frac{Wd_2}{d_1}$$

$$= \frac{(1.2\ \text{N}) \times (0.15\ \text{m})}{0.5\ \text{m}}$$

$$= 0.36\ \text{N}$$

$$mass = \frac{w}{g}$$

$$= \frac{0.36\ \text{N}}{10\ \text{N/kg}}$$

$$= 0.036\ \text{kg}$$

Therefore, a mass of 0.036 kg or 36 g is required for a system to be in equilibrium.

For the rod to be in translational equilibrium, the tension, T in the wire must equal the total weight of the rod and hanging mass.

$$Total\ upward\ force = Total\ downward\ force$$

$$T = 1.2\ \text{N} + 0.36\ \text{N}$$

$$T = 1.56\ \text{N}$$

Exercise 4.1

1. How can a turning force cause rotation?
2. What are the conditions for a moment of force about a point to occur?
3. What is the condition for a system to be in a rotational balance?
4. Explain two factors in which the moment of force depends.
5. Abu has a mass of 60 kg, and he is sitting on a see-saw at a distance of 2.5 m from the pivot. Calculate the moment due to his weight. ($g = 10$ N/ kg)
6. A force of 80 N acts on a uniform rod as shown in Figure 4.14. Determine the moment of this force.

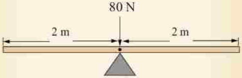


Figure 4.14

7. Calculate the force, F required to balance the metre rule in Figure 4.15.

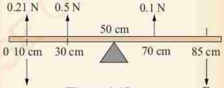


Figure 4.15

8. Use Figure 4.16 to calculate the total clockwise moment and show that it is equal to the total anticlockwise moment about O. Assuming that the mass of the rod is negligible.

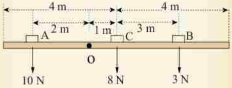


Figure 4.16

9. Why is the knob on a door placed as far as possible from the hinges? See Figure 4.17.

Figure 4.17

10. Explain the application of the principle of moments in a see-saw.
11. Explain why it is easier to loosen or tighten a nut with a long handle spanner than a short one.

Centre of gravity of a body

An extended object is one with finite dimensions while a point object has zero dimension. The centre of gravity (centre of mass) of an extended object is defined as the point in which all of its mass can be considered to be concentrated for the purposes of motion and equilibrium. For example, if a box is sliding across a floor, its motion can be described in terms of the position, velocity and acceleration of its centre of mass. A uniform object is one that has a regular shape, and whose density is the same in each of its dimensions. A cube, sphere or cylinder with uniform density can be considered as a uniform object. The centre of mass of a uniform object is located at the object's geometrical centre.

Centre of gravity of a regular shaped object

The centre of gravity (c.g.) of an extended body is the point on the body at which the weight of the body appears to act.

Location of the centre of gravity of some regular shaped objects is shown in Figure 4.18.

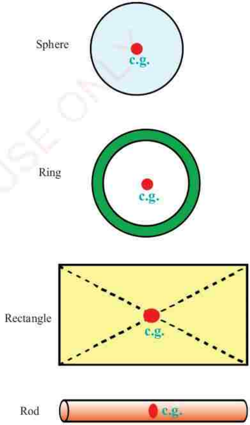


Figure 4.18: *Centre of gravity for regular shaped objects*

To locate the centre of gravity of an extended body, you can use the fact that, when the body is freely suspended in a vertical plane, the centre of gravity and suspension point lie on the same vertical line.

Activity 4.4

Aim: To locate the centre of gravity of a regular shaped object.

Materials: Heavy sheet of cardboard, punch, string, stand, marble or small mass

Procedure

1. Cut out a triangle with equal sides (equilateral triangle) from a heavy sheet of cardboard as shown in Figure 4.19.

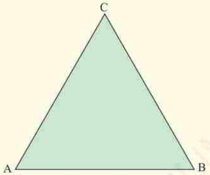


Figure 4.19

2. Place a mark on the cut-out where you estimate the centre of gravity is located.
3. Punch a hole with a diameter slightly greater than that of a pencil at one vertex (A, B or C) of the triangle (see Figure 4.20).
4. Insert a pencil through the hole and let the cut-out hang freely.

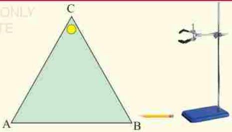


Figure 4.20

5. Attach a small mass to one end of a string and hold the other end next to the suspension point so that the string hangs straight down (see Figure 4.21).

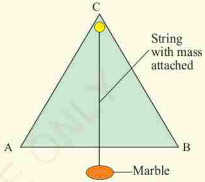


Figure 4.21

6. Using a felt pen, draw a line on the cut-out along the string as shown in Figure 4.22.

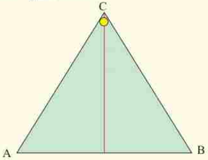


Figure 4.22

7. Repeat steps 3 to 6 using the other two vertices. The centre of gravity is located at the point of intersection of the three lines as shown in Figure 4.23.

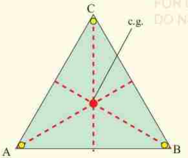


Figure 4.23

Questions

(a) Where do the three lines intersect?

(b) Where did you locate the centre of gravity?

The three lines in Figure 4.23 intersect at the centre of the triangle. The centre of gravity of the triangle is, therefore, located at this point of intersection.

Task 4.2

Cut out a polygon like the one shown in Figure 4.24 from a heavy sheet of cardboard.

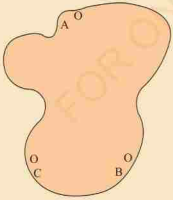


Figure 4.24

By using points A, B and C follow the procedure outlined in Activity 4.4 to locate the centre of gravity of the irregular shaped object.

Types of equilibrium

You have learnt that resultant forces cause objects to accelerate. If an object is stationary or moving at a constant velocity, then either no forces are acting on it, or the forces acting on the body are exactly balanced. For an object to be at rest or moving at constant velocity, the resultant force acting on the object is zero; then, the object is said to be in a state of balance called equilibrium. An object in equilibrium does not accelerate.

Examples of objects which are in a state of balance include: a book lying on a desk; a car moving along highways at a constant speed; and a weight suspended by spring.

Conditions for an object to be in equilibrium

Equilibrium conditions can be related to rotational, static, and dynamic or translational motion.

If an object is not moving at all conditions, the object is in a state of static equilibrium. When it is moving at a constant velocity, it is said to be in dynamic equilibrium. The conditions for equilibrium depend on three characteristics of forces which are magnitude, direction of forces and point of application.

For a body to be in a state of equilibrium under the action of parallel forces, certain conditions have to be satisfied alongside the above characteristics. These conditions are:

1. The sum of the forces in one direction must be equal to the sum of the forces in the opposite direction.
2. The sum of the anticlockwise moments about any point on the body is equal to the sum of the clockwise moments about that point. This means that the principle of moments must hold.

Generally, for a body to be in equilibrium, all forces acting on it and their turning effects must balance. The point of application of a force also determines the motion of a body. Force is also related to the centre of mass and/or centre of gravity of the body, as well as the line of action of the force. In Figure 4.25, the two objects A and B are in a state of static equilibrium.

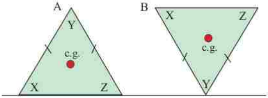


Figure 4.25: *Centre of gravity and equilibrium*

In Figure 4.26, each object is in equilibrium because its centre of gravity lies directly above its area of support.

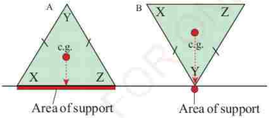


Figure 4.26: *Centre of gravity, stability and area of support*

Suppose you apply the same small horizontal force to both objects as shown in Figure 4.27 so that each rotates through an angle of about 10°, which of the objects will be easy to topple?

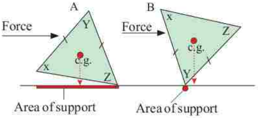


Figure 4.27: *Stable and unstable equilibrium*

With this small rotation, the centre of gravity of the object B is no longer directly above its area of support, and, if the force is removed it will topple over. On the other hand, the centre of gravity of object A remains above its area of support. If the force is removed, it will fall back to its original position. The stability of a body always increases by lowering its centre of gravity and increasing the area of its base. The lower the centre of gravity of the object the more stable the object will be, and the larger the area of the base the more stable the object will be. These are reasons why racing-cars are built with low centre of gravity, and a Bunsen burner has a wide base.

An object's equilibrium is *stable* if, after a small disturbance it returns to its initial position when released. A small disturbance raises its centre of gravity, and gravity pulls it back. If, after a small disturbance, the object moves further from its initial position, the equilibrium is *unstable*. This is because the centre of gravity falls and keeps on falling, for example, when balancing a ruler on the tip of a finger. If the object neither tends to return to its initial position nor moves far away, the equilibrium is said to be *neutral*. In other words, the position of centre of gravity (c.g.) does not change when the object moves. For instance, a sphere and a cone at rest on a horizontal table indicated in Figure 4.28 are in a *neutral equilibrium*.

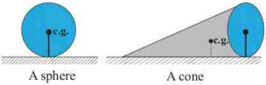


Figure 4.28: *Neutral equilibrium*

Task 4.2

Collect the following materials: Metre rule, pencil, Physics book, ball, rectangular glass block, triangular glass prism, dice, cone and cork fixed with a needle at one end.

(a) Place each material so that it stands on its edge. Record which items stand and which ones fall.

(b) Place each material on its base and give it a small displacement. Record your observations.

(c) Write down the type of equilibrium for each of the rest position of the materials. Present your observation in the class.

Applications of the concept of equilibrium

The concept of equilibrium is applied in many areas in our day-to-day life. For example, a car in motion, walking and rolling billiards.

Stable equilibrium

The state of an object to return to its rest position after being slightly displaced is called *a stable equilibrium*. For example, cars and trucks are designed to have stable equilibrium when executing a turn. As a vehicle makes a turn, it tends to rotate around the outer wheels. The inner wheels can leave the roadway (see Figure 4.29).

Figure 4.29: *Moving car turning to the right*

As long as the vehicle's centre of gravity remains above the wheelbase, it will not roll over. Stable cars and trucks have wide wheelbases and low centres of gravity. Car chassis and engines are placed at the bottom of vehicles so as to increase the vehicle stability. Luggage compartments in buses are also at the bottom. This lowers the centre of gravity and makes the vehicle more stable.

Unstable equilibrium

If an object at rest falls over when it is slightly displaced, this state is called *unstable equilibrium*. For example, the act of walking as shown in Figure 4.30

requires that each step should be in unstable equilibrium. When you walk, you achieve a brief unstable balance on one foot. Then you begin a non-equilibrium fall and catch yourself on the other foot. If you were always in a state of stable equilibrium, you would never move anywhere.

Figure 4.30: *Walking*

Neutral equilibrium

When a slight push or tilt neither raises nor lowers the centre of gravity of an object, the state is referred to as *neutral equilibrium*. When playing billiards (see Figure 4.31), you strike one ball which in turn can strike other balls. Eventually, all the balls that are struck come to rest in new positions. If the billiard table is truly flat, each ball will have a neutral equilibrium and remains in its position until struck again.

Figure 4.31: *Playing billiards*

Other applications of stability are:

(a) Tall structures such as buildings and pylons have wide bases and low centres of gravity so as to ensure stability.

(b) A bus with seated passengers and luggage in the lower compartments is more stable than one with standing passengers and loaded at the top. The former bus can negotiate a corner safely.

(c) Ships have long and wide projecting plates extending from their bases into the water to increase stability (see Figure 4.32).

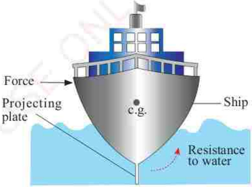


Figure 4.32: *Stability of a ship*

When a strong wave hits the ship on one side, it tends to overturn. The projection then meets a lot of resistance as it tends to sweep the large mass of water in contact with it. This resistance due to water causes an opposing moment about the centre of gravity (c.g.). The ship is thus saved from overturning.

(d) Cambered wheels: the wheels of a car are slightly tilted to increase stability. This is why, when a car is tilted to the side, it only skids (see Figure 4.33).

Figure 4.33: *Cambered wheels*

Exercise 4.2

1. Differentiate between centre of gravity and centre of mass.
2. What are the necessary conditions for a body to be in equilibrium?
3. Explain what is meant by stable, unstable and neutral equilibrium. Give one example for each.
4. (a) Why are luggage compartments located at the bottom of a bus?

   (b) State the conditions for stability of an object.
5. A uniform half metre rule is freely pivoted at the 15 cm mark and it balances horizontally when a body of mass 40 g is hung from the 2 cm mark. Draw a clear force diagram of the arrangement and calculate the mass of the rule.
6. It is found that a uniform wooden latch 100 cm long and mass 95 g balances on a knife-edge when a 5 g mass is hung 10 cm from one end. How far is the knife edge from the centre of the latch?

Chapter summary

1. A force can produce a turning effect when applied appropriately on an object. This turning effect is called moment, and it makes an object rotate about a pivot.
2. Moment of force is the magnitude of the turning force. Moment of force = force (in newtons) × perpendicular distance from pivot (in metres) and its SI unit is newton metre (Nm).
3. Forces can cause translational motion or rotational motion.
4. Centre of mass of an object is the point at which the whole mass of the object appears to be concentrated.

5. The principle of moments states that, for a system to be in a rotational balance, the sum of clockwise moments must be equal to the sum of anticlockwise moments.
6. Centre of gravity of an extended object is the point in which all of its weight is considered to be acting. The centre of gravity of a regular shaped object coincides with the centre of mass of the object.
7. Equilibrium is the state of balance of forces on a body.
8. There are three types of equilibrium; stable, unstable and neutral.
9. There are two equilibrium conditions, namely static and dynamic equilibrium. These conditions depend on; magnitude, direction and point of application of force.
10. Applications of equilibrium: in vehicles, shooting of billiards, walking and ships.

Revision exercise 4

Choose the most correct answer in items 1-2.

1. Which of the following equilibrium condition apply to walking?
   (a) Unstable equilibrium
   (b) Stable equilibrium
   (c) Neutral equilibrium
   (d) Both stable and unstable equilibrium

2. The equilibrium of a body depends on the following factors EXCEPT:
   (a) magnitude of force.
   (b) shape of the body.
   (c) direction of force.
   (d) point of application of force.

3. Match each item in **column A** against its corresponding item in **column B** by writing the correct response in the answer column.

Column A	Answer	Column B
(a) Stable equilibrium		(i) High centre of gravity
(b) Neutral equilibrium		(ii) Low centre of gravity
(c) Unstable equilibrium		(iii) Falls back moderately
		(iv) Narrow
		(v) Remains at new position
		(vi) Narrow but the same for all angles of turn
		(vii) No change
		(viii) Centre of gravity rises
		(ix) Falls forward

4. State the factors that affect the stability of a body.
5. (a) Why does a loaded test tube float upright in water?
   (b) It is more difficult to balance a nail on its tip than on its base. Explain.
6. Explain how each of the three characteristics of forces, namely magnitude, direction and point of application, play a role in determining an object's state of equilibrium.
7. Figure 4.34 shows three forces of equal magnitude applied at different points along a uniform rod. If the rod's axis of rotation is located at its centre of gravity:

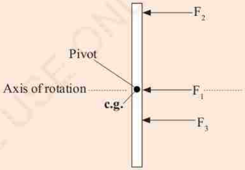


Figure 4.34

(a) Which force (s) could cause linear motion?
(b) Which force (s) could cause rotational motion?
(c) Which force has a clockwise moment?
(d) Which force has an anticlockwise moment?
(e) Which force has the largest moment?
(f) Is the rod in a state of linear or rotational equilibrium? Explain.

8. A uniform wooden plank with a mass of 75 kg and a length of 5 m is placed on top of a brick wall so that 1.5 m of the plank extends beyond the wall's edge as shown in Figure 4.35. How far beyond the edge of the wall can a 100 kg woman walk before the plank begins to rotate? (Let the plank's axis of rotation be at the wall's edge).

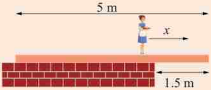


Figure 4.35

9. Can an object at rest be in a state of equilibrium? Explain your answer.
10. A uniform metre rule is freely pivoted at the 35 cm mark, and it balances horizontally when a body of mass 75 g is hung from the 10 cm mark.
    (a) Draw a clear force-diagram of the arrangement.
    (b) Calculate the mass of the metre rule.
11. A pole AB of length 10 m and weight 800 N has its centre of gravity 4 m from the end A and lies on a horizontal ground. The end B is to be lifted by a vertical force applied at B. Calculate the least force that is required to lift the end B.
12. For each of the following diagrams in Figure 4.36, indicate whether or not it shows a state of equilibrium, and if it does, name the type of equilibrium.

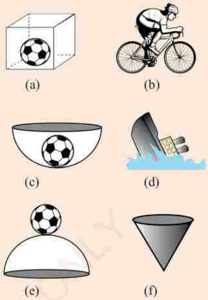


Figure 4.36

13. Figure 4.37 shows a 50 g rod balanced at its centre of gravity (c.g.). A 20 g mass is placed at 120 cm from the pivot point.

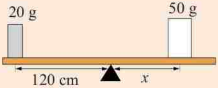


Figure 4.37

    (a) How far from the pivot point must the 50 g mass be placed for the system to be in equilibrium?
    (b) What upward force does the pivot exert on the rod?

Chapter Five

Simple machines

Introduction

Machines are tools and devices that simplify work. Various machines perform different tasks in daily activities. In this chapter, you will study simple machines which include levers, pulleys, inclined planes, screw jacks, wheel and axle as well as hydraulic press. The competencies developed from this chapter will enable you to construct and use simple machines for simplifying work. The use of simple machines increases the efficiency of performing work, resulting to improved productivity.

Concept of simple machines

The word machine originates from the Greek word "machos" which means something that "makes work easy." Therefore, the basic purpose of designing simple machines is to reduce the effort (force) required to perform a task. This purpose is achieved when the applied force acts over a longer distance or longer period of time. This allows one to perform work with a smaller force compared to performing work without a machine.

A simple machine is any device with a few or no moving parts that is used to modify motion and magnitude of force in performing work.

In general, simple machines help people to move objects from one point to another by:

(a) increasing the applied force as exhibited by crowbars;

(b) changing the direction of a force as can be seen in pulleys;

(c) changing the magnitude of force as done by screw jack;

(d) multiplying speed, as in the case of bicycles.

There are six types of simple machines. These are levers, the hydraulic press, the wheel and axle, the screw, the inclined plane and pulley. Examples of simple machines are shown in Figure 5.1. Simple machines can be combined to form complex machines.

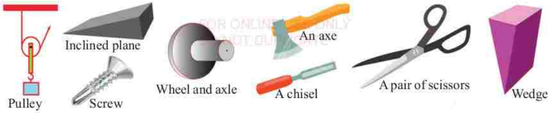


Figure 5.1: *Examples of simple machines*

Common terms

Common terms used in describing simple machines are load (L), effort (E), mechanical advantage (MA), velocity ratio (VR) and efficiency (ε). *Load* is the weight of an object being moved by a simple machine while *effort* is the force applied in moving the load.

Mechanical advantage (MA)

When we use less force to perform the same amount of work by using a machine, the machine is said to have offered *mechanical advantage*. Mathematically, mechanical advantage of a simple machine is the ratio of the load moved to the effort applied.

$$\textit{Mechanical advantage} = \frac{\textit{Load}}{\textit{Effort}}$$

If the load moved is smaller than the effort applied, the mechanical advantage is less than 1. Mechanical advantage indicates the factor to which the machine will increase or reduce the effort. For example, a machine with a mechanical advantage of 4 will multiply an effort of 10 N four times. Thus, the force applied on the load will be 40 N. However, if the MA of a machine is affected by friction present; extra force has to be applied to overcome friction.

Example 5.1

A person whose mass is 100 kg lifts a box of mass 500 kg by standing on one end of a lever. How much mechanical advantage does the lever provide to the person as he/she lifts the box?

Solution

$$MA = \frac{load}{effort}$$

$$= \frac{500\ \text{kg} \times 10\ \text{m/s}^2}{100\ \text{kg} \times 10\ \text{m/s}^2}$$

$$= \frac{5\,000\ \text{kg m/s}^2}{1\,000\ \text{kg m/s}^2}$$

$$= 5$$

The lever as a simple machine magnified the person's weight 5 times to lift the box. Therefore, the lever offered a mechanical advantage (MA) of 5 while lifting the box.

Velocity ratio (VR)

Velocity ratio of a simple machine is the ratio of the distance moved by the effort to the distance moved by the load. That is,

$$VR = \frac{\textit{Distance moved by the effort}}{\textit{Distance moved by the load}}$$

If the effort arm of a machine moves down a distance of 100 cm, resulting to the load being raised by 25 cm, then the velocity ratio of a machine will be;

$$VR = \frac{100 \text{ cm}}{25 \text{ cm}}$$

$$= 4$$

Therefore, velocity ratio of a machine is 4.

The velocity ratio of a machine is not influenced by the presence of friction.

Efficiency (ε)

Efficiency is a measure of the effectiveness of a machine in transforming the work input for the machine to work output. Mathematically, efficiency is given by the ratio of the work output to the work input. This ratio is usually expressed as a percentage, that is:

$$Effieciency,\ \varepsilon = \frac{work\ output}{work\ input} \times 100\%$$

Since, work done = force × distance moved , then efficiency can be written as:

$$Effieciency,\ \varepsilon = \frac{Load \times Load\ distance}{Effort \times Effort\ distance} \times 100\%$$

$$= MA \times \frac{1}{VR} \times 100\%$$

$$= \frac{MA}{VR} \times 100\%$$

Therefore,

$$Effieciency,\ \varepsilon = \frac{MA}{VR} \times 100\%$$

The efficiency of a machine is always less than 100%. This is because some of the effort applied is used to overcome frictional forces in the moving parts of the system. Therefore, the mechanical advantage is numerically always less than the velocity ratio.

Example 5.2

A machine having a velocity ratio of 5 requires 600 J of work to raise a load of 400 N. If the load moves a distance of 0.5 m, calculate the mechanical advantage and efficiency of the machine.

Solution

$$MA = \frac{Load}{Effort}$$

$$= \frac{400 \text{ N}}{Effort}$$

$$VR = \frac{Effort\ \ distance}{Load\ \ distance}$$

$$5 = \frac{Effort\ \ distance}{0.5\ \text{m}}$$

$$Effort\ \ distance = 0.5\ \text{m} \times 5 = 2.5\ \text{m}$$

Now,

$$work\ \ input\ = Effort\ \times Effort\ \ distance$$

$$Effort = \frac{work\ input}{Effort\ distance}$$

$$= \frac{600\ \text{J}}{2.5\ \text{m}}$$

$$= 240\ \text{N}$$

Thus,

$$MA = \frac{Load}{Effort}$$

$$= \frac{400\ \text{N}}{240\ \text{N}}$$

$$= 1.67$$

Finally,

$$Effieciency,\ \varepsilon = \frac{MA}{VR} \times 100\,\%$$

$$= \frac{1.67}{5} \times 100\%$$

$$= 33.4\%$$

Therefore, the efficiency of the machine is 33.4 %.

Types of simple machines

There are different types of simple machines which include levers, screw jack, pulley, wheel and axle, inclined plane, and hydraulic press.

Levers

A lever is possibly one of the oldest simple machine used to lift heavy loads. It consists of a rigid bar that moves about a fixed point. A lever has three main parts, namely *fulcrum, load* and *effort.* The distance between the load and fulcrum is called *the load arm* while the distance from the fulcrum to the effort is called *the effort arm* (see Figure 5.2). The longer the effort arm the easier it is to lift the load. Levers always act as force magnifiers.

The fulcrum is the fixed point about which the bar moves.

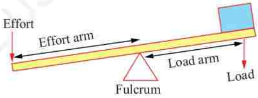


Figure 5.2: *Illustration of a lever*

Classes of levers

Depending on the positions of the load, the effort and the fulcrum, levers can be grouped into three classes, namely first class levers, second class levers, and third class levers.

First class levers

A first class lever has the fulcrum located between the effort and the load. The lever shown in Figure 5.2 is a first class lever. It changes the direction of the force acting on the load. The effort applied in the downward direction results in an upward movement of the load. Mechanical advantage of the lever depends on the position of the fulcrum. The closer the fulcrum is to the load, the less the effort needed to move the load. Examples of first class levers include crowbars, a pair of scissors, pliers and see-saws.

A pair of scissors in Figure 5.3 is a force magnifier because the distance between the effort and the fulcrum is greater than the distance between the load and the fulcrum. Thus, applying a small amount of force results in a large amount of work being done.

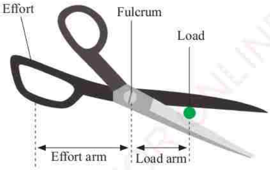


Figure 5.3: *Pair of scissors*

Second class levers

A second class lever has the load located between the fulcrum and the effort as shown in Figure 5.4.

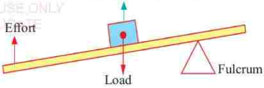


Figure 5.4: *Second class lever*

The load moves in the same direction as the applied force while the effort is multiplied. Just like in the first class lever, the closer the load is to the fulcrum, the easier it is to move it. Examples of second class levers include wheelbarrows, nutcrackers and bottle openers (see Figure 5.5).

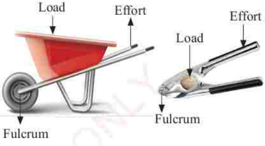


Figure 5.5: *Examples of second class levers*

Third class levers

A third class lever has the effort between the fulcrum and the load as shown in Figure 5.6.

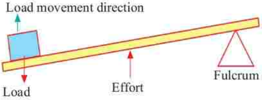


Figure 5.6: *Third class lever*

A third class lever does not change the direction of force and does not multiply the force. This means that the load moves in the same direction as the applied effort. Examples of third class levers include tweezers and shovels (see Figure 5.7).

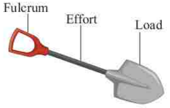


Figure 5.7: *Third class lever (a shovel)*

Task 5.1

Look around your class, school and home for simple machines that have movable parts.

(a) Which of these simple machines are levers? List them down.
(b) Classify the levers you have listed into first class, second class and third class.

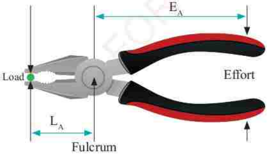
Mechanical advantage of levers

The mechanical advantage of a lever is the ratio of the effort arm, E_A to the load arm, L_A. That is:

$$MA = \frac{Effort\ arm}{Load\ arm} = \frac{E_A}{L_A}$$

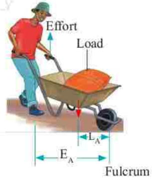
The effort arms and load arms of the three classes of levers are shown in Figures 5.8 (a), (b) and (c).

(a) First class lever



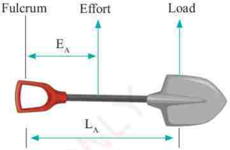
(a)

(b) Second class lever



(b)

(c) Third class lever



(c)

Figure 5.8: *Effort arms (E_A) and load arms (L_A) of the three types of levers*

Since the load arm of the third class lever is always longer than the effort arm, the mechanical advantage of third class levers is always less than 1. This means that third class levers waste part of the force applied. This type of lever is the most inconvenient one because, no matter how far the load is from the fulcrum, the effort needed to lift the load needs to be larger than the load.

The human forearm is a good example of a third class lever. This indicates that the human arm is not a force magnifier but a distance magnifier. A small contraction of an arm muscle produces a big movement of the hand.

Velocity ratio of levers

From the definition of velocity ratio of a machine, the velocity ratio of a lever is given by the ratio of the effort arm to the load arm.

That is,

$$VR = \frac{Effort\ arm\ (E_A)}{Load\ arm\ (L_A)}$$

Then, the efficiency, ε of the lever can be calculated using the formula:

$$Efficiency = \frac{MA}{VR} \times 100\%$$

Example 5.3

A certain first class-lever of length 2.5 m has a velocity ratio of 12 and an efficiency of 85%.

(a) How far from the fulcrum is the effort applied?

(b) What effort is required to lift a load weighing 75 N?

Solution

(a) $VR = 12 = \frac{E_A}{L_A}$

$$E_A = 12L_A$$

But, $E_A + L_A = 2.5$ m (from the total length of the lever).

Substituting for E_A in the above equations, you get:

$$12\,L_A + L_A = 2.5 \text{ m}$$

$$(12+1)\,L_A = 2.5 \text{ m}$$

$$L_A = \frac{2.5 \text{ m}}{13} = 0.192 \text{ m}$$

Substituting in $E_A = 12\,L_A$,

$$= 12 \times 0.192 \text{ m}$$

$$= 2.3 \text{ m}$$

Therefore, the effort is applied at 2.3 m from the fulcrum.

(b) $Efficiency\ (\varepsilon) = \frac{MA}{VR} \times 100\%$

$$MA = \frac{\varepsilon \times VR}{100\%}$$

$$= \frac{85\% \times 12}{100\%} = 10.2$$

But ,

$$MA = \frac{Load}{Effort}$$

$$Effort = \frac{Load}{MA}$$

$$= \frac{75 \text{ N}}{10.2}$$

$$= 7.35 \text{ N}$$

Therefore, effort is 7.4 N.

Activity 5.1

Aim: To determine the mechanical advantage, the velocity ratio and the efficiency of a first class lever using a balanced metre rule.

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Materials: Metre rule, spring balance, retort stand and clamp, masses and thread

Procedure

1. Suspend the metre rule from the clamp at the 50 cm mark using a thread as shown in 5.9.
2. Hang a 200 g mass at the 10 cm mark such that a load distance is 40 cm.
3. Suspend the spring balance loaded with a 50 g mass on the other side of the rule.
4. Adjust the position of the spring balance until the ruler is horizontally balanced. Record the new position of the spring balance and determine the effort distance.

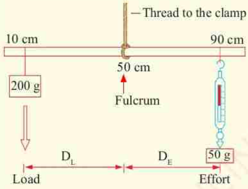


Figure 5.9

5. Repeat the procedure using a 500 g mass in place of the 200 g mass.

Questions

(a) Work out the values of the effort, E, load, L, effort distance, D_E and load distance, D_L for both the 200 g and the 500 g masses.

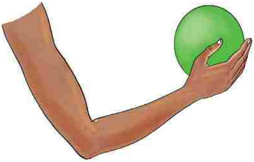
(b) Calculate the mechanical advantage and velocity ratio of the balanced metre rule for each of the two masses.

(c) Determine the efficiency of the balanced metre rule.

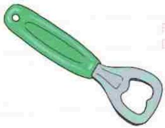
Other examples of levers are a spanner, a fishing rod, human arm and a bottle opener shown in Figure 5.10.

(a) Spanner

(b) Fishing rod



(c) Human arm



(d) Bottle opener

Figure 5.10: *Examples of levers*

Exercise 5.1

1. A lever system of velocity ratio 45 overcomes a load of 4500 N when an effort of 105 N is applied to it. Calculate:
   (a) the mechanical advantage of the lever system.
   (b) Its efficiency.
   (c) the percentage of the work input which is used to overcome friction in the system.
2. A see-saw of length 3.2 m has an efficiency of 70 % with a velocity ratio of 10.
   (a) Which class is this lever?
   (b) How far from the fulcrum is the effort applied?
   (c) Calculate the effort required to lift a load of 90 N.
3. An effort of 100 N is applied on a wheelbarrow carrying a load of 500 N with velocity ratio of 8. If the effort acts 2.5 m from the fulcrum, calculate:
   (a) load arm.
   (b) efficiency of the machine.
   (c) the percentage of the lost work input.
4. A certain third class lever with velocity ratio of 0.6 is acted by an effort at a point 1.6 m from the fulcrum. At which point the load can be placed.

Pulleys

A pulley is a simple machine composed of a rope and a hub or drum with a wheel mounted on an axle. The outer rim of the pulley is grooved as shown in Figure 5.11, to enable a rope, cable or belt to run inside the groove. Pulleys are used to change the direction of an applied force. When a system of two or more pulleys is used, the applied force can also be multiplied in addition to changing direction.

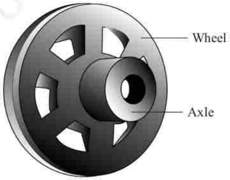


Figure 5.11: *Pulley*

Mechanism of pulleys

An effort is applied to one end of the pulley rope. The pulley changes the direction of the force such that the other end of the rope moves upwards.

For an ideal frictionless pulley, the tension of the rope is the same at all points. This makes the applied force to be transferred to lift the load.

Pulleys offer the mechanical advantage which can be calculated by the formula:

$$MA = \frac{Output\ force}{Input\ force} = \frac{L}{E}$$

The velocity ratio of a pulley is given as:

$$VR = \frac{Distance\ moved\ by\ the\ effort}{Distance\ moved\ by\ the\ load}$$

Types of pulleys

Pulleys are classified into different types depending on the number of ropes and arrangement. These include fixed pulleys, movable pulleys, combination or compound pulleys and the block and tackle system.

Fixed pulley

A fixed pulley is the one whose drum is hinged to a fixed pivot as shown in Figure 5.12 such that it cannot move up and down with the rope.

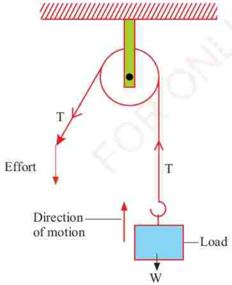


Figure 5.12: *A fixed pulley*

A fixed pulley only changes the direction of the force. Thus, a fixed pulley has a mechanical advantage of 1. The effort applied is equal to the weight of the load moved. This means there is no multiplication of force. Given that the tension T in the rope is the same, the distance moved by the effort equals that moved by the load. In this case, $VR = 1$. This implies that, $MA = 1$ and hence the efficiency of a fixed pulley equals 100%. A flag raising mechanism on a flag pole is an example of a fixed pulley system.

Movable pulley

A movable pulley is the one that is free to move up and down along with the load as shown in Figure 5.13.

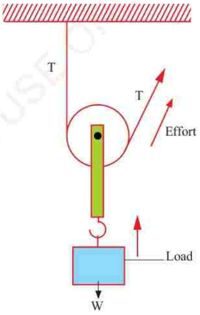


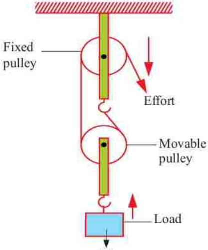
Figure 5.13: *A single movable pulley*

A movable pulley does not change the direction of the force but multiplies the effort applied. The mechanical advantage of a movable pulley is greater than 1.

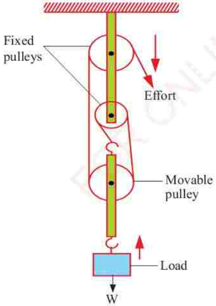
Combination or compound pulley system

A combination or compound pulley system comprises of fixed and movable pulleys. A compound pulley consists of two or more pulleys.

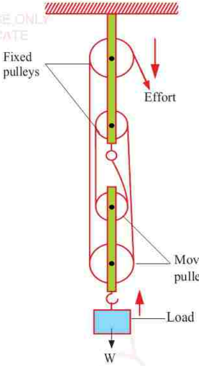
The number of pulleys varies from one pulley system to another as demonstrated by Figure 5.14. In this case, the direction of effort is changed, and its magnitude is multiplied.



(a) Two pulleys



(b) Three pulleys



(c) Four pulleys

Figure 5.14: *Combination pulleys system*

In Figure 5.14 (a), the pulley system consists of one fixed pulley and one movable pulley. One end of the rope is fixed while the other is left for a person to pull, thereby lifting the movable pulley and the load. Since there are two ropes lifting the load, the force on the load is twice the effort applied. But by how far would the effort move?

To lift the load through 1 m, the effort will have to move through a corresponding height. Since there are two ropes holding the lower pulley and because both ropes have to be shortened by 1 m, the effort will move through a distance of 2 m.

Thus, in a compound pulley, the effort distance is greater than the load distance. Pulley systems are used in cranes to lift heavy loads.

The block and tackle system

A block and tackle is a pulley configuration that contains two or more drums. Each drum contains one or more wheels rotating on the same axle. The rope loops back and forth between the drums passing through the individual wheels within the drums (see Figure 5.15).

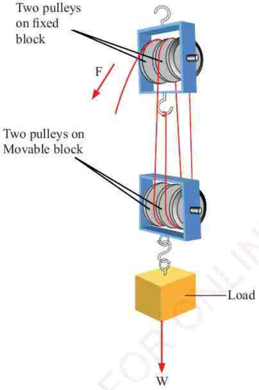


Figure 5.15: *Block and tackle*

A block and tackle system uses a single continuous rope to transmit a tension around the pulleys. The mechanical advantage of this system equals the number of parts of the rope that act on the load. In other words, the number of supporting rope sections gives the mechanical advantage of the block and tackle system.

An ideal block and tackle system with a moving block supported by n rope sections has;

$$MA = \frac{Output\ force}{Input\ force} = n$$

Block and tackle pulley systems are used in ships to lift heavy loads.

Task 5.2

Visit the nearest port or similar facility, observe how the cranes are used to lift very heavy loads. Carefully observe the number of pulleys in the cranes and how they operate. Discuss your findings in class.

Mechanical advantage of a pulley system

The mechanical advantage of a pulley system is equal to the number of ropes that are directly bearing the load. In combination pulleys, the mechanical advantage is also equal to the number of pulleys in the system.

A single movable pulley and compound pulley consisting of single fixed pulley and a single movable pulley have the mechanical advantage of 2 (see Figure 5.16).

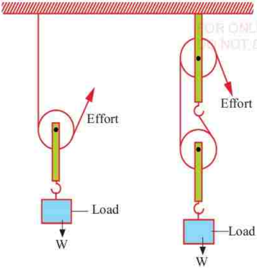


Figure 5.16: *Pulleys with a mechanical advantage of 2*

If n represents the number of ropes that are supporting the load in the pulley system and assuming that there is no friction, then the effort, E required to lift the load, L is given by:

$$E = \frac{L}{n}$$

But,

$$MA = \frac{L}{E} = \frac{L}{L/n} = \frac{nL}{L} = n$$

$$MA = n$$

Since, $MA = \frac{L}{E}$,

It could require an effort of 50 N to lift a load of 100 N using the pulleys shown in Figure 5.16 (mass × 10 N/Kg = weight). The combination pulleys shown in Figure 5.14 (b) and (c) have a mechanical advantage of 3 and 4 respectively.

Most pulley systems are designed to have a mechanical advantage of more than 1 so that a greater load can be raised with less effort.

Velocity ratio of a pulley system

If a pulley system is 100% efficient, its mechanical advantage is numerically equal to its velocity ratio.

However, the efficiency of a pulley system is always less than 100% for two reasons:

1. Energy is needed to lift the bottom pulleys and the ropes.
2. Friction between the moving parts of a machine transforms some of the energy into heat.

Consider the ideal pulley system shown in Figure 5.17.

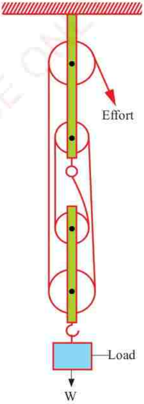


Figure 5.17: *Ideal pulley system with a velocity ratio of 4*

$$VR = \frac{\text{Distance moved by the effort}}{\text{Distance moved by the load}}$$

Since the pulley is ideal, if the load, L, moves a distance x in each pulley, then the distance moved by the effort is, therefore, equal to $4x$.

Since,

$$VR = \frac{\text{Distance moved by the effort}}{\text{Distance moved by the load}}$$

$$VR = \frac{4x}{x}$$

Therefore,

$$VR = 4.$$

The VR of a block and tackle system is equal to the number of ropes supporting the load. It is also equal to the number of pulleys, which is a general result for this kind of system. Due to the weight of the pulleys and the frictional forces in the moving parts, the mechanical advantage of a pulley system is always numerically less than its velocity ratio.

Example 5.4

A pulley system is made up of 8 pulleys. An effort of 200 N is applied on the pulley system. If the pulley system has an efficiency of 80%, what is the maximum load that can be raised by the effort applied?

Solution

MA = number of pulleys = 8

But, $MA = \frac{Load}{Effort} = \frac{L}{E}$

Therefore, $8 = \frac{L}{200\text{ N}}$

where L is the maximum load that can be raised by an effort of 200 N if the pulley system is 100% efficient.

$$L = 200\text{ N} \times 8$$

$$L = 1600\text{ N}.$$

But the system is 80% efficient. The maximum load that can be raised by the 200 N is, therefore, given by:

$$L_{max} = \frac{80}{100} \times 1600\text{ N}$$

$$= 1280\text{ N}$$

Exercise 5.2

1. Determine the effort required to lift a load of 100 N using:
   (a) a single fixed pulley
   (b) a single movable pulley
   (c) combination pulley system made up of 5 pulleys
   (d) compare your results. Which is a suitable pulley to use in this case? Why is it suitable?
2. A simple machine has a velocity ratio of 5, and it is 80% efficient. What effort would be needed to lift a load of 200 N with the aid of this machine?
3. While lifting a load of 200 N using a lever, an effort of 80 N moved through a distance of 20 cm to lift the load through a distance of 4 cm. Calculate:

(a) the mechanical advantage.

(b) the velocity ratio.

(c) the efficiency of the machine.

4. A block and tackle system consisting of 5 pulleys is used to raise a load of 400 N through a height of 10 m. If the work done against friction is 100 J, calculate:

   (a) the work done by the effort.

   (b) the efficiency of the system.

   (c) the effort applied.

5. If an effort of 60 N is needed to lift a load of 150 N with a three-pulley system, what is the efficiency of this machine?

Inclined plane

An **inclined plane** is a smooth flat rigid surface slanted at an angle θ to the horizontal as shown in Figure 5.18.

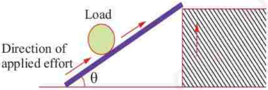


Figure 5.18: *An inclined plane*

The inclined plane makes it easy to move a load from a lower to a higher position. This is achieved by reducing the effort and increasing the distance through which the effort is applied. The smaller the angle of inclination, the easier it is to move the load. Examples of inclined planes include staircases, winding roads and ramps (see Figure 5.19).

Figure 5.19: *Ramps*

Mechanical advantage of an inclined plane

In an inclined plane, the effort applied along the slanted length is used to move the load to a position equal to the vertical height, L_d as shown in Figure 5.20.

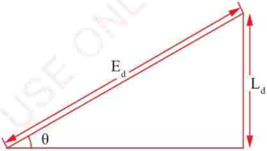


Figure 5.20: *Effort and load distances on an inclined plane*

The mechanical advantage of an inclined plane is equal to the ratio of the slanted length, E_d to the vertical height, L_d of the plane, that is:

$$MA = \frac{E_d}{L_d}$$

Velocity ratio of an inclined plane

Since,

$$VR = \frac{\textit{Distance moved by the effort}}{\textit{Distance moved by the load}}$$

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then, velocity ratio of an inclined plane is given by:

$$VR = \frac{Slanted\ \ height}{Vertical\ height} = \frac{E_d}{L_d}$$

This shows that the velocity ratio of an inclined plane is equal to its mechanical advantage. This is the case only if the plane is 100% efficient. However, there is always some frictional force resisting the movement of the load up the plane. This means that the mechanical advantage of the plane could be smaller than the velocity ratio. This is because part of the effort applied on the load is used to overcome the frictional force.

Example 5.5

A force of 600 N is used to move a load of 3 000 N up an inclined plane. Given that the slanted height and the vertical height of the plane are 18 m and 3 m respectively, determine:

(a) the velocity ratio of the plane.

(b) the mechanical advantage of the plane.

(c) the efficiency of the plane.

Solution

(a) $$Velocity\ ratio = \frac{Slanted\ length}{Vertical\ height}$$

$$= \frac{18\text{ m}}{3\text{ m}}$$

$$= 6$$

(b) $$MA = \frac{Load}{Effort} = \frac{3\ 000\text{ N}}{600\text{ N}}$$

$$= 5$$

(c) $$Efficiency = \frac{MA}{VR} \times 100\%$$

$$= \frac{5}{6} \times 100\%$$

$$= 83.33\%$$

Exercise 5.3

1. Figure 5.21 shows a box of weight 150 N being pulled at a steady speed up a ramp by a force of 100 N.

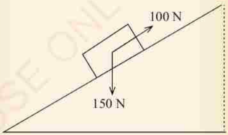


Figure 5.21

If the height of the plane is 2 m above the ground, and the length of the plane is 4 m, calculate:

(a) the mechanical advantage.

(b) the velocity ratio.

(c) the work done by the effort.

(d) the work done on the load.

(e) the efficiency of the machine.

2. A 200 kg crate is to be loaded onto the bed of a truck that is 1.4 m above

the ground. A metal ramp of 5 m long is leaned against the truck bed, and the crate is pushed up along it. Neglecting the frictional forces:

(a) calculate the force required to push the crate up the inclined plane at a constant velocity.

(b) calculate the mechanical advantage of the incline.

(c) determine the efficiency of the machine.

3. A trolley is pulled up an inclined plane 2 m high using a force of 4 N. If the mass of the trolley is 1 kg:

   (a) what is the mechanical advantage of the plane?

   (b) find its velocity ratio.

   (c) find its efficiency.

4. An effort of 20 N raises a bag up an inclined plane by 10 cm. If the mechanical advantage of the inclined plane is 10, calculate the load distance.

Activity 5.2

Aim: To measure the mechanical advantage of an inclined plane.

Materials: Four books (each with a thickness of about 1 cm), a board with a pulley attached at the end, a wooden block with a hook, a mass hanger, a piece of thread, weighing balance, standard masses

Procedure

1. Stack the four books on one edge of a table or bench.
2. Place the board on the books in a slanting position with the pulley on the upper edge as shown in Figure 5.22.
3. Measure and record the mass of the wooden block and the mass hanger.
4. Place the wooden block near the base of the inclined plane.
5. Measure and record the length of the plane, L, and the vertical height, H, from the table or bench to the edge of the pulley.
6. Suspend the mass hanger from the pulley by tying the other end of the thread to the wooden block as shown in Figure 5.22.

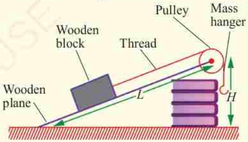


Figure 5.22

7. Place some masses on the mass hanger, one by one, until the wooden block is just about to move. Note the total mass on the mass hanger.
8. Repeat the procedure twice, removing one book each time to change the angle of inclined plane. Record your results in the following table.

	First	Second	Third
Height of the inclined plane, **H**			
Mass of the hanger + mass required to move the block, $\mathbf{M_E}$			

Questions

(a) Calculate:

(i) the velocity ratio of the inclined plane.

(ii) the mechanical advantage of the inclined plane.

(b) State the possible sources of errors in the experiment. Discuss your answers with your teacher.

Screw

A *screw* is a form of an inclined plane in which the plane is wrapped around a rod. There are two types of screws: fastening screws and lifting screws. An example of a lifting screw is the screw jack that is used to lift a car when changing tyres. An example of fastening screw is a bolt.

The *screw jack* shown in Figure 5.23 consists of a rod that is usually made up of a hard metal. A spiral groove is cut on the surface of the rod. The grooves are separated by raised bands known as *threads*. The distance between two successive threads is referred to as a *pitch*. The pitch of a screw jack is given by;

$$Pitch = \frac{Length\ of\ the\ rod\ in\ cm}{Number\ of\ threads}$$

For example, if there are 10 threads in 1 cm, then the pitch of the screw jack is: $\frac{1}{10}$ cm = 0.1 cm.

Figure 5.23: *A screw jack*

The screw jack has an arm which is used to turn it. The screw moves forward or backward in the direction of its length. For each complete turn the arm makes, the screw jack moves a distance equal to its pitch. The main characteristic of the screw is the radius, *R*, of the shaft and the pitch, *P*. All types of screws work in the same way as the screw jack. The only difference with them is the means of turning the screws.

Mechanical advantage of a screw jack

Mechanical advantage of a screw jack depends on its pitch. Without considering friction, the mechanical advantage of a screw jack is the ratio of the circumference of the circle made by the turning arm to the pitch of the screw, that is:

$$MA = \frac{\text{Circumference of the circle made by the turning arm}}{\text{Pitch of the screw}}$$

The mechanical advantage of a screw jack is very large because the pitch is very small compared to the length of the arm. If a screw jack has 100% efficiency, the mechanical advantage would be equal to the velocity ratio. However, because of friction, mechanical advantage of a screw jack is always less than the velocity ratio.

Velocity ratio of a screw jack

Since, $VR = \frac{\text{Distance moved by the effort}}{\text{Distance moved by the load}}$

the velocity ratio of a screw jack is given by:

$$VR = \frac{\text{Circumference of the circle made by the turning arm}}{\text{Pitch of the screw}}$$

If the radius of the circle made by the turning arm is R,

$$VR = \frac{2\pi R}{Pitch}$$

But, R is the length of the effort lever,

$$\text{Thus, } VR = \frac{2\pi \times \text{Length of effort lever}}{\text{Pitch of the screw}}$$

Note that, for each rotation of the screw $2\pi R$, it moves forward a distance P. Then,

$$VR = \frac{2\pi R}{P}$$

Example 5.6

A screw jack has 5 threads per centimetre. If the length of the turning arm is 20 cm, determine the velocity ratio of the screw jack. (Take $\pi = 3.14$)

Solution

$$VR = \frac{\text{Circumference of the circle made by the turning arm}}{\text{Pitch}}$$

$$\text{But, } circumference = 2\pi R$$

$$= 2 \times 3.14 \times 20 \text{ cm}$$

$$= 125.6 \text{ cm}$$

$$Pitch = \frac{length\ of\ the\ rod}{number\ of\ threads}$$

$$= \frac{1}{5} \text{ cm}$$

$$= 0.2 \text{ cm}$$

Therefore,

$$VR = \frac{125.6 \text{ cm}}{0.2 \text{ cm}}$$

$$= 628$$

Example 5.7

A screw jack which has 5 threads per centimetre is used to lift a car weighing 20 000 N. If the length of the turning arm is 40 cm, and the efficiency of the screw jack is 90%, find:

(a) the velocity ratio of the jack.

(a) the mechanical advantage of the jack.

(a) the minimum force required to raise the car. (Take $\pi = 3.14$)

Solution

(a) $VR = \frac{Circumference}{Pitch}$

$$Circumference = 2\pi R$$

$$= 2 \times 3.14 \times 40 \text{ cm}$$

$$= 251.2 \text{ cm}$$

$$Pitch = \frac{1}{5} \text{ cm} = 0.2 \text{ cm}$$

$$VR = \frac{251.2 \text{ cm}}{0.2 \text{ cm}}$$

$$= 1256$$

Therefore, velocity ratio of the screw jack is 1256.

(b) $Efficiency = \frac{MA}{VR}$

$$MA = VR \times Efficiency$$

$$= 1256 \times \frac{90}{100}$$

$$= 1130.4$$

The mechanical advantage of the screw jack is 1130.4.

(c) $MA = \frac{Load}{Effort}$

$$Effort = \frac{Load}{MA}$$

$$= \frac{20000 \text{ N}}{1130.4}$$

$$= 17.7 \text{ N}$$

The minimum effort required to lift the 20 000 N car with the jack is 17.7 N.

Exercise 5.4

1. A screw jack has an efficiency of 40% and it is used to lift a load of 400 kg. If its pitch is 0.5 cm and the effort arm is 0.5 m long, find the effort required.

2. The pitch of a screw jack is 0.5 cm. When used to raise a load, the handle turns through a circle of radius 40 cm. What is the *MA* of the screw jack if its efficiency is 25%? (Take $\pi = 3.14$)

3. The *VR* of a screw jack is 420. If it has 10 threads per centimetre, calculate the length of the turning lever.
4. A screw jack has 8 threads per centimetre of length. If the length of the turning handle is 10 cm, calculate the velocity ratio of the screw jack.

Task 5.3

In groups of four students, identify, list down and discuss the various situations in which the screw jack is used. Present your findings in class.

Wheel and axle

The wheel and axle is made up of a large wheel that turns a smaller wheel called the axle. A wheel and axle is also a lever with the centre of the axle acting as the fulcrum. The wheel has a larger radius than the axle as shown in Figure 5.24.

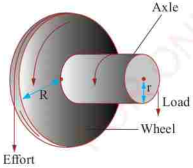


Figure 5.24: *Wheel and axle*

One full turn of the wheel causes a full revolution in the axle. Since the wheel is larger than the axle, a point on it always moves through a larger linear distance than to a point on the axle. An effort applied to the wheel is, therefore, multiplied when it is transferred to the axle. However, the distance covered and the linear speed are decreased. On the other hand, if an effort is applied to the axle in order to turn the bigger wheel, the force is decreased when it is transferred to the wheel, but the distance covered and the speed are increased. In practice, the wheel is used to turn the axle.

Wheel and axle machines are applied in screwdrivers, windmills, doorknobs, gear system, steering wheels, bicycle wheels, box spanners and windlasses. Figure 5.25 shows some examples of wheel and axle machines.

Windmills

Doorknob

Screwdriver

Adjustable spanner

Windlass   Steering wheel   Bicycle wheel

Figure 5.25: *Examples of wheel and axle machines*

Mechanical advantage of a wheel and axle

If there are no frictional forces opposing the movement of the wheel and the axle, its mechanical advantage is equal to the velocity ratio.

Due to the fact that there will always be some friction in the wheel and axle, the mechanical advantage is always less than the velocity ratio.

Velocity ratio of a wheel and axle

As is already seen, one complete turn of the wheel results in one complete turn of the axle.

Since the effort is applied at the wheel,

$$VR = \frac{Circumference\ of\ the\ wheel}{Circumference\ of\ the\ axle}$$

$$VR = \frac{2\pi R}{2\pi r}$$

$$VR = \frac{R}{r}$$

Therefore, velocity ratio of the wheel and axle machine is the ratio of the radius of the wheel to the radius of the axle.

Example 5.8

A wheel and axle has a velocity ratio of 6. Determine the radius of the wheel if the radius of the axle is:
(a) 5 cm (b) 8 cm (c) 12 cm

Solution

(a) Given $VR = 6$; $r = 5$ cm; $R = ?$

$$VR = \frac{R}{r}$$

$$R = 6 \times 5 \text{ cm}$$

$$= 30 \text{ cm}$$

(b) Given $VR = 6$; $r = 8$ cm; $R = ?$

From, $VR = \frac{R}{r}$

$$R = 6 \times 8 \text{ cm}$$

$$= 48 \text{ cm}$$

(c) Given $VR = 6$; $r = 12$ cm; $R = ?$

From,

$$VR = \frac{R}{r}$$

$$R = 6 \times 12 \text{ cm}$$

$$= 72 \text{ cm}$$

Example 5.9

A wheel and axle with an efficiency of 90% is to be used to raise a load of 10 000 N. The radius of the wheel is 40 cm while that of the axle is 5 cm. Calculate:

(a) the velocity ratio of the wheel and axle;

(b) the mechanical advantage of the wheel and axle;

(c) the effort required to raise the 10 000 N load.

Solution

Given, radius of the wheel (R) = 40 cm; radius of the axle (r) = 5 cm; VR = ?

(a) $\textit{Velocity ratio} = \frac{R}{r} = \frac{40 \text{ cm}}{5 \text{ cm}} = 8$

(b) $\textit{Efficiency}(\varepsilon) = \frac{MA}{VR} \times 100\%$

$$MA = VR \times \varepsilon$$

$$= 8 \times \frac{90}{100}$$

$$= 7.2$$

(c) $MA = \frac{Load}{Effort}$

$$Effort = \frac{Load}{MA}$$

$$= \frac{10\,000 \text{ N}}{7.2}$$

$$= 1388.9 \text{ N}$$

Gear system

A gear is an example of the wheel and axle machine. It is made up of a wheel that has teeth along its circumference. A system of two or more gears is used to magnify or change the direction of an applied force.

The gear in which a force is applied is called a *driver gear* while the other gear is called the *driven gear*. Figure 5.26 shows a two-gear system.

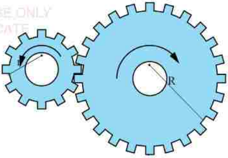


Figure 5.26: *Two gear system*

If friction is ignored, the mechanical advantage of a gear system is equal to the velocity ratio. The velocity ratio of the gear system is determined by the number of teeth on the gears, that is:

$$VR = \frac{\textit{Number of teeth of the driven gear}}{\textit{Number of teeth of the driver gear}}$$

High velocity ratio means the driven gear moves faster but with less force. In this case, the gear system is a speed magnifier.

Low velocity ratio means driven gear moves slower but with large force. In this case, the gear system is a force magnifier.

The velocity ratio also known as the gear ratio can alternatively be obtained from the number of revolutions made by the gears. That is,

$$VR = \frac{\textit{Number of revolutions made by driver gear}}{\textit{Number of revolutions made by driven gear}}$$

Thus, it reduces to:

$$VR = \frac{\textit{Radius of the driver gear}}{\textit{Radius of the driven gear}}$$

The principle of gear systems is applied in bicycles, motorcycles and car gear boxes.

In a car, the driver changes the gear ratio for force when going uphill or for speed when moving on a flat road or downhill.

Exercise 5.5

1. A crank handle with a length of 30 cm is attached to an axle with a radius of 5 cm and is used to lift a bucket of water from a deep well. If the bucket of water weighs 120 N and friction is neglible,
   (a) how much force is required to turn the crank?
   (b) find the number of turns of the crank required to raise the bucket to the surface if the well is 510 m deep.
2. Find the *VR* of a wheel and axle system if the load gear has 60 teeth, and the driven gearwheel has 20 teeth.
3. A gearwheel A has 20 teeth. It is used to drive a gearwheel B with 80 teeth.
   (a) Calculate the velocity ratio.
   (b) If wheel A rotates three times every second, how many times does wheel B rotate in a second?
4. (a) Why does a cyclist often zigzag when going up a hill?
   (b) Imagine that you are riding a bicycle. How many simple machines are in your possession?
5. What is the significance of the gearwheel as a simple machine?

Hydraulic press

A hydraulic press multiplies an applied effort using the pressure of a liquid or gas. This allows the lifting of a heavy load by applying little effort.

Mechanical advantage of a hydraulic press

The hydraulic press works on the principle that liquids cannot be compressed. If a force is applied on a liquid at one end of a container, force is transmitted to the other end and no pressure is lost.

Therefore, the pressure applied on the effort piston is equal to the pressure transferred to the load piston (see Figure 5.27). That is,

$$P_1 = P_2.$$

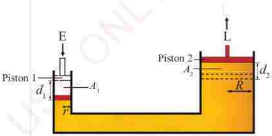


Figure 5.27: *Hydraulic press*

$$Pressure = \frac{Force}{Area}$$

Therefore,

$$P_1 = \frac{E}{A_1} \text{ and } P_2 = \frac{L}{A_2}$$

$$E = P_1 A_1$$

$$L = P_2 A_2$$

$$MA = \frac{Load}{Effort}$$

$$MA = \frac{L}{E} = \frac{P_2A_2}{P_1A_1}$$

But,

$$P_1 = P_2$$

Hence,

$$\frac{L}{E} = \frac{A_2}{A_1}$$

Taking the radius of piston 1 as r and that of piston 2 as R;

$$MA = \frac{\pi R^2}{\pi r^2} = \frac{R^2}{r^2}$$

Velocity ratio of a hydraulic press

The velocity ratio of a hydraulic press is given by:

$$VR = \frac{Effort\ distance}{Load\ \ distance}$$

In Figure 5.27, if there is no friction in the hydraulic press, then,

$$VR = \frac{d_1}{d_2}$$

Consider a fixed volume of liquid displaced when a piston moves a distance d. The volume of displaced liquid is given by,

$$V = Ad$$

Since the liquid is incompressible, it follows:

$$A_1d_1 = A_2d_2$$

$$A_1\frac{d_1}{d_2} = A_2\frac{d_2}{d_2}$$

$$\frac{d_1}{d_2} = \frac{A_2}{A_1}$$

But, $\frac{d_1}{d_2} = VR$

Then, $VR = \frac{A_2}{A_1} = \frac{\pi R^2}{\pi r^2} = \frac{R^2}{r^2}$

Hence;

In this case $VR = MA$

Efficiency of a hydraulic press

$$Efficiency = \frac{Work\ output}{Work\ input} \times 100\%$$

But, $Work = F \times d$

Where, $F =$ force

$d =$ distance moved in the direction of force

Work input $= Ed_1$

Work output $= Ld_2$

Therefore,

$$\text{Efficiency} = \frac{Ld_2}{Ed_1} \times 100\%$$

For ideal system,

Efficiency = 100%

In practical cases, the mechanical advantage is less than velocity ratio due to frictional forces in the hydraulic press. The efficiency of a hydraulic press is therefore less than 100%.

Example 5.10

Figure 5.28 shows a hydraulic press being used to lift a lorry weighing 25 000 N.

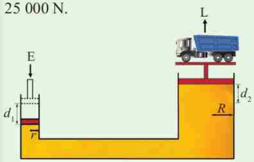


Figure 5.28

If the radii of the small and the large piston are 2.5 cm and 25 cm respectively, and the efficiency of the press is 90%, determine:

(a) the velocity ratio of the press.

(b) the mechanical advantage of the press.

(c) the minimum effort required to lift the car.

(d) the distance the car is raised through if the effort piston is pushed through 1 m.

Solution

(a) Given,

Radius of a small piston, $r = 2.5$ cm; radius of a large piston, $R = 25$ cm;

$$\text{Velocity ratio} = \frac{R^2}{r^2}$$

$$= \frac{(25\text{ cm})^2}{(2.5\text{ cm})^2}$$

$$VR = 100$$

(b) Given,

Efficiency $(\varepsilon) = 90\%$; $VR = 100$;

$$\varepsilon = \frac{MA}{VR} \times 100\%$$

$$MA = \frac{\varepsilon \times VR}{100\%}$$

$$= \frac{90\ \% \times 100}{100\%}$$

$$MA = 90$$

(c) Given,

Load, $L = 25\,000$ N; $MA = 90$

$$MA = \frac{\text{Load}}{\text{Effort}}$$

$$\text{Effort} = \frac{\text{Load}}{MA}$$

$$= \frac{25\,000\text{ N}}{90}$$

$$\text{Effort} = 277.8\text{ N}$$

(d) Given,

Effort distance, $d_1 = 1$ m; $VR = 100$

$$\text{Velocity ratio} = \frac{\text{Effort distance}}{\text{Load distance}}$$

$$VR = \frac{d_1}{d_2}$$

$$d_2 = \frac{d_1}{VR}$$

$$= \frac{1\text{ m}}{100}$$

$$= 0.01\text{ m}$$

Therefore; the car is lifted a distance of 0.01 m

Task 5.4

Identify the devices that apply the principle of a hydraulic press then describe their mode of action. Present your work in class.

Exercise 5.6

1. A hydraulic machine has a piston P of cross-sectional area 5 cm^2 and a piston Q of cross-sectional area 50 cm^2. Find the velocity ratio of the system.
2. If the VR of a hydraulic machine is 441, and the distance moved by the effort piston is 7 m, calculate the distance moved by the load.
3. The efficiency of a press is given as 75%. If the radius of the load piston is 3 cm while that of the effort piston is 1.5 cm, calculate:
   (a) the velocity ratio .
   (b) the mechanical advantage of the press.
4. Explain the mode of action of a hydraulic press.

Chapter summary

1. A machine is a device that is used to simplify work. It uses force applied at one point to overcome force at another point.
2. Simple machines are used to make work easier by:
   (a) changing the direction of force
   (b) multiplying the applied force
3. Some of the terms used in relation to machines are:
   (a) load
   (b) effort
   (c) mechanical advantage
   (d) velocity ratio
   (e) efficiency
4. The mechanical advantage (MA) of a simple machine is the ratio of the output force (load) to the input force (effort), that is:

   $$MA = \frac{Load}{Effort}$$

5. The velocity ratio of a simple machine is the ratio of the distance moved by the effort to the distance moved by the load, that is:

   $$VR = \frac{\text{Distance moved by the effort}}{\text{Distance moved by the load}}$$

6. The efficiency of a simple machine is the ratio of the work output to the work input. Efficiency is also equal to the ratio of the mechanical advantage to the velocity ratio. That is:

   $$Efficiency = \frac{MA}{VR} \times 100\%$$

7. The lever, pulley, inclined plane, screw jack, wheel and axle, and hydraulic press are examples of simple machines.

8. Levers exist in three classes, first class levers, second class levers and third class levers. Examples of levers are a pair of scissors, a wheelbarrow and a shovel, in order of their respective classes.
9. Pulleys are classified into:
   (a) fixed pulley
   (b) movable pulley
   (c) combination pulley system
   (d) Block and tackle pulley system.
10. Pulleys are important when lifting loads vertically. The number of ropes supporting the lower pulley and/or the load determine the effort size. Therefore, mechanical advantage and velocity ratio can also be determined by the number of pulleys in the system.
11. The efficiency of a pulley system is affected by friction that transforms some energy into heat and the fact that energy is required to lift the lower pulleys and the ropes.
12. Pulleys are used for lifting heavy loads in ships and cranes and in garages where it is used to lift vehicle engines.
13. Inclined planes are also a form of simple machine. They include staircases, winding roads and ramps.
14. There are two types of screws: fastening and lifting screws. A bolt is an example of fastening screw and a jack is an example of a lifting screw.
15. In the wheel and axle system, the small wheel or the axle is turned by the large wheel. Examples of the wheel and axle machines include the windmills, doorknobs, gears, steering wheels, box spanners and windlasses.
16. A hydraulic press works on the principle that liquids cannot be compressed and that pressure exerted at one point is equally transmitted throughout the liquid.

Revision exercise 5

Choose the most correct answer in items 1-2.

1. Which of the machines below is a first class lever?
   (a) A pair of scissors
   (b) A pair of pliers
   (c) Wheelbarrow
   (d) Arrow
2. What is the layout of the listed three components for a third class lever?
   (a) Arm, Load, Fulcrum
   (b) Effort, Fulcrum, Load
   (c) Load, Effort, Fulcrum
   (d) None of the above.

3. Match each item in **column A** against its corresponding item from **column B** by writing the number of the correct response in the answer column.

Column A	Answer	Column B
(a) Efficiency		(i) $\frac{\textit{Distance moved by the effort}}{\textit{Distance moved by the load}}$
(b) *MA*		(ii) Fulcrum is between load and effort
(c) First class lever		(iii) $\frac{\textit{Distance moved by the load}}{\textit{Distance moved by the effort}}$
(d) *VR*		(iv) No unit
(e) Three pulleys		(v) $VR = 3$
		(vi) $\frac{Load}{Effort}$
		(vii) Effort is between Fulcrum and Load
		(ix) Newton
		(ix) $\frac{MA}{VR} \times 100\%$

4. Match each class of lever against its corresponding examples in the following table;

Class of lever	Answer	Examples
(a) First class		(i) Fishing rod, human arm
(b) Second class		(ii) Wheelbarrow, nutcracker
(c) Third class		(iii) Pliers, see-saw

5. Write **TRUE** for a correct statement and **FALSE** for an incorrect statement.
   (a) A pair of scissors is an example of a third class lever.
   (b) Simple machines allow us to use a smaller force to overcome a larger force.
   (c) An inclined plane makes it easy to move a load by increasing the distance.
   (d) A screw jack works in the same way as a pulley.
   (e) The mechanical advantage of a machine is the ratio of the effort applied to the load moved.
   (f) The mechanical advantage of a third class lever is always less than 1.
6. Fill in the following blanks
   (a) Due to the presence of friction in simple machines, some _____ is always wasted.
   This means that the ______ is always ______ than 100%.
   (b) The human arm is not a force magnifier but a _____.
7. The efficiency of a simple machine is never 100%. Why?
8. Identify the class to which each of the levers shown in Figure 5.29 belongs.

Figure 5.29

9. A lever 2.4 m long is to be used to raise an object weighing 500 N by applying an effort of 100 N as shown in Figure 5.30. How far from the object should the fulcrum be placed?

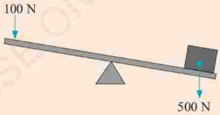


Figure 5.30

10. (a) In a pulley system, a load of 400 N requires an effort of 100 N to raise it. What is the mechanical advantage?
    (b) If this effort moves through a distance of 10 m, and the load is then moved up a distance of 2 m, calculate the velocity ratio and the efficiency of the machine.

11. A box weighing 560 N is pulled along an inclined plane of length 20 m onto a platform 2 m high with a force of 70 N. Calculate:
    (a) the velocity ratio of the plane.
    (b) the mechanical advantage of the plane.
    (c) the efficiency of the plane.
12. The pulley system shown in Figure 5.31 is to be used to raise a load of 150 N.

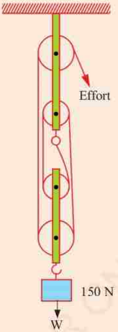


Figure 5.31

    (a) Ignoring friction and the weight of the pulleys, what force is required to raise the load at a constant speed?
    (b) If the cable (where the effort is applied) is pulled down 60 cm, how far will the object rise?
13. Figure 5.32 shows a box of weight 300 N being pushed along the inclined plane.

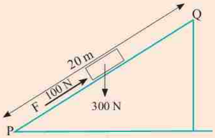


Figure 5.32

Calculate:
    (a) the work done in sliding the box up the inclined plane from P to Q if the applied force *F* is 100 N.
    (b) the power used if it takes 5 minutes to move the box from P to Q.
14. A pulley system has a velocity ratio of 5 and an efficiency of 60%.
    (a) What effort is required to lift a 750 N object using this pulley system?
    (b) How much work will be done in raising the object through a distance of 1.5 m?

15. A hydraulic press has effort and load pistons with areas of 0.02 m^2 and 0.3 m^2 respectively. A force of 550 N is required to lift a car with a mass of 680 kg using the press. What is the efficiency of the press?

16. Figure 5.33 shows a cross section of a bicycle wheel. The wheel has a radius of 35 cm while the rear sprocket has a radius of 3.5 cm. Assume that the wheel drives both sprocket and axle.

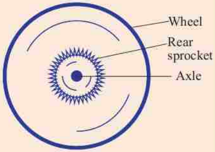


Figure 5.33

(a) If the axle has a radius of 1 cm, determine:

(i) the velocity ratio of the sprocket and axle.

(ii) the velocity ratio of the wheel and sprocket.

(iii) The velocity ratio of wheel and axle.

(b) An effort of 200 N is applied at the sprocket. If the efficiency of the entire system is 80%, what is the maximum load that can be carried by the bicycle?

17. A wheelbarrow is to be used to move a stone weighing 600 N. The wheelbarrow weighs 100 N. The weight of the wheelbarrow and its content act from a point on the wheelbarrow (See Figure 5.34).

Figure 5.34

Ignoring frictional forces, determine:

(a) the mechanical advantage of the wheelbarrow.

(b) the minimum amount of effort needed to just lift the legs of the wheelbarrow off the ground.

Chapter Six

Motion in a straight line

Introduction

In your life you have experienced different situations in which bodies are in motion. Examples of such situations include falling leaves from trees, flowing water in rivers, and moving vehicles. If there is a change of position of a body with respect to time, then motion has occurred. In this chapter you will learn the distinction between distance and displacement, speed and velocity and interpret distance, displacement, and velocity-time graphs. You will also learn about acceleration and equations of uniformly accelerated motion. Moreover, you will learn about motion under gravity and how to determine the acceleration due to gravity. The competencies developed from this chapter will enable you to apply motion in daily life situations such as riding bicycles, motorcycles, and driving cars.

Concept of motion

An object is said to be in *motion* when its position is continuously changing relative to a reference point such as an observer or a fixed object. For example, when you walk or run, your position is continuously changing with respect to the ground. When you see a car passing (see Figure 6.1), it is moving with respect to you. Suppose you are in a car that is moving at the same speed with another car, the other car will not be moving with respect to you. Both cars are now moving with respect to the ground. Therefore, motion is relative to the observer or to some fixed object. Motion in a straight line is referred to as *linear motion.*

Figure 6.1: *Car in motion past an observer*

When scientists study a physical phenomenon like motion, the first step is to observe the event. The second step is to develop the necessary concepts to describe those observations. What are the concepts that are useful in describing motion?

Distance and displacement

To define the position of an object, you first choose a *reference point.* For example, to measure the position of a book in the classroom you could choose a point either on the walls, floor or on the ceiling of the room as the reference point. You would then measure how far the book is from the front wall and a side wall, and how far it is above the floor as shown in Figure 6.2. These three measurements define a unique position for the book. If the book moves, at least one of these measurements will change.

Figure 6.2: *Determining position*

Distance and displacement are measures of how much the position of an object changes with respect to a reference.

Distance is the length of the path taken by an object while in motion. It has no specific direction.

However, displacement involves the length of the line drawn from the starting (initial) position to the end (final) position in a specific direction as shown in Figure 6.3.

Displacement is the distance covered in a particular direction.

The SI unit of both distance and displacement is metre (m). Distance and displacement can also be expressed in centimetre (cm), millimetre (mm) and kilometre (km). Though their SI units are the same, distance and displacement are not used interchangeably. Distance is a scalar quantity while displacement is a vector quantity. A scalar quantity has magnitude only, but a vector quantity has both magnitude and direction.

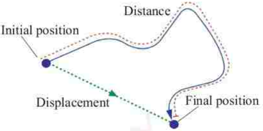


Figure 6.3: *Distance and displacement*

Suppose your home is 1.5 km due south of your school. In the morning, you walk along a straight path to school. The distance travelled is 1.5 km, but the displacement is 1.5 km towards the north. In the afternoon, you follow the same path to go back home. For that day, you have covered a total distance of 3 km, but your displacement is 0 km because at the end you are at the same position you were in the morning (Final position and initial position are the same).

Distance has *magnitude* only, but displacement has both *magnitude* and *direction*. So, when you walk to school you travel a distance of 1.5 km, but your displacement is 1.5 km due north (your home is south of the school). When you walk home in the afternoon, you again cover a distance of 1.5 km, but your displacement is 1.5 km due south.

Example 6.1

Halima runs twice round a field track of length 500 m.

(a) What distance does she cover?

(b) What is her displacement from the starting point?

Solution

(a) Distance in actual ground covered;

$$\begin{aligned} \textit{Distance} &= \textit{Length of track} \times 2 \\ &= 500 \text{ m} \times 2 \\ &= 1\,000 \text{ m} \end{aligned}$$

(b) Displacement means how far she is from the starting point.

Since she ends the race at the starting point, the displacement is zero metres (0 m).

Speed and velocity

Suppose you and your brother are walking to school in the morning. It takes 45 minutes for you to get to school, but it takes 1 hour and 10 minutes for your brother to get there. If each of you travelled the same distance, 1.5 km, it means you travelled faster than he did. *Speed* is defined as the rate of change of distance. Average speed is the rate at which an object travel. Speed can be determined as follows:

$$\textit{Speed (v)} = \frac{\textit{Distance (s)}}{\textit{Time (t)}}$$

$$v = \frac{s}{t}$$

So, in your case,

$s = 1.5$ km or 1500 m; $t = 45$ minutes or 2700 s.

Therefore, your speed is:

$$v = \frac{1500 \text{ m}}{2700 \text{ s}}$$

$$= 0.56 \text{ m/s}$$

For the case of your brother,

$t = 1$ hr 10 min = 4200 s. Therefore, the average speed at which your brother travelled is:

$$v = \frac{1500 \text{ m}}{4200 \text{ s}}$$

$$= 0.36 \text{ m/s}$$

Note: During your journey, you do not maintain the same speed at all times. That is why the term 'average speed' is normally used. So, if you walked to school in 45 minutes, your average speed was 0.56 m/s.

Speed may also be expressed in kilometres per hour (km/hr) or in centimetres per second (cm/s).

However, the term speed is usually confused with the term velocity. These terms do not mean the same thing. Velocity is a measure of the speed in a given direction. For example, The speed of a car is 120 km per hour, but its velocity is 120 km per hour in a south-west direction. If a car is moving at a constant speed around a bend, its direction changes continuously. Hence, its velocity will also be changing even if the speed remains constant.

Velocity is the rate of change of distance moved in a specified direction (i.e., the rate of change of displacement).

$$Velocity\ (v) = \frac{Displacement\ (s)}{Time\ (t)}$$

$$v = \frac{s}{t}$$

$$Average\ velocity = \frac{u+v}{2}$$

Where, u is the initial velocity, and v is the final velocity.

The SI unit for magnitude of average velocity is the same as the units for average speed, that is metre per second (m/s).

Note: Velocity at a particular instant is called *instantaneous velocity.* A body is said to move with uniform velocity if its rate of change of displacement with time is constant.

Example 6.2

An object travelled a distance of 20 m to the right in 4 s and then 12 m to the left in 3 s. For its total motion, what was its average speed and its average velocity?

Solution

When the object is moving to the right, its displacement is positive and when moving to the left it is negative. Time is always positive.

Average speed:

The total distance travelled is;

$$s = 20\text{ m} + 12\text{ m}$$

$$= 32\text{ m}$$

Total time is;

$$t = 4\text{ s} + 3\text{ s}$$

$$= 7\text{ s}$$

Average speed,

$$v = \frac{s}{t}$$

$$= \frac{32\text{ m}}{7\text{ s}}$$

$$v = 4.57\text{ m/s}$$

Therefore, its average speed was 4.57 m/s

Average velocity:

Displacement,

$$s = 20\text{ m} + (-12\text{ m})$$

$$= 8\text{ m}$$

The displacement is 8 m to the right.

Total time,

$$t = 4\text{s} + 3\text{s}$$

$$= 7\text{ s}$$

Average velocity,

$$v = \frac{s}{t}$$

$$= \frac{8\text{ m}}{7\text{ s}}$$

$$= 1.14\text{ m/s}$$

Therefore, its average velocity was 1.14 m/s to the right.

Example 6.3

A ball is dropped from a height of 20 m above the ground. It hits the ground in 2 s and bounces back up to a height of 12.7 m in 1.6 s (see Figure 6.4). What is its average velocity?

Solution

When the object is moving up its displacement is positive and when moving down it is negative.

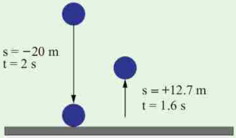


Figure 6.4

Displacement,

$$s = (-20\ \text{m} + 12.7\ \text{m})$$

$$s = -7.3\ \text{m}$$

The negative sign shows the net displacement is downwards.

Total time,

$$t = 2\ \text{s} + 1.6\ \text{s} = 3.6\ \text{s}$$

$$v = \frac{s}{t}$$

$$= \frac{-7.3\ \text{m}}{3.6\,\text{s}}$$

$$= -2.03\ \text{m/s}$$

Therefore, the average velocity is 2.03 m/s downwards.

The negative sign shows direction of the velocity is downwards. Therefore, average velocity for the entire motion is 2.03 m/s downwards.

Exercise 6.1

1. A car travels 6 000 m in 30 s. What is its average speed? Why is its actual speed usually different from its average speed?
2. What is the average speed of an athlete who runs 1 500 m in 4 minutes?
3. A bus increases its speed steadily from 10 m/s to 20 m/s in one minute.
   (a) What is its average speed during this time?
   (b) How far does it travel while increasing its speed?
4. A car moves 8 km due south and then suddenly changes its direction and moves another 6 km due west. Determine:
   (a) the total distance covered.
   (b) the displacement of the car.
5. An object starts from rest and takes 2 hours to cover a distance of 160 km. How fast is the object moving?
6. What are the differences and similarities between the following pairs of terms?
   (a) Speed and velocity.
   (b) Distance and displacement.

Activity 6.1

Aim: To determine the velocity of a toy car using a ticker-timer.

Materials: Toy car, ticker-timer, paper tape, remote-control device, stopwatch

Procedure

1. Attach a paper tape onto the toy car.
2. Pass the tape through the ticker-timer (see Figure 6.5).

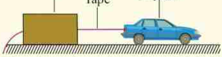


Figure 6.5

3. Set the toy car in motion using a remote-control device.
4. Record the starting time using the stopwatch.
5. Press the remote-control device to stop the toy car after one minute.
6. Record the final stopping time.

Questions

(a) What did you observe when the car was set in motion?

(b) Measure the interval between the marked dots on the paper tape.

(c) Calculate the velocity of the toy car.

(d) Explain your results.

Once the toy car is in motion, dots are made on the paper tape. When calculated, it is found that the time taken between any two consecutive dots is the same. The toy car moves with uniform velocity when the dots are equally spaced (see Figure 6.6).

Figure 6.6: *Dots showing uniform velocity*

Task 6.1

Measure the distance round your class using a measuring tape. Using a stop-watch, record the time when your classmate starts to move from the point A, round the class and back to the same point A. Calculate his or her speed.

Acceleration

When the velocity of a body is changing with time, it is said to be accelerating. Acceleration is the rate of change of velocity. Suppose you are travelling in a car moving at the speed of 20 m/s. The driver steps on the accelerator of the car and, over the next 5 s the speed of the car increases to 30 m/s. During those 5 s, the speed of the car increases by 2 m/s each second. Now, the driver steps on the brake pedal, and the car stops in 10 s. During the 10 s, the velocity of the car decreases by 3 m/s each second. In each case, the car was accelerating. Acceleration is taken to be positive if the velocity is increasing and negative if the velocity is decreasing. However, the term acceleration is used in cases of increasing velocity only, while a decreasing velocity or slowing down is usually called a *deceleration or retardation.*

Since acceleration is the change of velocity with time, the following equation is used to calculate it:

$$\text{Acceleration, } a = \frac{v - u}{t}$$

$$\text{Acceleration, } a = \frac{\text{Change in velocity, } \Delta v}{\text{Time taken, } t}$$

The SI unit of acceleration is metre per second square, in short m/s^2.

Acceleration of an object can be positive or negative. If the acceleration is in the same direction as the velocity, the magnitude of the velocity will increase. If the acceleration and velocity are in the opposite directions, the magnitude of the velocity will decrease.

Example 6.4

An object is initially moving at 15 m/s to the right. Eight seconds later, it is moving at 5 m/s to the left. During those eight seconds, what is the object's acceleration?

Solution

Initial velocity, u = 15 m/s

Final velocity, v = –5 m/s

Time, t = 8 s

Acceleration,

$$a = \frac{v - u}{t}$$

$$= \frac{(-5\ \text{m/s} - 15\ \text{m/s})}{8\text{s}}$$

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

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

Therefore, the object's acceleration is $-2.5\ \text{m/s}^2$. The negative sign indicates that the object is decelerating.

Example 6.5

A car accelerates from 5 m/s to 20 m/s in 3 seconds. What is the car's acceleration?

Solution

Acceleration,

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

$$= \frac{v - u}{t}$$

$$= \frac{(20\ \text{m/s} - 5\ \text{m/s})}{3\text{s}}$$

$$= \frac{15\ \text{m/s}}{3\ \text{s}}$$

$$= 5\ \text{m/s}^2$$

This means the car accelerates or speeds up by 5 m/s^2 every second.

A ticker-timer can be used to measure acceleration of a body.

Activity 6.2

Aim: To determine the velocity of a toy car using a ticker-timer.

Materials: Toy car, ticker-timer, paper tape, remote-control device, stopwatch

Procedure

1. Attach a paper tape onto the toy car.

2. Pass the tape through the ticker-timer (see Figure 6.7).

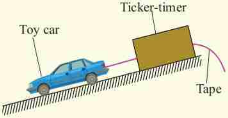


Figure 6.7

3. Set the toy car in motion down an inclined plane as in Figure 6.7 using a remote-control device.
4. Record the starting time using the stopwatch.
5. Press the remote-control device to stop the toy car after one minute.
6. Record the final stopping time.

Questions

(a) What did you observe when the car was set in motion?

(b) Measure the interval between the marked dots.

(c) Calculate the initial and final velocities of the toy car.

(d) What is the acceleration of the car?

(e) Explain your results.

If the dots are not equally spaced, then the toy is accelerating at that time.

Figure 6.8: *Unequally spaced dots showing toy is accelerating*

In Figure 6.8, the interval between two dots is increasing, this means that the toy is accelerating. The velocity can be calculated by measuring the length covered by 9 dots. Note that a ticker-timer (see Figure 6.9) uses frequency meanwhile its accuracy is higher than that of the stopwatch.

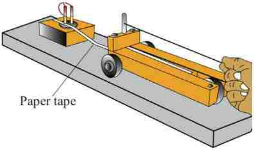


Figure 6.9: *Ticker-timer*

Frequency refers to number of complete cycles/oscillations per second. Its SI unit is Hertz (Hz).

$$\text{Frequency, } f = \frac{\text{Number of complete cycle}}{\text{Time } t}$$

$$f = \frac{1}{t}$$

Hence,

$$\frac{1}{f} = t$$

Therefore, time between two successive dots (tick) is given by:

$$\text{Time} = \frac{1}{\text{frequency}}$$

For a frequency of 50 Hz,

$$\text{Time} = \frac{1}{50\,\text{Hz}} = 0.02\ \text{seconds}.$$

Distance-time graphs

Graphs can be a useful method of representing relationship between parameters such as displacement, velocity, acceleration and time.

If the distance covered by a body is plotted against time taken, the graph obtained is *a distance-time graph.* It shows how far an object has travelled in a given time. Distance is plotted on the y-axis and time on the x-axis. In a distance-time graph, motion at a constant speed is represented by a straight line, and the slope of the line represents the speed of the body (see Figure 6.10).

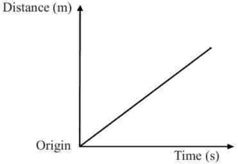


Figure 6.10: *Constant speed distance-time graph*

Note that for motion with acceleration, the slope of the distance-time graph is not constant, that is the graph is a curve. Figure 6.11 shows a distance-time graph, with events represented by numbers 1,2,3,4.

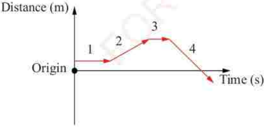


Figure 6.11: *Accelerated motion distance–time graph*

1- The body is stationary for a time at a point away from the origin in the direction of increasing distance.

2- The body moves further with a constant positive velocity.

3- The body stops and remains stationary for a time.

4- The body moves backwards past the origin with a constant negative velocity that is greater than its velocity in event 2.

Displacement-time graph

As in distance-time graph, the displacement of a body is plotted against time taken. The graph obtained is the displacement-time graph as shown in Figure 6.12.

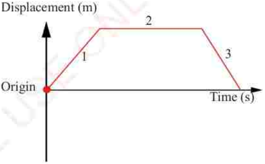


Figure 6.12: *Displacement versus time-graph for linear motion*

1- The body starts at the origin and moves fowards with a constant velocity.

2- The body stops and remains stationary for a while.

3- The body moves backwards with a constant velocity and ends at the origin.

Velocity-time graphs

If the velocity of a body is plotted against time taken, the graph obtained is a *velocity-time graph*. Velocity is plotted on the y-axis and the time on the x-axis. On a velocity-time graph, motion at a constant velocity is represented by a horizontal line while accelerated motion is represented by an inclined line. The slope of an inclined line represents the acceleration. Figure 6.13 shows the velocity-time graph corresponding to the distance-time graph in Figure 6.11.

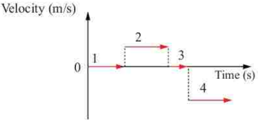


Figure 6.13: *Velocity versus time-graph for accelerated motion*

Figure 6.14 shows the velocity-time graph corresponding to the displacement-time graph in Figure 6.12.

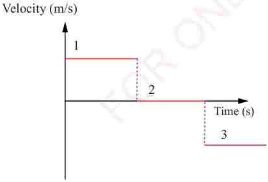


Figure 6.14: *Velocity versus time-graph for a body moving with uniform acceleration*

Example 6.6

1. A car starts from rest and accelerates uniformly at a rate of 4 m/s^2 for 5 seconds. It maintains a constant velocity for 20 seconds. The brakes are then applied, and the car decelerates for 3 s. Find:
   (a) The maximum velocity attained.
   (b) The total distance covered.

Solution

(a) From the equation of acceleration,

$$a = \frac{\Delta v}{t}$$

But

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

$t = 5\text{ s}$

$\Delta v = at$

$= 4\text{ m/s}^2 \times 5\text{ s}$

$= 20\text{ m/s}$

Therefore, the maximum velocity attained is 20 m/s.

(b) By graphical method.

Figure 6.15 shows the graph of velocity (m/s) against time (s).

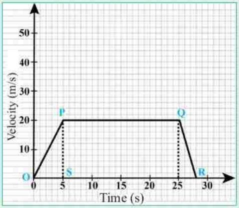


Figure 6.15

The area under the graph represents the distance covered by the car. Therefore,

$$Area = \frac{1}{2}(PQ + OR) \times PS$$

$$= \frac{1}{2}(20\text{s} + 28\text{s}) \times 20 \text{ m/s}$$

$$= \frac{1}{2} \times 48\text{s} \times 20\text{m/s}$$

$$= 480 \text{ m}$$

Therefore, the total distance covered is 480 m.

If the acceleration of an object is constant, the velocity will change uniformly, that is, by the same amount each second. In that case, the average velocity is equal to the sum of the initial and final velocities divided by two.

Therefore, for a uniformly accelerated body.

$$Average\ velocity = \frac{u+v}{2}$$

Where, u is the initial velocity and v is the final velocity.

Task 6.2

Using Figure 6.16, describe how the object was moving. Include where the position of object was (forth or backward from the origin), whether it was moving or not, the direction it was moving, the sign (direction) of the velocity and whether the velocity was constant, increasing or decreasing. Then sketch the corresponding velocity-time graph in Figure 6.17.

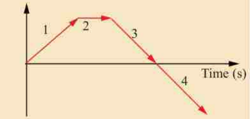


Figure 6.16

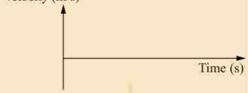


Figure 6.17

Consider an object that accelerates from zero to 30 m/s in 8 s and then continues at a constant velocity of 30 m/s for another 10 s. A velocity–time graph of this motion is shown in Figure 6.18.

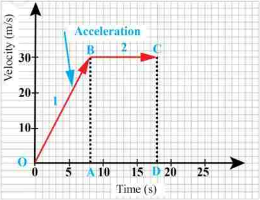


Figure 6.18: *A velocity–time graph*

In OB, the average velocity is obtained through:

$$\bar{v} = \frac{u+v}{2}$$

where, $u = 0\,\text{m/s}$, $v = 30\,\text{m/s}$ and $\bar{v}$ is the average velocity.

$$\bar{v} = \frac{0\text{ m/s} + 30\text{ m/s}}{2}$$

$$\bar{v} = 15\text{ m/s}$$

From,

$$\bar{v} = \frac{s}{t}$$

you get

$$s = \bar{v}t$$

Therefore, in OB, the object's displacement is:

$$s = 15\text{ m/s} \times 8\text{ s}$$

$$s = 120\text{ m}$$

Now consider triangle OAB in Figure 6.18. The length of its base is 8 s, and its height is 30 m/s. The area of a triangle is calculated using:

$$A = \frac{1}{2} \times \text{base} \times \text{height}$$

$$= \frac{1}{2} \times 8\text{ s} \times 30\text{ m/s}$$

$$= 120\text{ m}$$

In the BC the average velocity is 30 m/s

From,

$$\bar{v} = \frac{s}{t}$$

$$s = \bar{v}t$$

$$= 30\text{ m/s} \times 10\text{ s}$$

$$= 300\text{ m}$$

You should verify that the area of the rectangle ABCD is equal to the object's displacement in BC of the motion in Figure 6.18.

$$\textit{Area of } ABCD = AB \times BC$$

$$= 30\text{ m/s} \times 10\text{ s}$$

$$= 300\text{ m}$$

Displacement = 300 m

The area covered under a velocity-time graph represents the displacement.

Therefore,

total displacement = 120 m + 300 m

= 420 m

Note: The distance travelled is represented by the area under a velocity–time curve and the time axis irrespective of the shape of the curve.

Exercise 6.2

1. A body is thrown upward with a velocity of 20 m/s. It returns to the ground at the same position after 8 s.
   (a) Sketch a graph of velocity against time for the motion.
   (b) From the graph, determine the distance travelled and the total displacement.
2. Observe Figure 6.19 which shows a graph for a motorcycle travelling along a straight road, then answer the questions that follow:

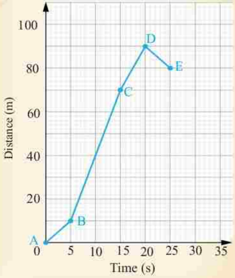


Figure 6.19

(a) When is the motorcycle:
   (i) accelerating?
   (ii) decelerating?

(b) Calculate its distance from A to D.

3. Amina drove her car from rest to a speed of 30 m/s in 10 seconds. She maintained this steady speed for 10 seconds, after which she applied the brakes and stopped after 5 seconds.
   (a) Draw a graph of speed against time.
   (b) From the graph in (a) above calculate:
      (i) the total distance travelled.
      (ii) the time taken for the whole journey.
      (iii) the maximum speed attained.
      (iv) the area under the graph.
4. What is meant by uniform speed, uniform velocity and uniform acceleration?

Equations of uniformly accelerated motion

Relationships between different quantities can be concisely expressed by using mathematical concepts. Also, new useful relationships can be derived by applying the rules of Mathematics. Many Physics problems about moving objects can be solved by using three equations of motion. These equations are applied in linear motion provided there is uniform acceleration. The equations relate the displacement of an object with its velocity, acceleration and time.

First equation of motion

If a body that is moving with an initial velocity u m/s accelerates at the rate of a m/s^2, its velocity will increase to a final velocity v m/s at the rate of a m/s^2 for each second it moves. This increase in velocity in time t seconds will be at.

The first equation of motion is derived from the definition of acceleration. That is, acceleration is the rate of change of velocity.

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

$$a = \frac{v - u}{t}$$

$$at = v - u$$

Making v the subject of the equation, the final velocity (v) will be:

$$v = u + at$$

This is the first equation of motion.

Second equation of motion

If a body is moving with uniform acceleration, its average velocity is obtained by taking the average of the initial velocity, u and the final velocity, v. That is,

$$Average\ velocity = \frac{u + v}{2}$$

But, $v = u + at$

Substitute v in $\frac{u + v}{2}$ to get $\frac{u + u + at}{2}$

$$\text{Average velocity} = u + \frac{1}{2}at$$

But distance moved (s) = average velocity × time

$$= (u + \frac{1}{2}at) \times t$$

$$s = ut + \frac{1}{2}at^2$$

This is the second equation of motion.

Alternatively, the second equation of motion can be derived from the definition of distance moved. That is:

$$\textit{Distance moved} = \textit{Average velocity} \times \textit{Time}$$

$$s = \left(\frac{v+u}{2}\right) \times t$$

but $v = u + at$,

$$s = \left(\frac{(u+at)+u}{2}\right)t$$

$$s = \frac{2ut + at^2}{2}$$

$$s = ut + \frac{1}{2}at^2$$

Third equation of motion

This equation is obtained by combining the first two equations and eliminating t. Using the first equation $v = u + at$, square both sides of the equation to get:

$$v^2 = u^2 + 2uat + a^2t^2$$

Factorise $2a$ on the right-hand side to get:

$$v^2 = u^2 + 2a\left(ut + \frac{1}{2}at^2\right)$$

But the term in brackets is displacement, s (i.e., from the second equation of motion). Therefore,

$$v^2 = u^2 + 2as$$

This is the third equation of motion.

Alternatively, from the definition of distance moved,

$$s = \left(\frac{v+u}{2}\right) \times t$$

From the first equation of motion, t can be found as:

$$t = \frac{v-u}{a}$$

Substitution gives

$$s = \frac{(v+u)}{2}\frac{(v-u)}{a}$$

$$s = \frac{v^2 - vu + vu - u^2}{2a}$$

$$2as = v^2 - u^2$$

$$v^2 = u^2 + 2as$$

Example 6.7

A car starts to move from rest and accelerates uniformly at the rate of 2 m/s^2 for 6 s. It then maintains a constant speed for 30 seconds. After the brakes are applied, it decelerates uniformly to rest in 5 s. Calculate:

(a) the total distance covered in metres.

(b) the maximum speed reached.

Solution

At the beginning:

$u =$ 0 m/s

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

$t = 6\text{ s}$

Substituting in $v = u + at$,

$v = 0\text{ m/s} + 2\text{ m/s}^2 \times 6\text{ s}$

$= 12\text{ m/s}$

Distance covered initially will be:

$$s = ut + \frac{1}{2}at^2$$

$$s = 0\text{ m/s} \times 6\text{ s} + \frac{1}{2} \times 2\text{ m/s}^2 \times 6^2\text{ s}^2$$

$= 36\text{ m}$

Therefore, during the second stage

$u = 12\text{ m/s}$ (constant)

$t = 30\text{ s}$

Therefore, distance covered $= u \times t$

$= 12\text{ m/s} \times 30\text{ s}$

$= 360\text{ m}$

In the third step:

$u = 12\text{ m/s}$

$v = 0\text{ m/s}$ (stopped)

$t = 5\text{ s}$

Therefore, acceleration is given by:

$$a = \frac{v - u}{t} = \frac{0\text{ m/s} - 12\text{ m/s}}{5\text{ s}} = -2.4\text{ m/s}^2$$

Therefore, using

$$v^2 - u^2 = 2as$$

$$s = \frac{v^2 - u^2}{2a}$$

$$= \frac{0 - 12^2\,(\text{m/s})^2}{2 \times (-2.4)\text{ m/s}^2}$$

$= 30\text{ m}$

(a) Total distance covered
$= 36\text{ m} + 360\text{ m} + 30\text{ m} = 426\text{ m}$

(b) Maximum speed $= 12\text{ m/s}$.

Exercise 6.3

1. A train travelling at 30 km/h stops when its brakes are applied. The train suffers a deceleration of 2 m/s^2.
   (a) How long does the train take to come to rest?
   (b) What is its final velocity?

2. An object travelling at 10 m/s accelerates at 4 m/s^2 for 8 seconds.
   (a) Calculate the final velocity.
   (b) How far does it travel for 8 seconds?

3. A car moves with uniform velocity of 12 m/s for 6 seconds. It accelerates at 2.0 m/s^2 for 4 seconds. It then travels for 2 more seconds with uniform velocity. The car finally decelerates to a stop in 15 seconds. Calculate:
   (a) the distance travelled in 5 seconds.
   (b) average velocity for the journey, assuming that the journey is in a straight line.

4. An object with initial velocity of 20 m/s moves due north at an acceleration of 8.0 m/s^2 for 5 seconds. What is the total displacement during that time?

Motion under gravity

If a ball is thrown straight up into the air, it will move upward. However due to earth's gravity, it will momentarily stop, and then, fall downwards. When the ball is falling, the magnitude of its velocity increases because the direction of its acceleration is downwards. The force of gravity and the acceleration of this body are always directed downward towards the centre of the earth. The acceleration in this case is called *acceleration due to gravity, g*. The value of g is 9.8 m/s^2 or approximately 10 m/s^2.

The point where the ball momentarily stops is the *maximum altitude* reached by the body. Due to constant acceleration, the ball will take the same time to reach its maximum altitude as it does when returning to its starting point.

Objects falling under the influence of gravity are moving with constant acceleration.

The equations of motion for a free falling body (see Figure 6.20 (a)) will be:

$$v = gt$$

$$h = \frac{1}{2}gt^2$$

$$v = 2gh$$

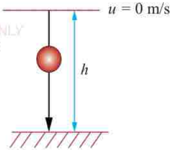


Figure 6.20 (a): *Downward motion under gravity*

Note that h is being used instead of s and g instead of a.

For a body moving/thrown downwards, the following equations are applied:

$$v = u + gt$$

$$h = ut + \frac{1}{2}gt^2$$

$$v^2 = u^2 + 2gh$$

When the body moves upwards (see Figure 6.20 (b)), the equations will change to:

$$v = u - gt$$

$$h = ut - \frac{1}{2}gt^2$$

$$v^2 = u^2 - 2gh$$

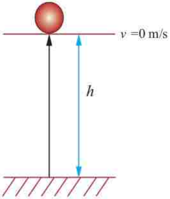


Figure 6.20 (b): *Upward motion under gravity*

The negative sign in the equations indicates that the body is moving upwards against acceleration due to gravity.

For a body moving upwards, velocity at the turning point is zero.

Example 6.8

A body moved vertically upward to a maximum height of 20 m. Calculate:

(a) the initial velocity.

(b) the time taken to reach the maximum height.

Solution

(a) From $v^2 = u^2 - 2gh$;

where
$v = 0$ m/s, $h = 20$ m and $g = 10$ m/s^2

$$v^2 = u^2 - 2 \times 10\text{ m/s}^2 \times 20\text{ m}$$

$$0 = u^2 - 2 \times 10\text{ m/s}^2 \times 20\text{ m}$$

$$u^2 = 2 \times 10\text{ m/s}^2 \times 20\text{ m}$$

$$\sqrt{u^2} = \sqrt{400\text{ m}^2/\text{s}^2}$$

$$u = 20\text{ m/s}$$

Therefore, the initial velocity is 20 m/s.

(b) To find time taken to reach maximum height, use;

$$v = u - gt$$

$$0 = 20\text{ m/s} - 10\text{ m/s}^2 \times t$$

$$t = \frac{20\text{ m/s}}{10\text{ m/s}^2}$$

$$= 2\text{ s}$$

So, the body initially starts with 20 m/s and used 2 s to reach a height of 20 m.

Exercise 6.4

1. A stone falling down a well takes 2 s to reach the water surface. Calculate:
   (a) the velocity with which the stone hits the water surface.
   (b) the distance of the water surface from the top of the well shaft.
2. A stone is thrown vertically upwards with an initial velocity of 29.4 m/s from the top of a tower 34.3 m high. Find:
   (a) the time taken to reach the maximum height.
   (b) the total time that elapses just before it reaches the ground.
3. A car is travelling at 20 m/s along a straight road. The brakes are applied for 5 s causing a retardation of 3 m/s^2. Find the car's final velocity.

Determination of the acceleration due to gravity

Early studies related to motion of objects under gravity were conducted by Galileo Galilei between the 16th and 17th centuries. Galileo was an Italian physicist, mathematician, astronomer and philosopher who is closely associated with the scientific revolution. His achievements include the first systematic studies of uniformly accelerated motion, improvements to the telescope and a variety of astronomical observations.

Galileo understood that free-fall was uniformly accelerated motion. The problem he faced in studying this motion was in measuring time. He discovered that over short distances of a few metres, free-fall occurs very rapidly. In Galileo's days, there were no clocks capable of accurately measuring very short periods of time. Therefore, he used his heart pulse to measure time in many of his experiments. Later, he developed a water clock and the pendulum clock, but none of these were capable of measuring time precisely. To overcome this problem, Galileo studied objects rolling down inclined planes, which slowed the motion sufficiently for accurate measurements to be made. Figure 6.21 shows a body rolling down an inclined plane.

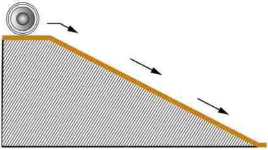


Figure 6.21: *Body rolling down an inclined plane*

Even using the inclined plane, Galileo was not able to accurately determine the acceleration due to gravity. One way in which the value for the acceleration due to gravity could be determined was by observing the motion of a *simple pendulum*. A pendulum consists of a bob suspended by a wire or string from a pivot point. When the pendulum bob is displaced from its equilibrium position and released, the pendulum swings back and forth in periodic motion as shown in Figure 6.22.

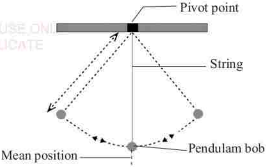


Figure 6.22: *A simple pendulum*

The time for the pendulum bob to swing back and forth once is called its period, abbreviated as T. When a pendulum moves forth and back once, it completes an oscillation. The period of oscillation of the pendulum depends on its length, l and the acceleration due to gravity, g. Hence,

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

After rearranging the above equation by making g the subject and substituting the value of π you get:

$$g = \frac{4\pi^2 l}{T^2}$$

$$\boxed{g = 39.5\frac{l}{T^2}}$$

This is the acceleration due to gravity.

Activity 6.3

Aim: To determine acceleration due to gravity using a simple pendulum.

Materials: Retort stand, stopwatch, clamp, thread, metre rule, bob

Procedure

1. Measure 90 cm of a thread by using

metre rule. Tie the bob to one end of the thread and suspend the bob from the retort stand so that it swings freely.

2. Displace the bob through a small angle sideways and release it so that it oscillates.
3. Record the time taken for 20 oscillations using the stopwatch.
4. Repeat step 3 thrice.
5. Repeat steps 1- 4 for a thread of length l = 80 cm, 70 cm, 60 cm, and 50 cm.
6. Tabulate the results in the following table.

Length, l (cm)	Time, t for 20 oscillations			Average time, t (s) $t = \frac{t_1 + t_2 + t_3}{3}$	Periodic time, T $T = \frac{t}{20}$	T^2 (s^2)	$\frac{T^2}{l}$	Acceleration due to gravity, g m/s^2
90	t_1	t_2	t_3					
80								
70								
60								
50								

Questions

(a) Use a table similar to the one shown above to calculate:

(i) the average time for 20 oscillations.

(ii) the average periodic time, T (time for one oscillation).

(b) Plot a graph of T^2 against l and calculate its slope.

(c) What is the nature of the plotted graph?

(d) Calculate the acceleration due to gravity, g using the formula,

$$g = \frac{4\pi^2 l}{T^2}$$

(e) Calculate the percentage error in an experimental value of g.

$$Percentage\ error = \frac{(Accepted\ value - Measured\ value)}{Accepted\ value} \times 100.$$

Note: The accepted value of g is 9.81 m/s^2.

The values of $\frac{T^2}{l}$ are constant, showing that T^2 is directly proportional to l,

That is, $T^2 \propto l$

Thus, $\frac{T^2}{l} = \frac{4\pi^2}{g} = \text{constant}$

This implies that $g = \frac{4\pi^2 l}{T^2}$

The graph obtained was a straight-line passing through the origin.
The expected value for gravitational acceleration is 9.81 m/s^2. When a body is moving against gravity, $g = -9.81$ m/s^2. However, the value of g is usually approximated to 10 m/s^2.

Example 6.9

An object is thrown vertically upwards with an initial velocity of 50 m/s.

(a) How long will it take to reach its maximum height?

(b) To what height will it rise?

(c) What will be its velocity when it returns to its starting point?

(d) How long will it be in the air?

Solution

(a) At its maximum height the object's velocity is zero ($v = 0$). From the first equation of motion:

$$v = u + at$$

But, $a = g = -10 \text{ m/s}^2$

$u = 50$ m/s

Hence,

$$0\,\text{m/s} = 50\,\text{m/s} - 10\,\text{m/s}^2 \times t$$

$$10\,\text{m/s}^2 t = 50\,\text{m/s}$$

$$t = \frac{50 \text{ m/s}}{10 \text{ m/s}^2}$$

$$t = 5 \text{ s.}$$

It will take 5 seconds to reach the maximum height.

(b) From the second equation of motion:

$$s = ut + \frac{1}{2}at^2$$

$$h = ut + \frac{1}{2}gt^2$$

$$h = 50 \text{ m/s} \times 5 \text{ s} + \frac{1}{2} \times (-10 \text{ m/s}^2) \times 5^2 \text{ s}^2$$

$$= 250\,\text{m} - 125 \text{ m}$$

$$= 125 \text{ m}$$

The maximum height reached is 125 m.

(c) When the object returns to its starting point its displacement is zero ($s = 0$).

From the third equation of motion

$$v^2 = u^2 + 2as$$

where, $u = 50$ m/s

$a = g = -10$ m/s^2

Hence, $v^2 = u^2 + 2\,gs$

$$v^2 = u^2 + 0$$

$$v^2 = u^2$$

$$v = \sqrt{u^2}$$

$$v = 50 \text{ m/s}$$

The object has a velocity of 50 m/s on its return.

(d) From the first equation of motion:

$$t = \frac{v - u}{g}$$

where $v = 50$ m/s, $u = -50$ m/s

Therefore,

$$t = \frac{50 \text{ m/s} - (-50 \text{ m/s})}{10 \text{ m/s}^2}$$

$$t = 10 \text{ s}$$

Therefore, the object will take 10 s in the air.

Upon returning to its starting point, the object has the same velocity it started with but in the opposite direction. As expected, the total time in the air is twice the time required to reach the maximum height. The object spends the same time going up as it does when coming back down.

Chapter summary

1. There are a number of concepts used to describe motion summarised as follows.

   (a) *Position* describes where an object is based on measurements from a chosen reference point.

   (b) *Distance* measures how much the position has changed. It is the length of the path followed by an object. It has magnitude only and is measured in metres.

   (c) *Displacement* measures the net change in position. It is the distance covered by an object in a particular direction and is also measured in metres.

   (d) *Average speed* measures the rate at which the position changes. This is given by distance divided by time. It is measured in metres per second, m/s.

   (e) *Average velocity* measures the rate of change of displacement, that is, displacement divided by time. It is measured in metres per second, m/s.

   (f) *Acceleration* measures the rate of change of velocity, that is, change in velocity divided by time. It is measured in metres per second squared, m/s^2. If acceleration and velocity are in the same direction, the magnitude of velocity will increase. If they are in opposite directions, the magnitude of velocity decreases.

2. Quantities like distance and speed have magnitude only, while displacement, average velocity and acceleration have both magnitude and direction.

3. An object's motion can be represented by lines and curves on distance-time and velocity-time graphs.
   (a) On a distance-time graph the slope of a line represents the object's speed.
   (b) On a velocity–time graph the area under the curve represents the object's displacement.

4. The relationship between displacement, average velocity and acceleration can be concisely expressed mathematically in equations. These can be manipulated to find new useful relationships called the equations of motion of a uniformly accelerating body.

5. Equations of uniformly accelerated motion are:

$$v = u + at$$
$$s = ut + \frac{1}{2}at^2$$
$$v^2 = u^2 + 2as$$

6. Motion under the effect of gravity is uniformly accelerated motion. All objects moving up or down have the same acceleration due to gravity. Hence, for a body moving along gravity:

$$v = u + gt$$
$$h = ut + \frac{1}{2}gt^2$$
$$v^2 = u^2 + 2gh$$

and for a body moving against gravity,

$$v = u - gt$$
$$h = ut - \frac{1}{2}gt^2$$
$$v^2 = u^2 - 2gh$$

For a free falling body,

$$v = gt$$
$$h = \frac{1}{2}gt^2$$
$$v^2 = 2gh$$

Revision exercise 6

Choose the most correct answer in items 1-3.

1. The displacement of an object for a round trip between two locations
   (a) is always greater than zero.
   (b) is always less than zero.
   (c) is zero.
   (c) can have any value.

2. Starting at rest an object falls a height, h in time, t. Assuming that the only force on the object is its gravitational attraction to the earth, how far does the object fall in an elapsed time of

3t, starting from rest?

(a) 3h (b) 9h (c) 27h (d) 6h

3. The following is the reason why different objects in the air tend to fall at the same time:
   (a) They have the same weight.
   (b) There is usually no resistance in the air.
   (c) Acceleration due to gravity is the same.
   (d) They move in the same direction.

4. Match the items in **column A** against the corresponding item from **column B** by writing the correct response in the answer column.

Column A	Answer	Column B
(a) Distance		(i) Metres per second
(b) Velocity		(ii) 0 m/s and stops
(c) Displacement		(iii) Rate of change of velocity
(d) Acceleration		(iv) Path of an object
(e) Maximum altitude		(v) 10 m/s^2
(f) Final velocity		(vi) Speed in metres
(g) Gravitational acceleration		(vii) Has magnitude only
		(viii) Momentarily stops
		(ix) Distance in a specific direction

5. Fill in the following blanks.
   (a) _____________ is the length of the path taken by an object in motion.
   (b) The speed of a body in a particular direction is called _____________. It is measured in _____________.
   (c) If the acceleration of an object is zero, its velocity must be _____________.
   (d) The area under velocity time-graph represents _____________.

6. Explain the following terms:
   (a) Distance
   (b) Displacement
   (c) Velocity
7. An object A has a displacement of –10 m while object B has a displacement of 10 m. Which object moved further than the other? Explain your answer.
8. In a race, cars travelled 200 times around a field track with a length of 1 km.
   (a) At the end of the race, what is the distance travelled by the winner?
   (b) What is the winner's displacement?
   (c) If the winner completed the race in 3 hours, what is his/her average speed?
   (d) What is his/her average velocity?
9. Figure 6.23 is the displacement–time graph representing the motion of an object.

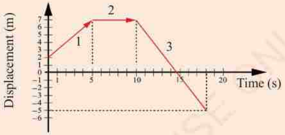


Figure 6.23

(a) Using the graph, copy and complete the following table:

Steps	1	2	3
Time interval	0 s – 5 s	5 s – 10 s	10 s – 18 s
Initial position, m_i			
Moving toward/away from the origin or stopped			
Final position, mf			
Velocity increasing, decreasing, constant			
Average velocity, (m/s)			

(b) At what time was the object at the origin?

(c) What was the average velocity for the entire motion?

10. Using the displacement–time graph in Question 8, sketch a velocity–time graph, (use Figure 6.24).

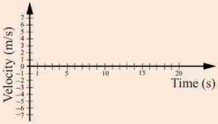


Figure 6.24

11. A car travelling at 20 m/s to the right stops in 10 s.

(a) What is the car's acceleration? Give both the magnitude and direction.

(b) How far will the car travel before stopping?

(c) How far will the car have to travel if its initial velocity is 40 m/s? (Assuming the car's acceleration is the same as that calculated in part (a).)

12. A stone was dropped from the top of a building and hit the ground 4 s later.

(a) How tall is the building?

(b) What was the stone's velocity when it hit the ground?

13. An object is thrown vertically upwards. Which of the following could equal zero when it reaches its maximum altitude?

(a) Displacement

(b) Velocity

(c) Acceleration.

Explain your answers.

14. An object thrown straight upward with an initial velocity of 88.2 m/s will reach its maximum height of 396.9 m in 9 s. If after 3 s, the object is at an altitude of 220.5 m moving upward, after what time will it be at a height of 220.5 m moving downwards?

15. A rocket car is propelled along a straight track by an engine that can produce an acceleration of 50 m/s^2. The car starts from rest. The rocket engine is turned on for 5 s and then turned off. Three seconds later, a parachute is deployed, which produces an acceleration of $-20\ m/s^2$.

(a) What is the car's velocity after the first 5 s?

(b) How far does the car travel while the engine is on?

(c) How far does the car travel between the time the engine is turned off and the parachute is deployed?

(d) From the time the parachute is deployed, how long does it take for the car to stop?

(e) What is the total displacement of the car?

(f) What is the total time for the entire motion?

(g) What is the average velocity for the entire motion?

16. An object is constrained to move along a track as shown in Figure 6.25.

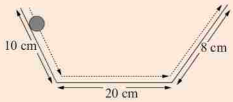


Figure 6.25

The acceleration of the object on both inclined planes is 6.9 m/s^2 (down), zero along the flat section and –6.9 m/s^2 up the inclined planes. If the object is released from rest at the top of the left inclined plane, how long will it take to reach the top of the right inclined plane?

17. An object is vertically thrown upwards with an initial velocity of 45 m/s. At what two times will the object be 50 m above the ground?

18. If you travelled from point A to point B 90 km apart, at an average speed of 60 km/h, how long did it take you to travel from point A to point B?

Chapter Seven

Newton's laws of motion

Introduction

Motion of bodies was carefully studied and analysed first by Galileo Galilei and then followed by Sir Isaac Newton. On the basis of his study, Newton clearly expressed three laws of motion, namely first law, second law and third law. These laws are known as Newton's laws of motion. The laws describe the relationship between a body and the forces acting upon it, and its motion. In this chapter, you will learn about inertia, Newton's first law, second law and third law of motion. You will also learn the application of Newton's laws of motion and conservation of linear momentum. The competencies developed will enable you to apply the physical laws in everyday life such as in games and sports, riding bicycles, driving cars, walking and fetching water from wells.

Concept of inertia

If you are standing on a moving bus and its brakes are suddenly applied, you could move forward. This is because your body is influenced to continue in the forward motion, but the feet are forced to stop. On the other hand, if you are standing on a stationary bus and it is suddenly moved forward, you could fall backwards. This is because your body is influenced to be at rest, whereas your feet are forced to a forward motion. These phenomena are results of a property known as *inertia.* Bodies tend to keep on doing what they are doing.

Inertia is a property of matter by which a body continues in its existing state of rest or uniform motion in a straight line, unless that state is changed by an external force. In order to overcome inertia, an external force must be applied, but inertia itself is not a force.

Consider a train, due to its massive size, it has large inertia. It is difficult to stop once it is in motion. Hence, it is also difficult to change its speed. In fact, a large net force is required to change its speed. Now compare this to the inertia of a soccer ball. Are they the same?

The inertia of a body is proportional to the mass of the body. That is, the larger the mass the larger the inertia. The larger the inertia, the more a body resists change in its state of motion.

There are three types of inertia, namely inertia of rest, inertia of motion and inertia of direction as explained in the following:

1. **Inertia of rest**
   This is the resistance to change in the state of rest of a body.

2. **Inertia of motion**
   This is the resistance to change in the state of uniform motion of a body. For example, a passenger sitting on a bus tends to fall forward when the bus suddenly stops because the lower part of his or her body comes to rest earlier than the upper part. Inertia tends to keep him or her moving.

3. **Inertia of direction**
   This is the resistance to change in the direction of motion of a body. For instance, mud from the wheels of a moving vehicle flies off tangentially. This implies that, it follows the straight path tangent to the wheel at the point of leaving as shown in Figure 7.1.

Figure 7.1: *Mud flying off a tyre of a car*

Activity 7.1

Aim: To demonstrate the effect of inertia.

Materials: Large sheet of paper, stone or rock

Procedure

1. Lay the sheet of paper on a table and place the stone on it.
2. Suddenly, pull the sheet of paper parallel to the table.

Question

What happened to the stone? Why?

The stone remained at rest on top of the table when the sheet of paper was suddenly pulled. This means that the stone tried to maintain its state of rest on top of the table. It resisted change in its state of rest due to inertia.

Sir Isaac Newton summed up the basic principles of motion into three laws. These laws are called *Newton's laws of motion*. They provide a relationship between the forces acting on a body and the motion of the body.

Newton's first law of motion

When a force is applied to a body, the body can accelerate. The degree of acceleration will depend on the mass of the body to which the force is applied. A body with a small mass is easier to accelerate than a body with a large mass. This is because the larger the mass of an object, the larger is its inertia and vice versa.

Newton's first law of motion states that A body will continue to be in its state of rest or uniform motion unless an external force acts on it.

It should be noted that, if there is no net force resulting from unbalanced forces acting on an object, then the object will maintain a state of rest or continue to move with a constant velocity. If that velocity is zero, then the object remains at rest. If an additional external force is applied, the velocity will change because of the applied force. This means that, if a body is at rest or is moving with constant speed in a straight line, there is no net force acting on it. If there is no net force on an object, its acceleration will be zero.

Newton's first law of motion is usually referred to as the law of inertia. Thus, an object with low inertia is easier to accelerate than an object with a large inertia.

It is due to inertia that passengers usually lose balance as a bus goes around a corner. In a crash, for example, the bus stops suddenly while the passengers inside continue in their forward motion. In this case, the passengers will hit themselves against the seats or even being thrown out through shattered windscreens. However, there will be minimal impact on the passangers if they fasten their seat belts and if the speed is low. During an accident, the seat belts exert force against the forward motion of passenger bodies due to inertia, as a result they remain in place.

Note: Please do not forget to fasten your seat belt once you board a car or a bus as shown in Figure 7.2 in order to ensure your safety.

Figure 7.2: *Car driver with a fastened seat belt*

Activity 7.2

Aim: To demostrate Newton's first law of motion.

Materials: A coin, wide-mouthed bottle, piece of smooth cardboard

Procedure

1. Place a small coin on a piece of cardboard and place the card over the mouth of a bottle so that the coin is directly above the mouth as in Figure 7.3 (a).

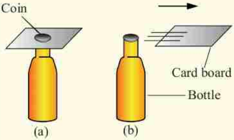


Figure 7.3

2. Flick the card forward using a finger as shown in Figure 7.3 (b). Make sure that the card is not tilted during the process.

Questions

(a) What happens to the coin?

(b) Where does it fall?

(c) What happens to the card?

The coin does not move forward as the card does. It falls into the mouth of the bottle. This means that the coin maintained its original position. If the card was rough, the coin would have missed the mouth of the bottle.

Newton's first law of motion shows force is the only factor that initiates or promotes motion. Consequently, the following conclusions can be drawn from this law:

1. If a body is at rest or is moving with constant velocity (constant speed in a straight line), the net force acting on the body is zero. This implies that, while in a state of rest or moving with constant velocity, the body has no acceleration.
2. If a body is pulled along the ground and moving with constant velocity, the force exerted on the body is not zero, while the net force is zero. This is because when the body is moving with constant velocity, the frictional force is equal to the applied force.
3. A body moving with constant velocity can only change its direction if force is applied.
4. If a body is exhibiting circular motion, then a force has to be applied to sustain the motion since the direction is changing.
5. For a body moving in a straight line to accelerate, force has to be applied in the direction of motion. To decrease the speed, force has to be applied in the opposite direction of motion. Therefore, a net force is required to overcome inertia of a body and cause acceleration.

Example 7.1

Consider an amount of meat being weighed as shown in Figure 7.4. This is an application of Newton's first law of motion. There are two forces acting.

Figure 7.4

The weight of the meat is due to the earth's gravitational force, F_E or pull acting on it. The force exerted by the scale is F_S. Since the meat is at rest, its acceleration is zero. The net force acting on the meat is zero.

That is, $F_E - F_S = 0$.

$$F_E = F_S$$

This is in accordance to Newton's first law of motion. In this case, therefore, the scale reads the weight of the meat.

Exercise 7.1

1. State Newton's first law of motion.
2. Explain why the following situations arise:
   (a) Mangoes fall down when the mango tree is shaken.
   (b) A ball thrown vertically upwards by a passenger inside a train moving with constant velocity returns to the thrower.
   (c) Dust particles are removed from a carpet by striking the carpet with a stick.
   (d) When a person jumps into a moving lorry from behind, he or she falls backwards.
3. A front-wheel drive car is travelling at constant velocity.
   (a) What are the forces acting on the moving car?
   (b) Draw a sketch to illustrate the forces acting on the car.
   (c) Passengers in a car are advised to fasten seat belts. Explain, in terms of Newton's first law of motion, how can a safety belt reduce injuries.

Task 7.1

Take two identical plastic bottles; fill one with wet sand and leave the other empty. Hang the two bottles from long pieces of string. Raise the bottles to the same height, keeping the strings stretched, and let both of them swing back and forth for 3 seconds. Try to stop them from swinging.

(a) Observe what happens.
(b) Which bottle has a higher resistance to stopping?

Present and discuss your findings in class.

Newton's second law of motion and momentum

The motion of a body incorporates, among other factors, its mass and velocity.

Linear momentum

The linear momentum p of a body is defined as the product of mass m and its linear velocity v. Linear momentum is associated with linear motion of a body.

$$\text{Linear momentum} = \text{mass} \times \text{velocity}$$

$$p = mv$$

Linear momentum has both magnitude and direction. It should be noted that momentum is always in the same direction as velocity. Thus, momentum of a body depends on its mass and velocity. The SI unit for linear momentum is kilogramme metre per second (kg m/s).

A moving body has large momentum if it has a large mass, and it is moving with high speed. For example, a 10 tonnes petroleum tanker (see Figure 7.5) moving at a speed of 100 m/s due east has the same momentum as a 1 000 kg missile travelling at a speed of 1 000 m/s in the same direction.

Figure 7.5: *Petroleum tanker*

Mass is constant for a given body. Therefore, the momentum of such a body will only change if velocity changes. This means that the body has to accelerate under the influence of a force. The larger the force applied to the body the larger the change in velocity and the larger is the change in momentum too.

The momentum of a body can only be changed if an external force is applied on the body. The force that causes the momentum change is the unbalanced force (net force). If the force does not cause change in momentum, then the body remains in its state of uniform motion. This is in agreement with Newton's first law. For example, if two bodies of unequal masses are acted on by the same external force for the same time, the magnitudes of their changes of momentum will be equal. However, the light body will have a higher final velocity than the heavy one.

Newton's second law of motion states
The rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction in which the force acts.

Suppose a force, F acts on a body of mass, m for a time, t, and causes its velocity to change from u to v. The momentum changes from mu to mv in time, t, thus;

$$\text{the rate of change of momentum} = \frac{mv - mu}{t}$$

From Newton's second law, the rate of change of momentum is proportional to the applied force. Therefore,

$$F \propto \frac{mv - mu}{t}$$

Taking out the common factor m;

$$F \propto \frac{m(v-u)}{t}$$

Since,

$$acceleration(a) = \frac{change\ in\ velocity}{time} = \frac{v-u}{t};$$

then,

$$F \propto ma$$

$$F = kma$$

where k is a constant of proportionality whose value is 1. Hence,

$$F = ma$$

This means the net force applied is equal to the rate of change of momentum. The SI unit of force is kilogramme metre per second square (kgm/s^2) which is newton (N).

Activity 7.3

Aim: To determine the linear momentum of a body.

Materials: Trolley, measuring tape, stopwatch, balance, an inclined plane at a small angle, several objects of different masses

Procedure

1. Fix the tape along the plane in order to record the distance travelled by the trolley.
2. Measure and record the mass, m of the trolley.
3. Make the trolley of mass, m to move along the plane by releasing it from rest (see Figure 7.6).

Figure 7.6

4. Record the time, t using a stopwatch and distance travelled during this time.
5. Repeat steps 2 to 4 using different values of mass, m by adding masses to the trolley

Questions

(a) Determine the average velocity of the trolley.
(b) Determine the linear momentum, assuming uniform average velocity.
(c) Comment on the determined values of the linear motion.

Task 7.2

You will need a collection of road safety pamphlets, slogans and a copy of the highway code. List some key road safety elements such as seat belts, the clothing that motor and cyclists wear. Identify the elements associated with the law of Physics that is expressed as:

Force × time = change of momentum

Produce a poster linking as many road safety ideas as you can with this law. Discuss your findings in class.

Example 7.2

A saloon car of mass 1 000 kg is moving with a velocity of 60 km/h. What is its momentum?

Solution

Mass m of the car = 1 000 kg

Velocity, v of the car = 60 km/h

Firstly, change speed from km/h to m/s

$$v = \frac{\dfrac{60\text{ km}\times 1\,000\text{ m}}{1\text{ km}}}{1\text{ hr}\times\dfrac{(60\times 60)\text{ s}}{1\text{ hr}}}$$

$$= \frac{60\times 1\,000\text{ m}}{(60\times 60)\text{ s}}$$

$$= \frac{100}{6}\text{ m/s}$$

$$= 16.7\text{ m/s}$$

Secondly, find momentum

$$p = mv$$

$$= 1\,000\text{ kg}\times 16.7\text{ m/s}$$

$$= 16\,700\text{ kg m/s}$$

Therefore, momentum of the car is 16 700 kg m/s.

Example 7.3

Suppose you exert an upward force of 10 N on a 3 kg object. What will be the object's acceleration?

Solution

There are two forces acting on the object, namely its weight and the upward force of 10 N. (See Figure 7.7). The weight of an object always acts downwards toward the center of the earth and is equal to mass, m times acceleration due to gravity, g.

$$\textit{Weight of the body} = mg$$

$$= 3\text{ kg}\times 10\text{ m/s}^2$$

$$= 30\text{ N}$$

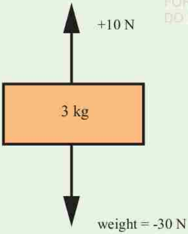


Figure 7.7

The net force (upward force) is therefore:

$F = 10 \text{ N} + (-30 \text{ N}) = -20 \text{ N}$

Using Newton's second law, the object's acceleration is given by:

$$a = \frac{F}{m}$$

$$= \frac{-20 \text{ N}}{3 \text{ kg}}$$

$$= -6.67 \text{ m/s}^2$$

The object will fall with an acceleration less than the acceleration due to gravity. What could be the object's acceleration if the upward force were 50 N?

The following points can sum up Newton's second law of motion:

1. It gives the relationship between force, mass and acceleration.
2. For a body of constant mass, $F \propto a$. Hence, the acceleration produced on a body is directly proportional to the net applied forces and its direction is the same as that of the force.
3. If there is no net force acting on a body, then the rate of change of momentum with time is zero. That is;

$$F = \frac{mv - mu}{t} = 0$$

This implies that momentum is constant. Hence, a body could be at rest or moving with constant velocity since mass, m is constant.

Example 7.4

A tennis ball whose mass is 150 g is moving at a speed of 20 m/s. It is then brought to rest by one player in 0.05 s. Calculate the average force applied.

Solution

Initial speed, u of the ball = 20 m/s

Final speed, v = 0 m/s

Time, t = 0.05 s

But

$$a = \frac{v - u}{t}$$

$$= \frac{0 \text{ m/s} - 20 \text{ m/s}}{0.05 \text{ s}}$$

$$= -400 \text{ m/s}^2$$

Applied force, F is given by

$$F = ma$$

$$= 0.15 \text{ kg} \times (-400 \text{ m/s}^2)$$

$$= -60 \text{ kg m/s}^2$$

Therefore, the magnitude of the applied force is 60 N.

Example 7.5

An unbalanced force of 12 N acts on a mass of 2 kg. Calculate:

(a) the resulting acceleration.

(b) the force that could give a body of 10 kg the same acceleration.

Solution

Force, $F = 12$ N

Mass, $m = 2$ kg

(a) By using $F = ma$, the resulting acceleration is:

$$a = \frac{F}{m}$$

$$= \frac{12}{2} \text{ N/kg}$$

$$= 6 \text{ m/s}^2$$

(b) Mass, $m = 10$ kg

Acceleration, $a = 6$ m/s²

$$F = ma$$

$$= 10 \text{ kg} \times 6 \text{ m/s}^2$$

$$= 60 \text{ N.}$$

Exercise 7.2

1. A body at rest is acted upon by a force for 20 seconds. The force is then withdrawn, and the body moves a distance of 60 m in the next 5 seconds. If the mass of the body is 10 kg, calculate the magnitude of the force.

2. A train of mass 22 400 kg moving at the rate of 112 km/hr is brought to rest in 24 seconds by the action of the brakes. Calculate the braking force.

3. (a) State Newton's second law of motion.

   (b) A trolley of mass 5.0 kg rests on a smooth horizontal track. A forward force of 4.5 N is applied to the trolley as shown in Figure 7.8. Find the acceleration of the trolley.

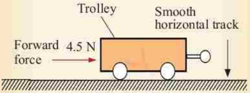


Figure 7.8

4. A car moves with an acceleration of 5 m/s². If its mass is 2 000 kg, find the force with which the car is moving.

5. A trolley of mass 20 kg loaded with a bag of maize of mass 100 kg rest on a smooth horizontal track. If two opposing forces of magnitude 55 N and 90 N are applied to the trolley as shown in Figure 7.9, find:
   (a) the acceleration of the trolley;
   (b) the direction of the resulting motion; and
   (c) the distance travelled by the trolley in 4 seconds.

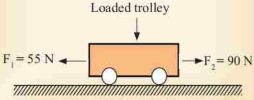


Figure 7.9

Activity 7.4

Aim: To verify Newton's second law of motion.

Materials: Masses of 100 g, 150 g, 200 g, 250 g and 300 g, long table, hook, tape, stopwatch, trolley, pulley, thread/ string, long paper tape

Procedure

1. Fix a frictionless pulley at the edge of a table as shown in Figure 7.10.
2. Place a trolley at the end of the table such that the distance between the trolley and pulley is about 1 m.
3. Tie a thread to the trolley and connect it to a hook of known mass passing over the frictionless pulley.
4. Add few analytical masses to the trolley.
5. Place a standard mass on the hook, the trolley will not move. Gently add masses to the hook till the trolley just starts to move.
6. Record the time taken for the trolley to cover a distance of 1 m on the observation table.
7. Repeat the experiment by changing the mass in the hook.

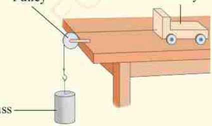


Figure 7.10

8. Record the time taken in each case.
   Note: For best results, use masses that are nearly equal; this will result into a slow motion, hence making more accurate measurement of time possible.
9. Calculate the acceleration for each mass and record the results in the following table.
   (Use $s = ut + \frac{1}{2}at^2$ with $u = 0$)

Mass (g)	Time (s)	Acceleration $a = \frac{2s}{t^2}$ (m/s^2)

Questions

(a) Plot the graph of mass against acceleration.

(b) Is there any relationship between force applied and acceleration? Explain.

Generally, the rate of change of linear momentum of a body is proportional to the force applied, and it takes place in the direction of the force.

Newton's second law is related to linear momentum. This is because the force that causes momentum change is the unbalanced (net) force. Newton's second law of motion could therefore be stated as:

> The rate of change of momentum of a body is directly proportional to the net force acting on the body and is in the same direction as the force.

Activity 7.5

Aim: To investigate the relationship between mass and acceleration when net force is constant.

Materials: Metre rule, slotted masses, string, pulley, ticker-timer, toy car, paper tape, inclined plane, wooden block, carrier

Procedure

1. Set up the apparatus as shown in the Figure 7.11.

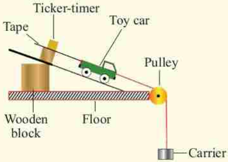


Figure 7.11

2. Place 100 g mass on the carrier to accelerate the toy car. Maintain this force throughout the activity.
3. Increase the mass of the toy car by adding masses and record the corresponding acceleration from the paper tape.
4. Tabulate the results in the following table.

m (kg)	a (m/s^2)	ma (N)	$\frac{1}{m}$ (kg^{-1})

Questions

(a) Plot a graph of a against $\frac{1}{m}$.

(b) Calculate ma.

(c) What are your observations?

Newton's third law of motion

This law emphasises that forces always come in pairs. It is often called the law of *action and reaction*.

Newton's third law of motion states that If object A exerts a force on object B, object B must exert an equal and opposite force on A.

Thus, for every action force there is an equal and opposite reaction force. Hence:

$F_{A\to B} = -F_{B\to A}$,

where $F_{A\to B}$ is the force that A exerts on B, and $F_{B\to A}$ is the force that B exerts on A. The negative sign indicates that the forces are in opposite direction.

A common misconception about the third law of motion is that action and reaction forces cancel each other. While the two forces are equal in magnitude and opposite in direction, they do not cancel. This is because they act on different bodies. The force that A exerts on B can cause B to accelerate, and the force that B exerts on A can cause A to accelerate.

While the third law of motion says that the forces are equal, it does not say that their effects are the same. The acceleration of B depends on the force A exerted on it and its mass. Likewise, the acceleration of A depends on the force B exerted on it and its mass. When you drop a ball, the earth pulls the ball down, and the ball pulls the earth up. However, because the earth's mass is so large, it can not be seen accelerating upwards. It is only the ball is observed accelerating downwards.

For example, if you wear roller skates (see Figure 7.12) and push yourself against a wall, the wall will exert a force in the opposite direction and move you backwards. But the wall does not move.

Figure 7.12: *Boy wearing roller skates*

Consider the Figure 7.13.

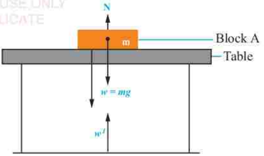


Figure 7.13: *Action and reaction force*

Forces acting on a block A of mass m placed on a table are as shown in Figure 7.13. The weight of the block $w = mg$ is the force acting downwards due to the earth's attraction, i.e., the earth exerts a force of w (mg) on the block.

An equal and opposite force w^1 is exerted on the block by the earth. Hence, w and w^1 are the action and reaction forces respectively. They act on different bodies, so, they do not cancel each other. Therefore, they do not place any object in equilibrium.

The above example should convince you that the book's weight and the contact force from the table cannot be an action-reaction pair if Newton's third law is observed.

Another example could be when you are standing in an elevator or lift. Assuming that your weight is w and the contact force from the floor is N, then if the elevator is moving with constant velocity (a = 0 m/s^2), $w = N$, and accelerating upwards, it is true that you are also accelerating upwards. To produce this acceleration, there must be a resultant upward force on you. Since only w and N act on you, N must be greater than w.

The following points can be used to sum up Newton's third law.

1. The action and reaction forces are equal in magnitude but opposite in direction.
2. The action and reaction forces act on different bodies, hence do not cancel each other.
3. The third law of motion involves only two separate bodies.
4. The forces occur in pairs only.

Example 7.6

A gorilla has a mass of 50 kg, and it climbs on a rope which can stand a maximum tensional force of 600 N. Do you expect the rope to break if the gorilla:

(a) climbs up with an acceleration of 6 m/s²?

(b) climbs with a uniform speed of 5 m/s?

(c) falls down the rope while holding it due to gravitational force?

(d) climbs down with an acceleration of 4 m/s²?

Solution

(a) Apparent weight of gorilla

Given that:

Acceleration, $a = 6\text{ m/s}^2$

Acceleration due to gravity, $g = 10\text{ m/s}^2$

Mass, $m = 50\text{ kg}$

$$w_1 = m(g + a)$$

$$= 50\text{ kg} \times (10\text{ m/s}^2 + 6\text{ m/s}^2)$$

$$= 50\text{ kg} \times 16\text{ m/s}^2$$

$$= 800\text{ kg m/s}^2$$

$$= 800\text{ N}$$

The tension in the rope is greater than the given tension (600 N). So, the rope will break.

(b) $a = 0$

$$w_2 = mg$$

$$w_2 = 50\text{ kg} \times 10\text{ m/s}^2$$

$$= 500\text{ kg m/s}^2$$

$$= 500\text{ N}$$

Therefore, the rope will not break.

(c) $a = g$ (down)

$$w_3 = m(g - a) = m(g - g) = 0$$

Therefore, the rope will not break.

(d) When $a = 4\text{ m/s}^2$ (towards the ground)

$$w_4 = m(g - a)$$

$$= 50\text{ kg} \times (10\text{ m/s}^2 - 4\text{ m/s}^2)$$

$$= 50\text{ kg} \times 6\text{ m/s}^2$$

$$= 300\text{ kg m/s}^2$$

$$= 300\text{ N}$$

The rope will not break.

Exercise 7.3

1. (a) State Newton's third law of motion.
   (b) Using examples, differentiate between action and reaction forces.
2. A pilot jumps from a plane on an air cushion. His/her speed is 24 m/s. The average force of the cushion on the body while he/she is being stopped is 9 400 N. If his/her mass is 70 kg, calculate the distance he/she will sink into the cushion.
3. A person standing in a lift holding a spring balance with a load of 5 kg suspended from it. What is the reading on the spring if the lift is descending with an acceleration of 3.8 m/s^2?

Applications of Newton's laws of motion

Newton's laws of motion are widely applied and experienced in daily life. As one turns a corner when travelling in a car, his/her body keeps moving in a straight line while the car turns the corner. It is as if he/she is pushed into the side of the seat. Also, when a moving bus suddenly stops, the passengers feel a jerk in a forward direction. This is because the upper part of the passenger's body tends to remain in the forward motion while the lower part of the body suddenly comes at rest. That is why it is advised to fasten a seat belt when travelling in a car to ensure safety throughout the journey.

When a person jumps off a small rowing boat in water, he/she will be pushed forward towards the water. The same force the person used to push forward will make the boat move backwards.

When walking on the ground, a person presses the ground backward with feet as a reaction and the ground gives an equal and opposite forward force which sets the person in motion.

If a ball is kicked in air, it will rise in air and eventually fall back to the ground. This is due to the pull of gravity.

When a rocket propels, it pushes out a burning gas (action) and exhaust gas pushes on the rocket (reaction) with an equal thrust but opposite in direction. The net rate of change in linear momentum produces the forward acceleration of the rocket.

Exercise 7.4

Explain the following phenomena using Newton's third law of motion.

1. An inflated balloon is released and shoots all around the room.
2. The recoil of a rifle when fired.
3. The launch of a rocket.
4. A hammer driving a nail into a block of wood.

Conservation of linear momentum

Consider a bat hitting a ball. The force rises from zero at the moment of contact to a very large value within a very short time, after which it returns to zero again.

Within this period, change in time, $\Delta t = t_2 - t_1 = t$, the force is continuously varying.

Taking F as the force exerted by the bat on the ball during the interval t and Δp as the change of momentum, then;

$$F = \frac{\Delta p}{t}$$
$$Ft = \Delta p$$

The product Ft is called *impulse,* denoted by I, and the forces that act over short time intervals are called *impulsive forces.* The impulse has both magnitude and direction, and its SI unit is kg m/s or Ns.

From Newton's second law of motion, the applied force is

$$F = \frac{mv - mu}{t}$$

which can be written as

$$Ft = mv - mu$$

Thus, change in momentum of a body depends on the force applied and the time taken for the force to act on the body. Therefore, in order to reduce the impact of force, time for the impact should be extended. Reducing momentum of a body in a short time upon impact is dangerous because a large force of impact is produced.

Example 7.7

A 3 kg hammer is used to drive a nail into a piece of wood. If at the time of impact, the hammer's speed is 5 m/s and it drives the nail 1 cm into the wood, calculate:

(a) the acceleration of the hammer;

(b) the force exerted;

(c) the time of impact; and

(d) the impulse.

Solution

(a) u of nail = 5 m/s and $v = 0$ m/s;

Distance covered by nail, $s = 1$ cm $= 0.01$ m

Using the equation,

$$v^2 - u^2 = 2as$$

$$a = \frac{v^2 - u^2}{2s}$$

$$= \frac{(0 \text{ m/s})^2 - (5 \text{ m/s})^2}{2 \times 0.01 \text{ m}}$$

$$= -1250 \text{ m/s}^2$$

$a = -1250 \text{ m/s}^2$, a reterdation

(b) Force exerted on the nail

$$F = ma$$

$$= 3 \text{ kg} \times 1250 \text{ m/s}^2$$

$$= 3750 \text{ kg m/s}^2$$

$F = 3750 \text{ kg m/s}^2$ (or 3750 N)

(c) Time of impact,

$$t = \frac{v - u}{a}$$

$$= \frac{0 \text{ m/s} - 5 \text{ m/s}}{-1250 \text{ m/s}^2}$$

$$= 0.004 \text{ s}$$

$t = 0.004$ s

(d) Impulse,

$$I = Ft$$
$$= 3750\ \text{N} \times 0.004\ \text{s}$$
$$= 15\ \text{Ns}$$
$$I = 15\ \text{Ns}$$

Exercise 7.5

1. A rocket of mass 2×10^4 kg is launched by applying a force of 5×10^6 N for 20 seconds. Calculate the velocity it attains at the end of the 20 seconds.
2. Find the average force needed to change the velocity of a 20 000 kg lorry from rest to 13.6 m/s in 20 seconds.
3. A force of 5 N acts on a body for 3×10^{-6} seconds.
   (a) Find the impulse.
   (b) If the mass of the body is 5 g, calculate the change in velocity.
4. A car of mass 1 800 kg is moving at an initial velocity of 20 m/s. It hits a wall and stops after covering 1.8 m. What is the average stopping force that the wall applied on the car?

Some practical examples in which impulse and momentum play an important role are in the following situations:

1. While catching a ball a player extends his hands forward so that he has enough room to let his hands move backwards at the moment of impact. This reduces the force of impact while extending the time of impact.
2. A person jumping from a high ground to the floor bends his or her knees upon making contact. So next time you jump from a high point to the floor or you become a parachutist and you are approaching the ground, remember to *bend* your knees, otherwise you may *break* your legs.
3. Glassware is wrapped in paper before packing to avoid breakage.

Principle of conservation of linear momentum

Consider the case of a person firing a bullet from a gun. As the bullet leaves the gun, that is the action, the person experiences a backward push. This is due to reaction force from the butt of the gun. According to Newton's third law of motion, these two forces are equal and opposite. Since the two forces act at the same time, the impulse (change in momenta) produced must be equal in magnitude and opposite in direction. Thus, the sum of the two momenta is equal to zero. This implies that momentum cannot be produced somewhere without producing an equal and opposite momentum somewhere else.

Consider two balls of masses m_1 and m_2 approaching each other with their initial velocities u_1 and u_2 respectively. Let the balls collide and leave with their respective final velocities v_1 and v_2 as shown in Figure 7.14.

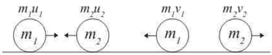


Figure 7.14: *Colliding bodies*

Let F_1 and F_2 be forces acting on m_1 and m_2 respectively during collision. Now by Newton's third law of motion, these forces are equal and opposite. Since the two forces act during the same time t, the impulses produced are therefore equal and opposite.

$$F_1t = -F_2t$$

This implies that the sum of momenta of the two colliding bodies is zero. Thus, the total momentum after collision is constant.

But,

$$F_1t = m_1v_1 - m_1u_1 \text{ and } F_2t = m_2v_2 - m_2u_2$$

Thus,

$$m_1v_1 - m_1u_1 = -(m_2v_2 - m_2u_2)$$

On rearranging you obtain

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

The above expression shows that the total momentum before collision equals the total momentum after collision. This is the mathematical implication of the Law of conservation of linear momentum.

The law of conservation of linear momentum states that "When two or more bodies act upon one another, their total momentum remains constant, provided there is no influence of external forces.

Collisions

Collision of bodies occurs when a body in motion strikes another body that is either at rest or in motion. For example, an apple falling from a tree and hitting the ground, two cars colliding at an intersection and a player's foot kicking a soccer ball. Collisions, like all motions, are governed by Newton's laws. They also obey laws relating to momentum and energy. When such collisions occur, bodies move together or separately after the impact. Collision can be either elastic or inelastic.

Elastic collision

This is the collision where colliding bodies move separately after collision without losing their total kinetic energy. In this type of collision, both total momentum and kinetic energy of the bodies are conserved.

That is, sum of kinetic energy before collision = sum of kinetic energy after collision

$$\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$$

Two billiard balls bouncing off each other is an example of an elastic collision.

Inelastic collision

This is the collision which occurs when the colliding bodies stick together after colliding. In this type of collision, bodies move together with a common velocity after the impact. Kinetic energy of the colliding bodies is not conserved but the momentum is conserved. Kinetic energy is not conserved because some of it is converted into other forms of energy such as sound, light and heat.

Example 7.8

A 1 000 kg car collides with a 5 000 kg truck. During the collision, the truck exerts a force of 10 000 N on the car. What are the accelerations of the car and the truck?

Solution

If the truck exerts a force of 10 000 N on the car, the car must exert a force of – 10 000 N on the truck.

Hence,

(a) For truck,

$$F = m_{truck} \times a$$

$$a = \frac{F}{m_{truck}}$$

$$= \frac{10\ 000\ \text{N}}{5\ 000\ \text{kg}}$$

$$= 2\ \text{N/kg}$$

Therefore, $a = 2\ \text{N/kg}$ or $2\ \text{m/s}^2$

(b) For car,

$$F = m_{car} \times a$$

$$a = \frac{F}{m_{car}}$$

$$= \frac{10\ 000\ \text{N}}{1000\ \text{kg}}$$

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

Therefore, $a = 10\ \text{N/kg}$ or $10\ \text{m/s}^2$

The car experiences a larger acceleration than that of the truck because of its smaller mass.

Example 7.9

A 4 kg object is moving to the right at 2 m/s when it collides elastically head-on with a stationary 6 kg object as shown in the Figure 7.15 (a). After the collision, the velocity of the 6 kg object is 1.6 m/s to the right.

(a) What is the velocity of the 4 kg object after the collision?

(b) What is the total KE before and after collision?

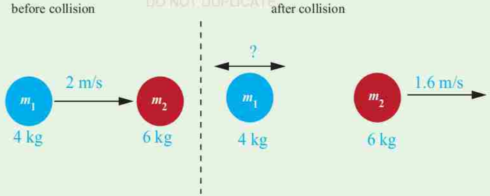


Figure 7.15 (a)

Solution

(a) By the principle of conservation of linear momentum, the total momentum before the collision must be equal to the total momentum after the collision.

Momentum before collision = Momentum after collision

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

$$m_1v_1 = m_1u_1 + m_2u_2 - m_2v_2$$

$$v_1 = \frac{m_1u_1 + m_2u_2 - m_2v_2}{m_1}$$

$$= \frac{(4\text{ kg} \times 2\text{ m/s}) + (6\text{ kg} \times 0\text{ m/s}) - (6\text{ kg} \times 1.6\text{ ms})}{4\text{ kg}}$$

$$= \frac{8\text{ kg m/s} + 0\text{ kg m/s} - 9.6\text{ kg m/s}}{4\text{ kg}}$$

$$= \frac{-1.6\text{ kg m/s}}{4\text{kg}}$$

$$= -0.4\text{ m/s}$$

After the collision, the 4 kg object is moving at 0.4 m/s. The negative sign shows that the body is moving in the opposite direction as shown in Figure 7.15 (b).

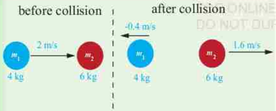


Figure 7.15 (b)

(b) Kinetic energy is associated with a moving object.

$$KE = \frac{1}{2}mv^2$$

Kinetic energy before collision

$$KE = \frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2$$

$$= \frac{1}{2} \times 4\text{ kg} \times (2\text{ m/s})^2 + \frac{1}{2} \times 6\text{ kg} \times (0\text{ m/s})^2$$

$$= 8\text{ J} + 0\text{ J}$$

$$KE_{before} = 8\text{ J}$$

Kinetic energy after collision

$$KE = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$$

$$= \frac{1}{2} \times 4\text{ kg} \times (-0.4\text{ m/s})^2 + \frac{1}{2} \times 6\text{ kg} \times (1.6\text{ m/s})^2$$

$$= 0.32\text{ J} + 7.68\text{ J}$$

$$KE_{after} = 8\text{ J}$$

So, you see that kinetic energy is also conserved. This is a characteristic of elastic collisions.

Example 7.10

The same two objects as in example 7.9 collide, but this time they stick together after the collision as shown in Figure 7.16. What will be their velocity after the collision? Is the total kinetic energy conserved?

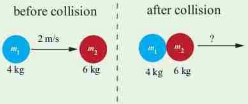


Figure 7.16

Solution

Momentum is still conserved.

Momentum before collision = *Momentum after collision*

If v *is* the common velocity, then:

$$m_1u_1 + m_2u_2 = (m_1 + m_2)v$$

$$v = \frac{m_1u_1 + m_2u_2}{(m_1 + m_2)}$$

$$= \frac{4\text{ kg} \times 2\text{ m/s} + 6\text{ kg} \times 0\text{ m/s}}{4\text{ kg} + 6\text{ kg}}$$

$$= 0.8\text{ m/s}$$

After the collision, the two objects move together at 0.8 m/s to the right.

Kinetic energy before collision (KE_b)

$$KE_b = \frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2$$

$$= \frac{1}{2} \times 4\text{ kg} \times (2\text{ m/s})^2 + \frac{1}{2} \times 6\text{ kg} \times (0\text{ m/s})^2$$

$= 8\ \text{kg m}^2/\text{s}^2 + 0\ \text{kg m}^2/\text{s}^2$

$= 8\ \text{kg m}^2/\text{s}^2$

$KE_{before} = 8\ \text{J}$

Kinetic energy after collision (KE_a)

$$KE_a = \frac{1}{2}(m_1 + m_2)v^2$$

$$= \frac{1}{2} \times (4\ \text{kg} + 6\ \text{kg}) \times (0.8\ \text{m/s})^2$$

$$= \frac{1}{2} \times 10\ \text{kg} \times (0.8\ \text{m/s})^2$$

$$= 3.2\ \text{kg m}^2/\text{s}^2$$

$KE_{after} = 3.2\ \text{J}$

The kinetic energy is not conserved. This is a characteristic of inelastic collisions, only momentum is conserved.

Exercise 7.6

1. Define momentum.
2. A trolley A of mass 1.5 kg is travelling at 6 m/s. It collides with a stationary trolley B of mass 2 kg. After the collision, the two continue travelling together at 3 m/s.
   (a) Calculate the momentum of A before the collision.
   (b) Calculate the momentum of A after the collision.
   (c) Why is there a change in the momentum of A?
   (d) Determine the kinetic energy of each trolley after the collision.
3. A car A of 2 000 kg travelling at 10 m/s, has a head-on collision with a car B of 500 kg. If both cars stopped on colliding, what is the velocity of B?
4. Calculate the resultant force needed to accelerate a space shuttle of mass 3.0×10^6 kg from rest to 600 m/s in 33 seconds.

Chapter summary

1. Inertia is the property of matter that causes it to resist changes in its state of motion or rest. It is related to the mass of an object.
2. A body can have three types of inertia, namely:
   - Inertia of rest.
   - Inertia of motion.
   - Inertia of direction.
3. An external force has to be applied in order to change the state of motion of a body, i.e., initiate a motion or stop it from moving.
4. Newton's three laws of motion give the relationship between force, mass and acceleration.
5. Newton's first law (law of inertia) states that an object at rest will remain at rest and an object in motion will remain in motion in a straight line at constant speed unless acted upon by an external unbalanced force.
6. Force has both magnitude and direction and the net force produced by a number of individual forces acting on an object is the sum of all the individual forces. The SI unit of force is kg m/s^2 or newton (N).

7. Newton's second law (law of resultant forces) states that the acceleration of an object is directly proportional to and in the same direction as the net (unbalanced) force acting on it and inversely proportional to its mass. That is; $a = \frac{F_{net}}{m}$ or $F_{net} = ma$.
8. Linear momentum, like kinetic energy, is a property of an object due to its motion. Linear momentum is defined as the product of an object's mass and its velocity. Momentum has both magnitude and direction and its SI unit is kg m/s.
9. In terms of momentum, Newton's second law of motion states that the rate of change of the momentum of a body is directly proportional to the applied force and takes place in the direction of action of the force. Impulsive forces act within a very short time.
10. In both collisions, elastic and inelastic, the total momentum is conserved. Total kinetic energy is also conserved in elastic collisions.
11. The principle of conservation of momentum states that if there is no external force acting on a colliding system, total momentum before collision and after collision is conserved (is equal).
12. Newton's third law (law of action and reaction) states that if object A exerts a force on object B, then object B must exert an equal and opposite force on A.
    That is; $F_{A \to B} = -F_{B \to A}$
13. Action and reaction forces never cancel because they act on two different objects. While action and reaction forces are equal, the accelerations they produce can be very different. This is because the accelerations also depend on the masses of the objects. Action and reaction forces always occur in pairs.

Revision exercise 7

Choose the most correct answer in items 1-4.

1. Which of the following quantities is most closely related to inertia?
   (a) Weight (c) Mass
   (b) Acceleration (d) Force
2. Action and reaction forces never cancel each other because:
   (a) they are not equal in magnitude.
   (b) they are in the same direction.
   (c) they act on different objects.
   (d) they are in different direction.
3. Rockets are unable to accelerate in outer space because:
   (a) there is no air in space for the rockets to push off.
   (b) there is no gravity in space.
   (c) there is no air resistance in space.
   (d) there is gravity in space.
4. A 5 000 kg truck collides head-on with a 500 kg car. Which of the following statements is true?

(a) During the collision, the force exerted on the car by the truck is 10 times the force exerted on the truck by the car.

(b) After the collision, the velocity of the car is 10 times the truck's velocity.

(c) During the collision, the acceleration of the car is 10 times the truck's acceleration.

(d) After collision, the velocity of the car is $\frac{1}{10}$ times the truck's velocity.

5. Match the item in **column A** against its corresponding response from **column B** by writing the correct response in the answer column.

Column A	Answer	Column B
(a) Momentum		(i) Net force
(b) Impulse		(ii) The product of force and time
(c) Inertia		(iii) Third law of motion
(d) Occurs in pairs		(iv) Act over short time intervals
(e) Resultant force		(v) kg.m/s
		(vi) Resists change of state of rest or uniform motion
		(vii) Action and reaction forces

6. A 10 kg object on Jupiter would weigh 260 N. What is the acceleration due to gravity on Jupiter?

7. Suppose an object is not moving, can you conclude that there are no forces acting on it? Explain your answer.

8. With examples explain the types of inertia.

9. Your inertia can kill you! With reference to moving vehicles, explain the Physics behind this statement.

10. A 4 kg object is acted upon by three horizontal forces: force I is 20 N to the right, force II is 8 N to the left. If the acceleration of the object is 0.75 m/s^2 to the left, what is the magnitude and direction of force III?

11. A 12 kg object is acted upon by an upward force of 150 N. What is the magnitude and direction of its acceleration?

12. A 0.2 kg helium balloon is acted upon by an upward buoyant force of 4 N.

If released from rest, determine the time required for the balloon to reach an altitude of 200 m.

13. A body of mass 8 kg moving with a velocity of 20 m/s collides with another body of mass 4 kg moving with a velocity of 10 m/s in the same direction. The velocity of the 8 kg body is reduced to 15 m/s after collision. If the bodies do not stick together after the collision, calculate the velocity of the 4 kg body.

14. In the picture shown in Figure 7.17, identify at least 5 pairs of action/ reaction forces and describe their effects.

Figure 7.17

15. Object A has a mass of 5 kg and a velocity of –10 m/s. Object B has a mass of 10 kg and a velocity of 5 m/s.
    (a) Which object has the largest momentum?
    (b) Which object has the highest kinetic energy?

16. A 0.2 kg ball is travelling at 20 m/s to the left when it is struck by a bat. After being struck the ball has a velocity of 25 m/s to the right. If the ball and bat were in contact for 0.3 s, what was the average force exerted on the ball?

17. A 4 kg ball travelling at 2 m/s to the right collides head-on with a 6 kg ball travelling at 2 m/s to the left. After the collision the velocity of the 4 kg ball is 2.8 m/s to the left.
    (a) Determine the velocity of the 6 kg object after the collision.
    (b) Was the total kinetic energy conserved during the collision? Justify your answer.

18. If the two balls in question 17 had stuck together after the collision, what would have been their final velocity?

19. A 4 kg ball travelling at 6 m/s to the right collides head-on with a 6 kg ball travelling at 4 m/s to the left. If the collision is perfectly elastic, what are the velocities of the two balls after the collision?

20. A model car of mass 2 kg is travelling in a straight line. If its velocity increases from 3 m/s to 9 m/s in 4 s, what is the resultant force on it?

21. A bullet of mass 10 g was fired into a block of wood of mass 390 g lying at rest on a smooth surface. The wood then moves at a velocity of 10 m/s.
    (a) What was the velocity of the bullet?
    (b) What was the *KE* before and after the collision?

Chapter Eight

Temperature

Introduction

Temperature refers to a physical quantity that expresses the degree of hotness or coldness of a body. Temperature determines the kinetic energy of particles in a body. In this chapter, you will learn the concept of temperature, its SI unit and instruments used for measuring it. You will also learn the measurable physical properties that change with temperature, fundamental interval of a thermometer, scale conversion and the mode of action of a liquid-in-glass thermometer. The competencies developed will enable you to measure the temperature of objects by using a thermometer.

Concept of temperature

What is temperature? When is the temperature high or low? What is the temperature of your body?

Temperature is important in everyday life. It brings the sense of hotness and coldness. However, these terms are ambiguous because they involve the use of sense of touch, which can vary from one person to another. Suppose you have been playing outside on a very hot day and you stop to wash your hands at a nearby tap. The water coming from the tap feels cold. On the other hand, you may have been outside on a cold day, and when you stop to wash your hands, the same tap water feels warm. The temperature of the water is the same in both instances, but your sensation of it is quite different. The sense of touch therefore varies with the prevailing weather conditions.

Task 8.1

1. Identify and explain the ways temperature affects our everyday life.
2. Discuss the limitations of measuring the degree of hotness or coldness of a body using the hand.

The degree of coldness or hotness of a body at a particular time is called *temperature, T*. The SI unit of temperature is Kelvin (K). The other units of temperature are Fahrenheit degrees (ºF) and degree Celsius (ºC)

Temperature scales

There are three temperature scales that are commonly used today.

These are:

1. Degree Celsius scale (ºC)
2. Fahrenheit scale (ºF)
3. Kelvin scale (K).

Celsius scale (ºC) is a very commonly used scale. The scale is based on 0 ºC that corresponds to the temperature at which water freezes and 100 ºC that corresponds to the boiling point of water at sea level. Sometimes, the scale is called the centigrade scale because of the 100-degree interval between the fixed points.

Fahrenheit scale (ºF) is a scale based on 32 ºF corresponding to the freezing point of water and 212 ºF for the boiling point of water. The interval between the two fixed points is divided into 180 divisions.

It is important to note that both Celsius scale and Fahrenheit scale degrees are not very practical as their zero points are not the lowest possible temperatures. It is possible to have negative temperatures. Also, their temperature scales are based on the freezing and boiling points of water.

Kelvin scale (K) was designed in order to set the absolute zero (0 K) as the lowest temperature to which matter can be cooled. The 0 K is equivalent to -273 ºC. Therefore, on Kelvin scale, water freezes at 273 K (equivalent to 0 ºC) and boils at 373 K (equivalent to 100 ºC). It should be noted that a temperature difference of one degree on the Celsius scale is the same as that of one degree on the Kelvin scale and one degree on the Fahrenheit scale (see Figure 8.1).

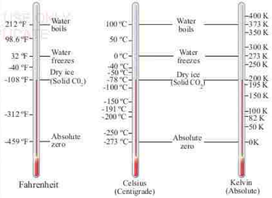


Figure 8.1: *Correspondence of thermometer scales*

Measurement of temperature

Temperature is measured using a thermometer. The word thermometer comes from two Greek words: thermos and meter. 'Thermos' means heat and 'meter' means to measure. A common example of a thermometer is the liquid-in-glass thermometer (see Figure 8.2). This thermometer contains a liquid, usually mercury or coloured alcohol. The liquid expands or contracts as its temperature changes. This change in volume of the liquid causes it to move up or down a narrow tube that runs the length of the thermometer. The position of meniscus of the liquid indicates the temperature on a calibrated scale on the thermometer.

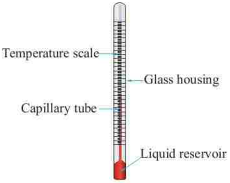


Figure 8.2: *Liquid-in-glass thermometer*

Thermometer is used by inserting it into the sample whose temperature is to be measured. Once the level of the liquid in the thermometer is no longer varying, the temperature is recorded from the scale of the thermometer.

Thermometric properties of substances

Any observable and measurable property of matter that changes with temperature can be used as a basis of a thermometer. Such a property is called thermometric property. Nearly all solids, liquids and gases expand when heated and contract when cooled. Expansion involves change in length or volume. Therefore, *the length of solid bar, volume of liquid or gas* can be used as thermometric properties. Other thermometric properties include electrical *resistance* and capacitance of a material.

Liquid-in glass thermometer

This is one of the most common thermometers used in the laboratories and at home. It uses mercury and alcohol as thermometric liquids. Mercury and alcohol have thermometric properties that change linearly with temperature. The decision to use either mercury or alcohol in a thermometer depends on the range of temperatures to be measured in relation to the properties of the two liquids. Figure 8.2 shows an example of a liquid-in-glass thermometer.

Table 8.1 compares the properties of mercury and alcohol that determine their use in different thermometers.

Table 8.1: *Comparison of properties of mercury and alcohol*

Mercury	Alcohol
It does not wet glass	It wets glass
It is not volatile	It is very volatile
It boils at 360 ºC	It boils at 78 ºC
It freezes at -39 ºC	It freezes at -115 ºC
It is opaque; so it is easily seen	It is colourless and has to be coloured
It does not absorb much heat from substances being measured since it has small heat capacity	It absorbs more heat from substances being measured since its heat capacity is 18 times that of mercury
It is a good conductor of heat	It is a poor conductor of heat
It expands steadily	Its expansion is abrupt and rapid

Other examples of thermometers include: resistance thermometers, constant-volume gas thermometers, and thermocouple thermometers.

Task 8.2

Your teacher will provide the mercury thermometer and the alcohol-filled thermometer. Use both thermometers to measure the temperature of hot water, cold water and melting ice. Record your observations and explain the results.

Fundamental interval of a thermometer and scale conversion

The fundamental interval of a thermometer is the span of numbers between its two fixed points. In the Celsius scale, the interval is from 0 ºC to 100 ºC. For Fahrenheit scale the interval is from 32 ºF to 212 ºF, and for Kelvin scale, the interval is from 273 K to 373 K.

Celsius and Kelvin scale conversion

Conversion between Celsius and Kelvin scales is based on the fact that Celsius and Kelvin scales intervals are equal (1 ºC =1 K), and the ice point on the Celsius scale is 0 ºC while on the Kelvin scales is 273 K.

If θ is temperature on the Celsius scale and T is temperature on the absolute (Kelvin) scale, the conversion equations are as follows:

1. Celsius temperature scale to Kelvin scale:

$$T = (\theta + 273)\,\text{K}$$

2. Kelvin temperature scale to Celsius scale:

$$\theta = (T - 273)\,^{\circ}\text{C}$$

These are mathematical equations that give the relationship between the Celsius and Kelvin scales.

Other relations are:

$$-273\ ^{\circ}\text{C} = 0\ \text{K}$$
$$0\ ^{\circ}\text{C} = 273\ \text{K}$$

Celsius and Fahrenheit scale conversion

The conversion between Celsius and Fahrenheit is based on the fact that the Celsius interval is nearly twice as large as the Fahrenheit interval (1 ºC=1.8 F), and the ice point on the Celsius scale is 0 ºC while on the Fahrenheit scale it is 32 ºF. Conversion equations for Celsius and Fahrenheit scales are:

1. Celsius temperature scale to Fahrenheit temperature scale:

$$F = \left(\frac{9}{5}\theta + 32\right)^{\circ}\text{F}$$

2. Fahrenheit temperature scale to Celsius temperature scale:

$$\theta = \left(\frac{5}{9}(F - 32)\right)^{\circ}\text{C}$$

These are mathematical equations that give the relationship between the Fahrenheit and Celsius scales.

Example 8.1

If the temperature of nitrogen liquid is 77 K, what is the temperature reading on the Celsius and Fahrenheit scales?

Solution

First, convert Kelvin to Celsius.

$$\theta = (T - 273)^{\circ}\text{C}$$

$$\theta = (77 - 273)^{\circ}\text{C}$$

$$\theta = -196\ ^{\circ}\text{C}$$

Therefore, temperature on Celsius scale is –196 °C.

Second, convert Celsius to Fahrenheit.

$$F = \left(\frac{9}{5}\theta + 32\right)\ ^{\circ}\text{F}$$

$$F = \left(\frac{9}{5}\times(-196) + 32\right)\ ^{\circ}\text{F}$$

$$F = -320.8\ ^{\circ}\text{F}$$

Therefore, temperature on Fahrenheit scale is –320.8 °F.

Fixed points of a thermometer

The scale on a thermometer must be calibrated against standards. The standards used are called *fixed points*. These points are distinguished as lower fixed point and upper fixed point which are typically the melting point of ice and the boiling point of water respectively.

The temperature of melting ice is called the *ice point* and has a temperature of 0 °C or 32 °F or 273 K. The temperature at which water boils to change to steam is called the *steam point* and has a temperature of 100 °C or 212 °F or 373 K.

Calibration of a thermometer

The process of marking the upper and lower fixed points on the thermometer is referred to as *calibration of the thermometer*.

The following is the procedure for calibrating a liquid-in-glass thermometer scale.

Step 1: The thermometer is immersed in a container of melting ice (see Figure 8.3).

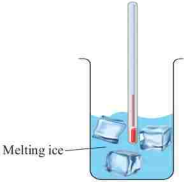


Figure 8.3: *Calibrating the lower fixed point*

Step 2: When thermal equilibrium is reached, a mark is placed on the thermometer at the upper meniscus of the liquid in the themometer. This is labelled either 0 °C or 32 °F or 273 K depending on the type of scale being used as shown in Figure 8.4.

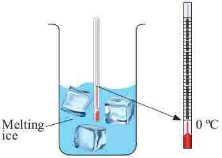


Figure 8.4: *Determining the position of the ice point*

Step 3: The thermometer is then held in the steam of boiling water. A source of heat ensures the continued boiling of the water. The thermometer is held such that it is not dipping into the boiling water as shown in Figure 8.5. This is because the temperature of water is affected by impurities dissolved in but steam temperature is not affected.

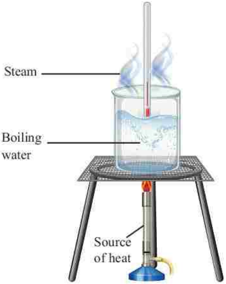


Figure 8.5: *Calibrating the upper fixed point*

Step 4: A mark is then placed on the thermometer at the meniscus of the liquid and labelled either 100 °C or 212 °F or 373 K. This is done only after thermal equilibrium is attained.

Step 5: The distance between ice and steam points is then measured as shown in Figure 8.6.

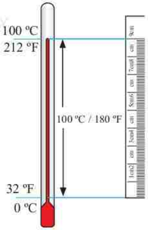


Figure 8.6: *Distance between the ice and steam points*

Step 6: There are 100 subdivisions between the ice and steam points on a Celsius and Kelvin scale and 180 subdivisions on a Fahrenheit scale. Therefore, the distance just measured is divided by either 100 or 180 subdivisions. This gives the scale to be used in placing other calibration marks between the ice and steam points. Once the scale is determined, calibration marks below the ice point and above the steam point can be made as shown in Figure 8.7.

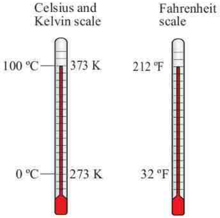


Figure 8.7: *Calibrated thermometers on Celsius, Kelvin and Fahrenheit scales*

Example 8.2

(a) Suppose that, in calibrating a Celsius thermometer (Figure 8.8), the distance between ice point and steam point is 20.0 cm. The scale is then $\frac{20.0 \text{ cm}}{100 \text{ °C}} = 0.2 \text{ cm/°C}$. If you measure 0.2 cm up from the ice point (0 °C) and place a mark, it could represent 1 °C.

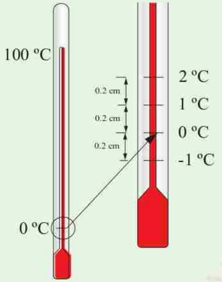


Figure 8.8

(b) If you are calibrating a Fahrenheit thermometer (see Figure 8.9), the scale will be $\frac{20.0 \text{ cm}}{180 \text{ °F}} = 0.11 \text{ cm/°F}$. Thus, the degree marks on a Fahrenheit thermometer are closer than on a Celsius thermometer.

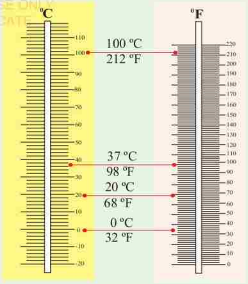


Figure 8.9

Activity 8.1

Aim: To calibrate a thermometer scale.

Materials: Liquid-in-glass thermometer, a sheet of cardboard, pencil, uncalibrated thermometer, beaker, tongs, coloured felt pen, metre rule, ice container of melting ice

Procedure

1. Tape the uncalibrated liquid-in-glass thermometer to a sheet of cardboard.
2. Carefully trace around the thermometer with a sharp pencil.

3. Put a mark on the cardboard next to the upper meniscus of the liquid and label it "room temperature" as shown in Figure 8.10.

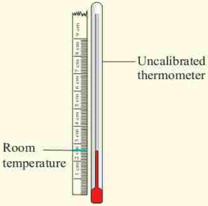


Figure 8.10

4. Carefully immerse the thermometer into a container of melting ice.
5. When the liquid column reaches equilibrium, place a mark on the thermometer at the upper meniscus of the liquid using a coloured felt pen.
6. Dry the thermometer and lay it on its outline on the cardboard.
7. Place a mark on the cardboard next to the mark on the thermometer and label it "ice point" as shown in Figure 8.11.

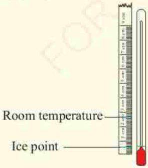


Figure 8.11

8. Hold the thermometer over boiling water using a pair of tongs.
9. At equilibrium, place a mark on the thermometer at the upper meniscus of the liquid using a coloured felt pen.
10. Dry the thermometer and lay it in its outline on the cardboard.
11. Place a mark on the cardboard next to the mark on the thermometer and label it "steam point" as shown in Figure 8.12.

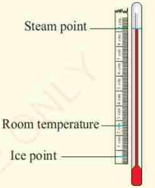


Figure 8.12

12. Measure and record the distance between the ice point and steam point marks to the nearest 0.1 cm (see Figure 8.13).

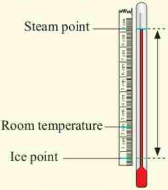


Figure 8.13

13. Determine the calibration scale using the formula;

$$\textit{Calibration scale} = \frac{\textit{Distance between ice and steam points}}{100\ °\mathrm{C}}\ (\mathrm{cm}/°\mathrm{C})$$

Questions

(a) Using a metre rule, measure and record the distance between the ice point and the room temperature mark.

(b) Divide this distance by the calibration scale to get the number of °C between the ice point and room temperature.

$$\frac{\text{Distance between ice point and room temperature (cm) on calibration scale}}{100\ °\mathrm{C}}$$

(c) Add this result to the temperature of the ice point (°C) to get the room temperature.

0 °C + ____°C = room temperature (°C)

(d) Compare this measurement with the measurement of room temperature using the commercially calibrated thermometer.

(e) Explain the results.

Exercise 8.1

1. What is meant by fixed points of a thermometer ?
2. Describe how you will calibrate a clinical thermometer.
3. Differentiate the Celsius scale from Kelvin scale.
4. Convert the following Kelvin (K) temperatures to Celsius (°C) temperatures:
   (a) 300 K. (b) 293 K.
5. Convert the following Celsius (°C) temperatures to Fahrenheit (°F) temperatures:
   (a) 58 °C (b) 100 °C
6. Convert −40 °C to °F.

Task 8.3

Use temperature conversion equations to convert your room temperature recorded with a Celsius scale thermometer into Kelvin (K) and Fahrenheit (F) scales.

Mercury-in-glass thermometer

A mercury-in-glass thermometer consists of a glass cylinder with a bulb at one end, a capillary tube down the axis, connected to the reservoir in the bulb filled with mercury. The capillary tube is a vacuum that is filled with mercury. The glass cylinder of the thermometer has an engraved temperature scale as shown in Figure 8.14.

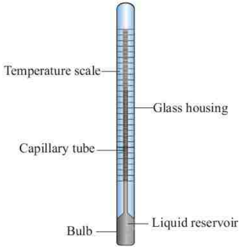


Figure 8.14: *Structure of a mercury-in-glass thermometer*

As the temperature of the thermometer changes, the mercury in the reservoir expands or contracts. This causes the height of the liquid in the capillary tube to rise or fall. When the thermometer has reached thermal equilibrium with the sample whose temperature is to be measured, the temperature is determined by reading the scale at the upper level (meniscus) of the liquid.

However, different thermometers have different structures depending on the desired function. For example, a sensitive thermometer requires a long scale. It is therefore constructed with a narrow bore tube and a large bulb. A quick-acting thermometer has a small bulb made of thin glass so that heat easily gets into the liquid inside the bulb.

Clinical thermometer

A clinical thermometer shown in Figure 8.15 is typically a mercury in-glass thermometer used to measure human body temperature. It has a constriction in the neck close to the bulb.

Figure 8.15: *Clinical thermometer*

As the temperature rises, the force of the expansion forces the mercury up through the constriction to the capillary tube. When the temperature falls, the column breaks at the constriction and mercury cannot return to the bulb. It remains stationary in the tube. This allows an accurate measurement of the body temperature after the thermometer is removed.

Therefore, the purpose of constriction in the clinical thermometer is to prevent the mercury from dropping back to the bulb when the reading is being taken.

Temperature is obtained by reading the scale inscribed on the side of the thermometer. The scale of a clinical thermometer normally ranges from 35 °C to 42 °C. This is because the temperature of a human body is 37 °C which can fluctuate between the ranges 35 °C to 42 °C. To reset the thermometer, it must be shaken sharply several times.

The clinical thermometer may be placed in the mouth (oral) or under the armpit (auxiliary), where the exact body temperatures can be determined.

Limitations of the clinical thermometer

Clinical thermometers have the following limitations:

1. They do not necessarily reflect the core temperatures of the body.
2. They may spread infection if not properly sterilised.
3. They are delicate and can break easily.

Precautions of using the clinical thermometer

1. Do not drop the thermometer or subject it to heavy shock.
2. Do not bend the thermometer or bite the bulb.
3. Do not use a damaged or broken thermometer as it can cause injury.
4. Keep the thermometer away from unsupervised children.
5. Sterilise after use to avoid contamination.

Task 8.4

Follow instructions from your teacher about a clinical thermometer, then:

1. Explain its main features and how it measures the body temperature.
2. Draw a diagram of a clinical thermometer and label it.
3. Use the clinical thermometer to measure the body temperature of your group members.
4. Explain the limitations of the clinical thermometer and the precautions to be taken when using it.

Maximum and minimum thermometer

A maximum and minimum thermometer is a mercury-in-glass and an alcohol-in-glass thermometer which can measure the highest and lowest temperatures reached over a period of time (see Figure 8.16). This combined thermometer is usually referred to as *Six's thermometer*, named after James Six.

It consists of a U-shaped capillary tube with two separate temperature readings, maximum temperature and minimum temperature. Note that the two temperature scales are inverted.

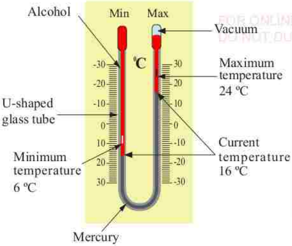


Figure 8.16: *Maximum-minimum thermometer*

Maximum and minimum thermometer

The maximum and minimum thermometer is a U-shaped parallel tubes made up of glass. One side of the U-shaped glass measures the minimum temperature, whereas the other side records the maximum temperature. The bend of the glass contains mercury which moves up or down based on the expansion and contraction of alcohol above the mercury. There are reservoirs at the top of each side of the U-shaped glass. The one at the top of the minimum reading scale contains alcohol while the other reservoir is vacuumed.

When the temperature rises, the alcohol expands and pushes the mercury up the maximum column. This also pushes the mercury down in the minimum column. When the temperature falls, the alcohol contracts and pulls the mercury up in the minimum column resulting in a fall of mercury level in the maximum column. The steel indexes are located on the surface of the mercury and move along with the rise and fall of mercury. When the temperature reaches the maximum and minimum limits, the indexes remain at those positions. One can record the maximum and minimum temperature by reading the positions of the indexes.

The maximum and minimum temperatures are read from the lower end of each marker. The indexes are reset using a small magnet that drags them along the tube. When reset, the indexes rest on the surface of the mercury.

Task 8.5

In this task, your teacher will show you a maximum and minimum thermometer.

Explain the main features of the thermometer, draw its diagram and label it well.

Hang the thermometer in the laboratory. Record the highest and the lowest temperatures for three consecutive days.

Explain your procedures and results.

Chapter summary

1. Temperature is the degree of hotness or coldness of a substance. Temperature is measured using a thermometer and its SI unit is Kelvin (K). Other units are Celsius (°C) and Fahrenheit (°F).
2. The temperature scale that is commonly used is the degree Celsius (°C).
3. A liquid-in-glass thermometer works on the principle that as the

temperature of a liquid changes the liquid expands or contracts.

4. Fundamental interval of a thermometer is the span of numbers between its two fixed points.

5. A liquid-in-glass thermometer is calibrated using two fixed points, the ice point, 0 ºC or 32 ºF and the steam point, 100 ºC or 212 ºF.

6. Conversions between the three temperature scales; Celsius, Kelvin and Fahrenheit, are done by conversion equations:

$$F = \left(\frac{9}{5}\theta + 32\right)^{\circ}\text{F}$$

$$\theta = \left(\frac{5}{9}(F - 32)\right)^{\circ}\text{C}$$

$$T = (\theta + 273)\,\text{K}$$

$$\theta = (T - 273)^{\circ}\text{C}$$

7. Some of the physical properties that change with temperature are:
   - volume of a liquid
   - resistance of a wire
   - Capacitance of a material

   The liquid-in-glass thermometers uses the above properties.

8. Sensitive thermometers have narrow bore tubes and large bulbs made up of thin glass.

9. A clinical thermometer is used to measure human body temperature. It has a constriction near the reservoir so that the mercury remains stationary after the thermometer is removed from the armpit or mouth.

10. A maximum and minimum thermometer is used to record the highest and lowest temperatures over a period of time. It contains alcohol and mercury as its thermometric fluids.

11. In the maximum and minimum thermometer, mercury moves up or down based on expansion and contraction of alcohol.

Revision exercise 8

1. Match the item in **column A** against the corresponding item from **column B** by writing the correct response in the space provided.

Column A	Answer	Column B
(a) Mercury		(i) Freezes at –115 °C
(b) Alcohol		(ii) Six's thermometer
(c) 0 °C		(iii) 273 K
(d) Steam point		(iv) Is a good conductor of heat
(e) Maximum and minimum thermometer		(v) 100 °C

2. With examples explain the following terms:
   (a) Temperature
   (b) Thermometer
3. Give three reasons why mercury is preferred to be used as a thermometric fluid.
4. Two objects, A and B are identical in size and type but possess different temperatures of 10 °C and 50 °C respectively. If the two objects are placed in contact with each other they will come to thermal equilibrium. What do you think their common final temperature will be? Why?
5. What is the function of the constriction in a clinical thermometer?
6. The temperature of the surface of the sun is approximately 6000 K. What is this temperature in °C and °F?
7. Two mercury-in-glass thermo meters are identical except that, one is calibrated in Celsius scale and the other in Fahrenheit scale. One thermometer indicates temperature of 25 °C, and the other indicates temperature of 77 °F.
   (a) Do the two thermometers record the same temperature? Show how.
   (b) If the two thermometers were placed side by side, would the level of the mercury in one side be the same as that in the other side? Explain.
8. If temperature X is recorded in Celsius and Fahrenheit scales, what is the value of temperature X?
9. On a particular liquid-in-glass thermometer the distance between the 0 °C and 100 °C marks is 22.3 cm. What could be the distance between the 30 °C and 60 °C marks?
10. Briefly explain how a thermometer measures temperature?
11. Why liquid in glass thermometer uses mercury or alcohol as thermometric liquids but not water?

Chapter Nine

Sustainable energy sources

Introduction

Sustainable energy sources include renewable sources. These comes from natural sources or processes that are constantly being replenished on a human time scale. In this chapter, you will learn the sustainable sources of energy which occur naturally and are readily available. These include solar radiation, wind, water, ocean waves, ocean tides and geothermal sources. The competencies developed will enable you to construct a model of a hydroelectric power plant, convert solar energy into electric energy and construct models of wind turbines.

Concept of sustainable energy sources

The energy used in daily life comes from sources which are either renewable or non-renewable. Sources of energy which occur naturally and are constantly replenished are termed as renewable energy sources. Examples of renewable energy sources include: sun, water (hydro), wind, sea wave, tides and geothermal.

Non-renewable energy sources are those which will run out or can not be replenished in our life time. In this case their supplies are limited as they are depleting with time. Examples of non-renewable sources are fossils (oil, natural gas, and coal) and nuclear energy.

When these fuels are burned in factories, homes, vehicles and power stations, the combustion produces carbon dioxide (CO_2) which pollutes the atmosphere. The combustion of coal also produces other toxic gases such as sulphur dioxide.

Sustainable sources of energy are the natural resources that cannot be depleted and are able to supply a continuous source of clean energy. These sources of energy are also called *renewable energy resources*.

Water energy

Water is used more than any other renewable energy resource for producing electricity. Hydroelectric power plants use water to produce electricity. About 24% of the world's electricity is produced from hydroelectric power plants. In Tanzania, hydroelectric power stations include Kidatu with capacity of

(204 MW), Mtera (80 MW), New Pangani (68 MW), Hale (21 MW), Kihansi (180 MW), Nyumba ya Mungu (8 MW) and Nyerere dam which is projected to have a capacity of 2115 MW.

Generation of electricity from water energy

Production of electricity from water energy is done in a hydroelectric power plant. Normally, a dam is built to trap water (see Figure 9.1). This is usually done in a valley where there is an existing water source for example, a river.

Figure 9.1: *Dam built across river*

Water is allowed to flow from the dam through a penstock to a turbine which converts the kinetic energy of the water into mechanical energy. The mechanical energy spin the generator to produce electricity. The electricity produced is fed into the grid to be used in households, industries and other applications as shown in Figure 9.2.

Note that the walls of the dam are made much thicker at the bottom than at the top because the pressure of the water increases with depth. Thick walls are meant to withstand the high pressure exerted by water.

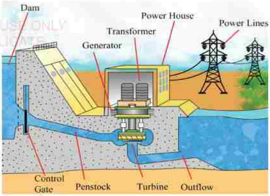


Figure 9.2: *Hydroelectric power plant*

Advantages of hydroelectric power plant

A hydroelectric power plant used in generating electricity has various advantages. These include:

Low operating cost: It is important to note that river water is a domestic resource, and always available for power generation. Since no fuel is used, and no cost of water, the operation cost of hydroelectric power plant is low.

Emission free: Hydroelectric power stations do not produce waste or pollutant in atmosphere. This is because no fuel is used during operation. Thus, it is termed as environmentally friendly energy source.

Hydroelectric power is more reliable: With hydropower, the electricity can be generated constantly provided there is a constant flow of water.

Hydroelectric power plant is adjustable: Hydroelectric power plants can be adjusted to control the flow of water. This allows the plant to produce more energy during high demand and reduce the production during low demand.

Hydroelectric power (hydroelectricity) has the following applications:

1. *Industrial purposes:* Electricity is used in industries to drive machines that in turn help in manufacturing goods.
2. *Lighting purposes:* Hydroelectricity is used for lighting for example, in homes, schools, hospitals and offices (see Figure 9.3).

Figure 9.3: *Lighting for security*

3. *Heating and cooking:* Electric heaters and cookers use electricity. This forms an efficient way of cooking. Figure 9.4 shows an electric cooker.

Figure 9.4: *Electric cooker*

4. *In health facilities*: Electricity is used to maintain some medical processes. For example, to run incubators, freezers and x-ray machines.

Disadvantages of hydropower plants

The following are some disadvantages of hydropower plant as source of energy:

(a) High initial capital cost: Hydropower plants require construction of dams. Dams are expensive to build and need large area of land.

(b) Hydropower plant affect the ecology of the area around because of flooding large area of land.

(c) They can disrupt habitat of fish and marine animals.

(d) Susceptibility to drought: Hydropower plant operation depends on the amount of water available in a given location. This means that the plant can be affected by a drought.

Task 9.1

In groups, visit the nearest power plant if available. If not available, use the internet to find the text and pictures of hydroelectric power stations.

Construct a model of a hydroelectric power plant. Assemble your models in class.

Solar energy

The sun is the primary source of energy for the earth. It emits energy in the form of waves. These waves reach the earth as solar radiation. *Solar energy* is the radiant light and heat from the sun. The sun shines every day. The energy produced by the sun can be used for drying clothes and food crops, heating water, cooking, warming buildings and generating electricity. There are various types of technologies that convert solar energy into other useful forms of energy. For example, solar energy can be converted into electricity using two technologies. These technologies are photovoltaics (PV) and concentrating solar power (CSP).

Applications of solar energy

Solar energy is harnessed by mankind and put to several uses. Some of the applications of solar energy are: generation of electricity used by electric appliances such as televisions and radios, lighting purposes, heating purposes for example, solar heaters and cookers. It is also used for drying purposes for example, in crop driers.

Sun as a source of electricity

Solar energy can be converted into electricity using solar cells (photovoltaic cells). When the sun shines onto a solar panel, the radiant energy from the sun is absorbed by the solar cell. The absorbed energy creates electrical charges that move in response to internal electrical field in the cell, and hence generate electricity. Multiple solar cells that are oriented in the same way make up a solar panel (see Figure 9.5).

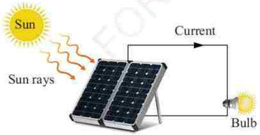


Figure 9.5: *Solar panels*

Heating effect of solar radiation

Solar energy is also used for heating water for domestic purposes. A solar heater has coiled pipes in contact with an absorber as shown in Figure 9.6. Most solar absorber surfaces are coated black. This enhances the absorption rate of the radiant energy from the sun. The absorbing surface is covered with clear glass to prevent it from damage. The glass allows sun rays to pass through easily. In order to minimise heat loss, the back of the solar heater is normally insulated. The absorbed solar energy is converted into heat. The pipes of a solar heater, connected to the solar absorber are bent or coiled and are made up of copper (see Figure 9.6). Coiling the pipes increases the surface area over which heat is transferred to the water that flows through these pipes

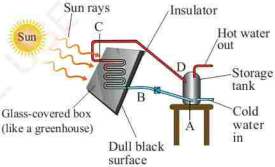


Figure 9.6: *Solar hot water system*

Cold water from the storage tank flows into the solar panel through pipe AB. As the water passes through the coiled pipe, it is heated by energy from the sun. The heated or warmed water then goes back into the storage tank via pipe CD. There is a safety pipe to lead hot water out once the storage tank is full. Recall that hot water rises, hence the position of the safety pipe.

Solar cooker

Solar cooker uses energy from the sun for heating and cooking food. The cooker always traps and concentrates energy from the sun which is then used for heating or cooking. Solar cooker can be either a box solar cooker, parabolic solar cooker, or panel solar cooker. The inner surface is coated black to enhance radiation absorption. Figure 9.7 shows a box solar cooker.

Figure 9.7: *Box solar cooker*

Task 9.2

In groups, discuss and show the conversion of solar energy into electricity.

Use a circuit diagram to show this conversion in a solar cell.

Project 9.1

Construct a model of a solar cooker using locally available materials. During your presentation in class, explain why you used each type of material as an insulator or absorber.

Wind energy

Wind has been used by Babylonians and Chinese as a source of energy to pump water for irrigation since 4000 years ago.

Wind as a source of energy

Wind is air in motion. It is produced by the uneven heating of the earth's surface by the sun. It is an air current carrying energy in a form of kinetic energy. It is this kinetic energy that is harvested and can be converted to useful form, for example, electricity.

Two parameters are necessary to specify wind; these are speed and direction. The available energy from wind depends on the speed.

Windmills and wind turbines

Sometimes people use the terms windmill and wind turbine interchangeably, but there are important differences.

Windmills generate mechanical energy, but they do not generate electricity. People have been using windmills for centuries to grind grain, pump water and perform other activities that demand application of a large force. Windmills are usually installed in coastal areas, at the top of rounded hills, in open plains and in narrow valleys between mountain ranges. These areas experience high wind speed. For water pumping systems, many blades of the windmills are preferred (see Figure 9.8).

Figure 9.8: *Windmill*

Wind turbines are machines which convert the kinetic energy of the wind into electrical energy. When wind blows, it rotates the blades which produce the mechanical energy that is converted by generator into electricity. Nomally, more than one wind turbine is installed on one location for increasing production of electricity. A group of wind turbines in the same location is called a *wind farm* or *wind farm power station* (see Figure 9.9).

Figure 9.9: *Wind farm power station*

Activity 9.1

Aim: To observe wind energy.

Materials: Feathers, sheets of paper, rulers, coloured pens

Procedure

1. Collect feathers of different sizes.
2. Release them from a suitable position above the ground outside the classroom. Observe the direction of their fall.
3 Fold sheets of paper to form paper jets.
4. Use coloured pens to write your name on your 'jet'. Also, colour the wings differently from your classmates for easy identification.
5. Release the paper jet into the air and observe the distance covered before it lands.
6. Repeat step 2 and 5 in the absence of wind, for example, in a closed room.

Question

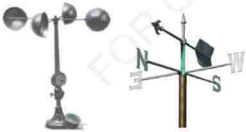
Does wind possess energy? Explain.

Strong winds have been known to damage trees and destroy houses and other forms of property. Iron sheets or roofing materials are found scattered several metres or even kilometres away from the scene of a building damaged by strong wind. Strong winds cause trees to bend in one direction as shown in Figure 9.10.

Figure 9.10: *Strong wind bending trees*

Applications of wind energy

For centuries, people have used the power of the wind to move ships, boats, pump water and grind corn. Today, wind energy is used to turn generators to generate electricity. Though wind turbines are efficient, very large turbines are required to provide the much-needed power. In this case certain parameters such as speed and direction of wind have to be measured. Wind speed is measured by an instrument called anemometer. (see Figure 9.11(a)). Wind direction is measured by using a wind vane. (see Figure 9.11(b)).



(a) Anemometer (b) Wind Vane

Figure 9.11: *Wind-measuring instruments*

Advantages of wind energy source

Wind as an energy source has several advantages such as:

1. Wind is an emission free source. It does not emit toxic gases.
2. Wind is cost effective energy source. Once the wind turbines are built, the operating and maintenance cost is low, since no fuel is needed.
3. Wind is a renewable energy source.

Disadvantages of wind as a source energy

Wind as source of energy has several disadvantages including:

1. Wind speed and direction at a given area is not constant over the year, it varies greatly. Thus, energy production varies too, and it is not reliable.
2. The wind turbines are noisy and can spoil the landscape.
3. Large windy sites are required.
4. A wind farm has effect on local wild life. For example, birds can be killed by flying in rotating wind turbines.

Project 9.2

Construct a windmill using locally available materials. During the construction, note down each step. Hand the completed work to your teacher.

Sea wave energy

Motion of sea water is influenced by wind. As the wind blows over the sea, it causes ocean waves. A wave causes the ocean water surface to oscillate up and down. These waves are powerful sources of energy. They can be used to drive generators to produce electricity. Figure 9.12 (a) and (b) shows water waves.

(a)

(b)

Figure 9.12: *Water waves*

There are several methods of harvesting energy from sea waves for generating electricity. One of the methods is the use of conversion device. These operates by using of the up and down motion of the water particles as the wave passes. Figure 9.13 shows an example of a set up for generating electricity from sea wave.

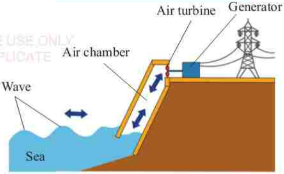


Figure 9.13: *Generating electricity from sea wave*

The waves cause the water in the chamber to rise and fall, which means that air is forced in and out of the hole at the top of the chamber. The air turbine is placed in the hole of that chamber and is rotated by air as it rushes in and out. The air turbine turns the generator to produce electricity.

Advantages and disadvantages of sea wave as energy source

Sea waves have a number of advantages and disadvantages as source of energy, as follows:

1. **Advantages of sea waves as source of energy**

Sea waves as source of energy has several advantages such as:

(a) Sea waves are abundant, widely available and easily predictable.

(b) The source is renewable.

(c) A variety of wave power devices can be designed to harness the wave energy.

(d) Sea waves are non-polluting, they produce clean energy.

2. **Disadvantages of sea waves as source of energy**

The following are disadvantages of sea waves as source of energy:

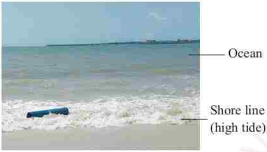
(a) This source is suitable to certain locations only where water waves are abundant and large enough for generating electricity.

(b) Energy conversion devices can have effect on marine ecosystems.

(c) Processes of energy extraction can be a source of disturbance to marine vessels.

Tidal Energy

Apart from ocean waves, ocean tides move huge amounts of water twice each day. A tide is a rise and fall of sea level caused by the gravitational pull of the moon, the sun and the rotation of the earth. There are high and low tides twice a day as shown in Figure 9.14 (a) and (b).



(a) High tide

(b) Low tide

Figure 9.14 *Sea/Ocean tides*

Conversion of tidal energy to electrical energy

The water potential energy difference between high tide and low tide appears as *tidal energy.* Tidal energy is a renewable energy produced by natural rising and falling of the ocean water. During the high tide, water is allowed to enter the upper basin and fill in a dam. At low tide, the water in the dam flows back to a lower basin and pass-through installed turbines. The mechanical energy of the moving water turns a turbine which is connected to a generator for producing electricity (see Figure 9.15).

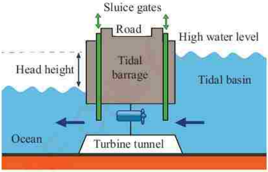


Figure 9.15: *Tidal energy extraction system*

Advantages of tides as source of energy

Tides as source of energy has several advantages such as:

1. The source is renewable. The gravitational pull between the sun and the moon will not stop.
2. Tidal power plants can last much longer than wind and solar conversion systems.
3. Tidal energy extraction does not produce waste or any pollutant into the atmosphere.

Disadvantages of tides as source of energy

The following are disadvantages of tides as source of energy:

1. It is expensive to construct tidal power plants.
2. Tidal energy conversion devices can have effect on marine life.
3. Availability of energy from tides is not constant; tides are periodic.

However, wave and tidal power sources are not widely used as commercial sources of electricity compared to other renewable energy sources, because the technology and devices are expensive.

Project 9.3

In groups, construct one model system each for converting sea wave energy and tidal energy into electricity.

Geothermal energy

Generally, the earth's interior stores a large amount of heat as a result of processes that occurred during its formation and evolution. Some parts have more stored heat than other parts due to natural radioactivity. This makes the earth's interior a natural energy source. The stored heat constitutes geothermal energy.

Geothermal as a source of energy

Geothermal energy is the heat that comes from the interior of the earth. It is contained in the rocks and fluids of the earth's crust. It can be found as far down to the earth's hot molten rocks and magma. Geothermal reservoirs are situated deep underground, usually with no visible sign above the ground (surface). Sometimes, geothermal heat can find its way to the surface in the form of volcanos, hot springs or geysers as shown in Figure 9.16.

Geothermal energy is found in areas of high volcanic activity. Areas like Lake Ngozi and Oldonyo in Tanzania and the Rift Valley in Kenya are potential geological areas for geothermal energy.

Figure 9.16: *Hot spring or geyser*

The geothermal energy can be extracted and brought to the surface where it can be converted to electricity. It can also be used for heating purposes.

Task 9.3

Explain how geothermal reservoirs originated.

Conversion of geothermal energy to electricity

Geothermal energy usually is harnessed by drilling a hole in the ground through rocks to reach a geothermal reservoir. The drilled hole creates a vent where pipes are inserted to bring steam from the hot zone to the earth's surface (see Figure 9.17). Once the steam rises to the surface, it is directed into turbines. The steam drives turbines which are used to drive generators to produce electricity.

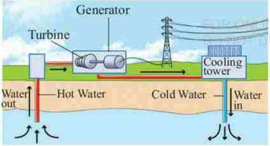


Figure 9.17: *Geothermal plant*

Advantages of geothermal energy source

Geothermal energy source has several advantages such as:

1. Conversion and use of geothermal energy do not produce pollutants. The energy source is environmentally friendly.
2. The source is renewable. The heat from the interior of the earth is always available.
3. It is cost effective. Heat from the interior of the earth is naturally occurring, no fuel is required for generating electricity.
4. A geothermal power plant does not require a large space.
5. Energy production is independent of the weather.

Disadvantages of geothermal energy source

The disadvantages of geothermal energy are explained as follows:

1. The source is close to active volcanoes. Sometimes, it can release harmful gases such as hydrogen sulphide.
2. Geographical dependency. Geothermal plants need to be built in locations where the energy is accessible. It is not possible to exploit this resource in areas with low natural radioactivity.
3. Initial cost to build the geothermal power plant is high.

Task 9.4

In groups, draw a diagram to describe how geothermal energy can be converted into electricity.

Exercise 9.1

1. How is electricity produced from:
   (a) water?
   (b) wind?
   (c) the sun?
2. In a solar heated water system;
   (a) What is the importance of:
      (i) coiling the pipes inside the box?
      (ii) having a shorter outlet pipe?
   (b) If you were to add an electric heater to the system, where could you connect it and why?
   (c) Which pipes require insulation?
3. List three areas in Tanzania where geothermal energy can be harnessed.

Contribution of the sun to other sources of energy

Most of the energy comes from the sun. For instance, the solar cell generates electricity using solar energy which has just arrived from the sun.

Energy from the sun also makes the water cycle work. It evaporates water from the sea. This water later falls as rain which fills up rivers and lakes which is used for hydroelectric power generation.

Wind is caused by the unequal heating of the earth by the sun. Wind energy therefore is a derivative of solar energy. All green plants use the energy from the sun during the process of photosynthesis. They store chemical energy in a form of starch. The energy obtained from fire wood is originally from the sun. This is similar to the fossil fuels formed hundreds of millions of years ago. Plants died and became compressed to form coal. The energy from the burning coal originally came from the sun. Figure 9.18 shows the contribution of the sun to other sources of energy.

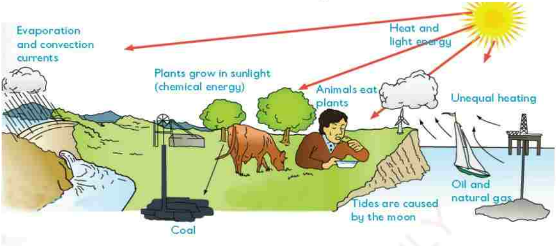


Figure 9.18: *Contribution of the sun to other sources of energy*

Chapter summary

1. Sustainable energy sources are the natural resources that cannot be depleted and are able to supply a continuous source of clean energy.
2. Examples of sustainable sources of energy include the sun, water, wind, geothermal energy, sea waves and tides.
3. The advantages of hydroelectric energy are:
   (a) reliable,
   (b) readily available in many places,
   (c) environmentally friendly, and
   (d) can be constantly generated.
4. Solar energy can be converted to electricity by using the solar cell.
5. Electricity from the solar cells can be used for:
   (a) lighting
   (b) heating water
   (c) powering spacecrafts and satellites
   (d) powering calculators and torches.
6. Wind energy also comes from the sun. Wind energy is used in moving ships, boats, pumping water and grinding corn. It can also be used to drive generators to produce electricity.
7. The disadvantages of wind energy:
   (a) is not reliable
   (b) is harnessed using noisy turbines

(c) requires large wind sites to install the turbines.
8. Sea wave energy is a result of wind blowing on the surface of sea, creating ocean waves.
9. Gravitational pull of the moon and the sun produces tides.
10. Geothermal energy is associated with volcanic activities. Steam produced in the deep underground can be used for heating homes and driving turbines for producing electricity.

Revision exercise 9

Choose the letter of the most correct answer in items 1-2.

1. Which of these resources of energy is non-renewable?
   (a) Ocean waves (b) Water (c) Solar radiation (d) Fossil fuel
2. Which of the following statements is not true?
   (a) Hydroelectric power stations are easy to set up.
   (b) Windmills are noisy.
   (c) Hydroelectric power plants degrade the environment.
   (d) Windmills cannot be set up near the seabed.
3. Match the item in **column A** against corresponding item from **column B** by writing the correct response in the space provided.

Column A	Answer	Column B
(a) Geothermal energy		(i) Energy from the sun
(b) Solar energy		(ii) Energy from firewood
(c) Wind energy		(iii) Energy from coal
(d) Sea wave energy		(iv) Energy from falling water
(e) Hydroelectric energy		(v) Energy from the nucleus of the atom
		(vi) Energy from hot underground rocks
		(vii) Energy from fossils
		(viii) Energy from charcoal
		(ix) Air current energy
		(x) Energy from batteries
		(xi) Energy from up and down motion of water

Fill in the following blanks

4. (a) Sea wave energy is a result of ____________ the sea.

   (b) Geothermal energy is ________________.

5. The following are the advantages of geothermal energy.

   (a) ________________________________

   (b) ________________________________

   (c) ________________________________

6. Explain the importance of hydropower.
7. State the applications of hydropower.
8. Using a diagram, illustrate that all the other sources of energy depend on energy from the sun.

Answers to numerical questions

Chapter 1

Exercise 1.2

1. 1.5×10^{-9} C and -1.5×10^{-9} C
3. 3.6×10^{-5} C
4. 60 F

Exercise 1.3

1. 2.5×10^{-2} C
2. 2.5×10^{-3} C
3. 2.73 μF
4. (a) 1μF (b) 11μF

Revision Exercise 1

16. (a) 2.7×10^{-10} C (b) 4.05×10^{-9} C
18. (a) 0.9μF (b) 2.7×10^{-6} C

Chapter 2

Exercise 2.1

1. (b) 0.008 Ω
2. 40 Ω
4. (d) (i) 0.5 A (ii) 18 V

Exercise 2.2

1. (a) 14.28 V (b) 5.24 A
3. 1 V
4. (a) 18 Ω (b) 3.61 Ω (c) 7.73 Ω

Revision Exercise 2

2. (b)
5. (b) (i) 5×10^{-4} A (ii) 2.5×10^{-4} A
11. 500 V
12. 0.27 A
13. (a) 4 Ω (b) (ii) 2 Ω
    (iii) 10 V
14. (a) 4.4 Ω (b) 2.73 A
15. (b) 1.38 Ω
17. (a) 1.33 Ω (b) 6 Ω
18. b
19. (a) 2.4 Ω (b) 9 Ω
21. 4.2 A

Chapter 3

Revision Exercise 3

14 (a) No
(b) 0.75 m from P

Chapter 4

Exercise 4.1

5. 1500 Nm
6. 0 Nm
7. 3.28 N
8. 20 Nm

Exercise 4.2

5. 52 g
6. 2.0 cm

Revision Exercise 4

8. 0.75 m
10. (b) 125 g
11. F = 320 N
13. (a) 48 cm (b) 0.7 N

Chapter 5

Exercise 5.1

1. (a) 42.86 (b) 95.24%
   (c) 4.76%
2. (b) 2.9 m (c) 12.86 N
3. (a) 0.31 m (b) 62.5%
   (c) 37.5%
4. 2.67 m

Exercise 5.2

1. (a) 100 N (b) 50 N
   (c) 20 N
2. 50 N
3. (a) 2.5 (b) 5
   (c) 50%
4. (a) 4100 J (b) 97.6%
   (c) 81.97 N
5. 83.3%

Exercise 5.3

1. (a) 1.5 (b) 2
   (c) 400 J (d) 300 J
   (e) 75%
2. (a) 2000 N (b) 3.57
   (c) 100%
3. (a) 2.5
   (b) 2.5
   (c) 100%
4. 1 cm

Exercise 5.4

1. 15.92 N
2. 125.6
3. 6.69 cm
4. 502.4

Exercise 5.5

1. (a) 20 N (b) 270.7
2. 3
3. (a) 4 (b) $\frac{3}{4}$

Exercise 5.6

1. 10
2. 0.016 m
3. (a) 4 (b) 3

Revision Exercise 5

9. 0.4 m
10. (a) 4 (b) 5 , 80%
11. (a) 10 (b) 8
    (c) 80%

12. (a) 37.5 N (b) 15 cm
13. (a) 2 000 J (b) 6.67 W
14. (a) 250 N (b) 375 J
15. 82.4%
16. (a) (i) 3.5 (ii) 10 (iii) 35
    (b) 560 N
17. (a) 3 (b) 233.3 N

Chapter 6

Exercise 6.1

1. 200 m/s
2. 6.25 m/s
3. (a) 15 m/s (b) 900 m
4. (a) 14 km (b) 10 km
5. 80 km/h

Exercise 6.2

1. (b) 80 m, 0 m
2. (b) 90 m
3. (b) (i) 525 m (ii) 25 s
   (iii) 30 m/s (iv) 525 m

Exercise 6.3

1. (a) 4.2 s (b) 0 m/s
2. (a) 42 m/s (b) 208 m
3. (a) 60 m (b) 12.1 m/s
4. 200 m

Exercise 6.4

1. (a) 20 m/s (b) 20 m
2. (a) 2.94 s (b) 6.88 s
3. 5 m/s

Revision Exercise 6

8. (a) 200 km (b) 0 km
   (c) 66.67 km/h (d) 0 km/h
11. (a) -2 m/s^2 (to the right)
    (b) 100 m (c) 400 m
12. (a) 80 m (b) 40 m/s
14. 15 s
15. (a) 250 m/s (b) 625 m
    (c) 750 m (d) 12.5 s
    (e) 2937.5 m (f) 20.5 s
    (g) 143.29 m/s
16. 0.435 s
17. 7.7 s , 1.3 s
18. 1.5 hours

Chapter 7

Exercise 7.2

1. 6 N
2. 29 036 N
3. (b) 0.9 m/s^2
4. 10 000 N

5. (a) 0.29 m/s^2 (b) Towards 90 N
   (c) 2.32 m

Exercise 7.3

2. 2.14 m
3. 31 N

Exercise 7.5

1. 5 000 m/s
2. 13 600 N
3. (a) 1.5×10^{-5} Ns (b) 3.0×10^{-3} m/s
4. 2×10^5 N

Exercise 7.6

2. (a) 9 kg m/s (b) 4.5 kg m/s
   (d) 6.75 J of A, 9.0 J of B
3. 40 m/s
4. 5.5×10^7 N

Revision Exercise 7

6. 26 m/s^2
10. 15 N to the left
11. 2.5 m/s^2 upward
12. 6.3 s
13. 20 m/s
16. 30 N
17. (a)1.2 m/s
18. -0.4 m/s
19. 4 m/s (for 6 kg), - 6 m/s (for 4 kg)
20. 3.0 N
21. (a) 400 m/s (b) 800 J (before collision) , 20 J (after collision)

Chapter 8

Exercise 8.1

4. (a) 27 °C (b) 20 °C
5. (a) 136.4 °F (b) 212 °F
6. –40 ºF

Revision Exercise 8

4. (a) 30 ºC
6. 5727 °C, 10340.6 °F
8. – 40 ºF and – 40 ºC
9. 6.69 cm

Appendix

Drawing of graphs

Plotting of graphs from a table of data is a basic skill requirement of every physicist. A graph is one method of presenting evidence (data) so that one can clearly see a trend. There are some fundamental points to be remembered while plotting graphs. Note that carelessly plotted graphs lead to wrong conclusions.

Example

The following data set was collected by Form Two students of Jitegemee Secondary School during their Physics practical class. Plot a graph of resistance, R against length, l of a nichrome wire using the information given in the Table below.

Resistance (Ω)	0	2	4	6	8	10	12	14	16	18	20
Length, l (cm)	0	5	8	10	15	16	20	25	35	40	45

(a) Is the resistance proportional to length?

(b) What is the gradient of the line?

After carefully reading through the example and understanding it, proceed as follows:

1. **Choosing a title**

   Decide a title for a graph depending on the data to be plotted.

   In this case, the title can be *A graph of resistance against length of a nichrome wire*.

2. **Choosing axis**

   Draw the axes and choose the variable to put on the horizontal and vertical axes. *Independent variables* should always be on the x-axis. The *dependent variable* must always be on the y-axis.

   Resistance and length are the dependent and independent variables respectively.

3. **Labelling axes**

   Label the axes, including their units of measurement.

4. **Choosing scales**

Choose a convenient scale by considering the lowest and the highest values of the given data, that is, the range of the data. Choose the suitable scale to make your graph as large as possible.

In the example, values on the *x*-axis are selected up to 55 cm, so that 45 cm (the highest value) is accommodated. Hence, for the x-axis, 1 unit represents 5 cm. For the resistance the highest value is 20 Ω, so the highest value on y-axis can be selected as 2 Ω. Therefore 1 unit represents 2 Ω.

5. **Plotting the points**

Plot all the points given in the Table.

There are two ways of joining the points.

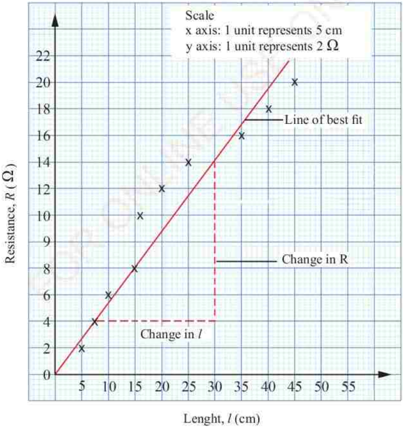
(a) If the points obviously fall on a straight line, join them using a rule.

(b) If they are scattered or un-evenly distributed,

(i) draw a line of best-fit, as shown below.

(ii) draw a smooth curve using free hand.

A graph of resistance against length of nichrome wire



From the way the points are scattered about the line of best-fit or smooth curve that is close to them, one can tell the reliability of the data.

The straight line is the easiest and simplest graph to draw. A graph of resistance versus length is a straight-line graph passing through the origin.

The graph of resistance versus length will show that, when the length of the wire increases, resistance also increases. This means that doubling the length of the wire doubles the resistance. Resistance is therefore said to be *directly proportional* to length.

$$
\begin{aligned}
Gradient &= \frac{change\ in\ R}{change\ in\ l} \\
&= \frac{(14\ \Omega - 4\ \Omega)}{(30.0\ \text{cm} - 7.5\ \text{cm})} \\
&= \frac{10.0\ \Omega}{22.5\ \text{cm}} \\
&= 0.44\ \Omega/\text{cm}
\end{aligned}
$$

Sketching of graphs is equally important especially when answering questions. Sketches normally carry almost all the information in a given question. Students are therefore advised not to waste time drawing graphs to scale when they can sketch them.

Glossary

Acceleration	the rate of change of velocity of an object with time. Symbolised as *a*
Acceleration due to gravity	acceleration produced as a result of the gravitational attraction on an object
Alnico	is a family of iron alloys which in addition to iron are composed primarily of either aluminium, nickel or cobalt
Ammeter	a device for measuring electric current in a circuit. It is calibrated in amperes (A)
Ampere	indicates the rate at which charge is flowing in a circuit. It is the SI unit of electric current
Angle of declination	the angle between the geographic axis and the magnetic axis
Angle of inclination	angle between the resultant magnetic field and the horizontal component of the earth's magnetic field. It varies from 0° at the magnetic equator to 90° at the magnetic poles. Also known as angle of dip
Atom	the smallest particle of an element that can exists and retains its identity as chemical element
Average velocity	the average rate at which displacement changes with time
Axis of rotation	an imaginary line around which all points in a body rotates
Battery	a number of electric cells connected together to produce electric current through the conversion of chemical energy to electrical energy
Celsius scale	is an international metric temperature scale on which water freezes at 0°C and boils at 100°C under normal conditions

Centre of gravity	the point in an object where the force of gravity is considered to be acting
Centre of mass	the point in a body at which the mass of all particles forming a body appear to be concentrated
Clinical thermometer	thermometer used for measuring the temperature of patients. It is a typical mercury-in-glass thermometer except that it has a constriction in the neck close to the bulb and its scale ranges from 35 °C to 42 °C
Conduction electron	free electron that can move from one atom to another within a material
Contact charging	the process of transferring electric charges from one body to another by making the bodies touch each other or by rubbing
Coulomb	a quantity of electric charge which passes through a given point in a circuit in one second when a steady current of 1 Ampere is flowing. It is the SI unit of electric charge
Demagnetization	the process of destroying magnetic property or magnetism of an object
Dip needle	an instrument used to measure the angle of inclination of magnetic field
Displacement	distance covered in a particular direction
Distance	length of the path taken by an object while in motion
Dynamic equilibrium	a state whereby all forces acting on a moving body balance such that the body moves with constant velocity
Efficiency	the ratio of the work output to the work input. It is usually expressed as a percentage
Effort	the force applied to move a load

Effort arm	the length of a lever from the fulcrum to the point of application of the effort
Electric circuit	a closed path for electric charge to flow through. It consists of a source of moving charge (cell), connecting wires and devices such as resistors and switches
Electrical conductor	material that permits current to flow freely through it under the action of an applied voltage. Metals are good conductors
Electric current	the rate of flow of electrons or it is the sustained movement of electrical charge
Electrification	the process of introducing electric charges to a body so that it is electrically charged
Electromagnet	a type of magnet whose magnetic property is produced by an electric current
Electromagnetic force	force resulting from the interaction of charged particles and their electric and magnetic fields
Electrophorus	a simple manual electric generator used to produce electrostatic charges by electrostatic induction
Electrostatic force	push or pull of electric charges at rest
Electrostatics	study of stationary electric charges
Equilibrium	state of balance of forces on a body
Fahrenheit	unit for measuring temperature in the Fahrenheit scale
Farad	the SI unit for capacitance
Ferromagnetic	magnetic materials that can be permanently magnetised
Force of gravity	a force of attraction exerted by massive bodies in the universe
Free fall	motion of an object falling freely to the ground under the action of the earth's gravitational pull

Friction charging	charging of an object by rubbing it with another object
Frictional force	a resistive force experienced by two moving objects when in contact to each other
Fulcrum	a pivot point about which a lever turns
Galvanometer	an instrument used to detect electric currents
Geothermal energy	heat that is generated within the earth
Geothermal reservoirs	natural chamber in the interior of the earth (porous rock) where geothermal energy can be tapped
Impulse	change in the momentum of an object to which force is applied within a very short time
Leaf electroscope	an instrument that is used for detecting the presence of electric charges on an object
Line of action	line through the point at which the force is applied in the same direction as the vector force
Load	mass moved by a machine. It is the amount or quantity of material or goods that is carried or moved by a given force
Load arm	length of a lever from the fulcrum to the point of action of the load
Magnet	a material, often a piece of metal, that has the tendency of attracting some materials such as iron and steel to itself
Magnetic compass	a device used for determining the direction of a magnetic field
Magnetic dipole	tiny subatomic magnet, equivalent to a flow of electric charge around a loop
Magnetic domain	a region within a magnetic material in which the magnetisation is in a uniform direction
Magnetic field	region around a magnet in which magnetic materials are affected by the magnet. It is represented by lines of action of magnetic

	force
Magnetic lines of force	imaginary lines of action of magnetic force that run from the north pole to the south pole of a magnet and through a magnet to form closed loops
Magnetic meridian	a vertical plane in which the magnet comes to rest with its axis lying in the magnetic north-south direction
Magnetic poles	two ends of a magnet or magnetised body where the lines of force are most concentrated. The strength of a magnet is strongest at the poles
Magnetic shielding	process of limiting the passage of magnetic field lines through a region by diverging them
Magnetisation	process of aligning the dipoles in a material so as to produce a net effect of attraction or repulsion. It is the process of making magnets
Magnetism	a physical phenomenon arising from the force caused by magnets
Maximum and minimum thermometer	a themometer specially designed to measure the highest and lowest temperatures attained in a day and in a particular period of time. It has steel indices that act as indicators for the temperature value
Mechanical advantage (MA)	measure of the benefit provided by a machine in reducing the effort required to perform certain amount of work
Moment of force	measure of the tendency of a force to cause rotation of a body
Motion	continuous movement that involves a change in position relative to a reference point
Net force	this is a resultant force obtained by summing up all the individual forces acting on a body in a given direction
Neutral equilibrium	a state of balance in which a body remains in its position until displaced
Neutral point	point where the net magnetic field is zero. Has no magnetic force

Normal force	force exerted perpendicularly upon an object as a result of being in contact with another stable object
Ohm's law	relationship between voltage across the ends of a conductor and the current flowing through it when the physical conditions of the conductor are constant
Paramagnetic	materials that can be temporarily magnetised. Examples are aluminium and chromium
Permanent magnet	a magnetised material which retains its magnetism for a very long period of time
Pivot	a fixed point supporting a body which turns or balance; a point about which a body rotates
Potential energy	the energy stored in an object due to its position. It is measured in joules (J)
Proof plane	a metal disc with an insulated handle with its disc smaller than that of an electrophorus. It is normally used for transferring small amounts of charge from one body to another
Pulley	a simple machine which consists of a wheel with a groove that rotates round a point called an axle and is used for changing the direction of an applied force so as to realise a mechanical advantage
Resistance	the opposition that a circuit component or substance offers to the flow of electric current
Resistor	an electric component specially designed to offer resistance and is used to control the flow of electric current, for example, a rheostat
Rheostat	a resistor designed to provide variable resistance without breaking the electric circuit of which it is a part

Rotational motion	the motion of a rigid body whereby each particle of the body moves in a circle, and the centre of all circles are on a straight line called axis of rotation
Screw	a form of an inclined plane in which the plane is wrapped around a rod
Screw jack	an example of a lifting screw that is used for lifting heavy objects like a car when changing tyres
Sea wave energy	energy obtained from sea waves. These waves are caused by wind blowing on the surface of sea water
Single touch	a method of making a magnet (magnetisation). Also known as stroking method
Six's thermometer	a maximum and minimum thermometer
Solar energy	energy carried by electromagnetic waves from the sun. It mainly involves the visible light and heat
Solenoid	an electrical device consisting of a coil of wire of several turns along which a magnetic field is formed when an electric current is passed through it
Speed	the rate of change of distance
Static electricity	the accumulation of excess electric charge in a region
Static equilibrium	a condition whereby all forces acting on a body balances such that the body is stationary
Steam point	the fixed upper point of a thermometer with a temperature mark of 100°C
Sustainable energy sources	natural resources that may be used in the production of electricity and they can be replenished

Switch	a device that is used for breaking or closing an electric circuit. It can be electrical or mechanical. For example, a switch used to turn lights on or off
Temperature	degree of hotness or coldness of a substance which is measured using a thermometer
Temporary magnet	a material which loses its magnetic property shortly after the magnetising field is removed
Thermometer	any instrument for measuring temperature; for example a liquid-in-glass thermometer has a glass tube that is graduated and a bulb often containing mercury or alcohol
Thermometric property	physical property of a material that changes with temperature such as length, volume, pressure, resistance and capacistance
Thunder	a booming sound often heard after lightning. It is caused by the rapid expansion of air that has been heated by lightning
Tidal energy	energy obtained due to change in ocean water level produced by tides. Tides produce heaps of water that move around the sea/ ocean
Turning force	a force that causes an object to rotate or turn about a fixed point
Uniform velocity	occurs when a body's rate of change of displacement is constant
Unstable equilibrium	a state of equilibrium of which a small disturbance will produce a large change
Velocity	the rate of change of distance moved in a specified direction, that is, the rate of change of displacement
Velocity Ratio (VR)	ratio of the distance moved by the effort to the distance moved by the load

Voltage	potential energy given to each coulomb of charge pushed out
Voltmeter	an instrument that measures potential difference between two points in a circuit. It is calibrated in volts (V)
Wheel and axle	a simple machine that consists of two connected rings or cylinders, one inside the other, such that they both turn in the same direction around a common axis
Wind energy	energy carried by the wind in form of kinetic energy (KE)

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