O' Level

Physics

Integrated With Technology

LEARNER'S BOOK

NCDC
NATIONAL CURRICULUM DEVELOPMENT CENTRE

FOR GOD AND MY COUNTRY
THE REPUBLIC OF UGANDA
Ministry of Education and Sports

O' Level Physics

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Preface

The major reason for undertaking this new approach to teaching-learning Sciences and Mathematics at O level is to improve the academic achievements and interest of learners.

The idea of integrating Technology into Sciences and Mathematics at lower secondary education was conceived after realising that Science and Mathematics teaching at this level hardly generated interest in the learners. In addition, these learners were lacking in practical skills and rarely applied Science and Mathematics to everyday life situations.

The National Curriculum Development Centre (NCDC) has developed this new approach of teaching Science and Mathematics by including practical activities that enable learners to come up with products or be able to offer services to the community leading to national sustainable development by generating their own income.

Acknowledgment

This book was developed and prepared in a series of writing and discussion workshops organised by the National Curriculum Development (NCDC) between 2007 and 2011.

I wish to acknowledge the contribution of the subject panel members, teachers and learners from various schools who participated at trial activity phase and other education stakeholders that provided input and direction of this material.

I am grateful to all those who worked behind the scenes for the commitment in ensuring the work is done and feedback from the field is incorporated.
I also thank the African Development Bank (ADB) Project Phase-III for the financial support.

Last but not least, I wish to recognise agencies, companies and websites for the reference materials and pictures used in this book.

Connie Kateeba
Director
National Curriculum Development Centre (NCDC)

Introduction

This book has been written to help you to develop interest in Physics. The concepts, ideas and activities included are related to real life situations. As you go through the book, you will come across several interesting activities which will make learning Science more rewarding and fulfilling.

Throughout the book, an effort has been made to integrate technology into Physics. This means that activities which will enable you to produce products that are useful to you and the community have been included in the book. It is a very hands-on intended to enable you develop new skills and a new way of appreciating and practising Science.

How to use this book

Under every topic, there are three sections, namely: what you need; what to do; and learning points.

a) **What you need**: This is a list of materials and equipment you will need in order to carry out any activity. The list consists of ordinary objects and materials found in your immediate environment.

b) **What to do:** This is the procedure you will follow, step-by-step, in order to achieve the objectives of the activity. In some of the activities you will work alone, while in others you will work in groups or with your teacher. There are a few activities you will need assistance by a craftsman or other people in your community who are experienced in one or more aspects concerning the activity. In some activities, hints and precautions have been provided to enable you to accomplish it successfully. Some activities are normal laboratory experiments while others will require more time than is normally allocated to classroom / laboratory lessons.

For the latter, you will have to plan how to accomplish them outside class time. There are follow-up activities (additional activities) that you are required to carry out in addition to the main activity.

c) **Learning points:** This is the theory behind the activities you will be carrying out in the relevant topics**.** The theory has been written in simple language to enable you to understand it easily**.** As well the content has been accompanied with relevant pictures or diagrams which will enable you to understand the concepts clearly. Note that theory has only been provided on topics where activities in the book have been derived.

Chapter 1: Matter

Matter consists of things (materials) in our environment that we touch, see, feel, smell and taste. They are the things around us. Some of these things have shapes, others do not and can be moved from one place to another while others have no shapes and cannot even be moved. The shapes of some of these things can be changed. What are they?

In this chapter, you will learn about these 'things' and their properties.

Activity 1.1: Grouping things in our environment

What you need

Different types of 'things' which are found in the environment

What to do

- Collect as many different 'things' as possible from the nearby environment.

Answer the following questions:

1. What is common to all the different 'things' you have been working with above?
2. Name some 'things' in the environment which you can see or experience that
   (i) can move from one place to another,
   (ii) have shape.
   (iii) have no shape

Activity 1.2a: Investigating the effect of heat on matter

What you need

- Ice block

- A sauce pan or beaker
- Source of heat

What to do
- Put some ice blocks in a sauce pan or beaker.
- Heat the saucepan or beaker until all the ice has turned into water (liquid).
- Continue heating until the water boils.
- Record what happens as the ice is heated.
- Write down the physical characteristics of each of the three 'states of water'.

Activity 1.2b: Making ice

What you need
- Clean water in a pail (plastic or metallic).
- A refrigerator.
- Metallic or plastic containers (e.g. plastic cups or bottle tops).

What to do
- Fill each of the containers with clean water.
- Place the containers in the freezing compartment of a refrigerator.
- Open the refrigerator after every 15 minutes for a period of six hours. Observe what gradually happens to the water.
- When all the water has frozen, remove the ice from the containers.

Congratulations, you have made ice so easily.
What economic activity would you do with ice you have made?

Activity 1.2c: Making candles

What you need
- Candle wax,
- Thick thread, e.g. the type used in knitting,

- Cylindrical moulds of different sizes,
- Metal pan,
- A source of heat e.g. stove or bunsen burner.

What to do

- Cut the pieces of thread of the size slightly longer than the length of each mould.
- Warm the wax gently in the pan until it has all liquefied.
- Hold the thread vertically along the axis of the mould.
- Carefully pour molten wax into each of the moulds up to one centimetre below the brim.
- Leave the setting undisturbed until when all the wax has solidified.
- Repeat the procedure for each of the remaining moulds.
- Mention the characteristics of candle wax that make it suitable for moulding.

Activity 1.3: Demonstrating the existence of tiny particles in liquids

What you need

- Beaker,
- Water,
- Copper sulphate crystals,
- A straw or a narrow glass tube.

What to do

- Pour a half-full beaker of water.
- Using a straw or narrow glass tube, drop a crystal of copper sulphate to the bottom of the water.
- Place the set up in a corner of the laboratory.
- Leave the set-up undisturbed for one or two days.

Precaution

Hold the mouth of the straw/glass tube tightly while removing it from the beaker to avoid the spreading of copper sulphate in the water.

Observation

- Write down what you observe on the first and second day..
- What is your conclusion?

Activity 1.4: Brownian motion (Observing the movement of tiny particles in air)

What you need

- A dusty room with doors and windows,
- A rag.

What to do

- When you are in the room, close all the doors and windows so that it is dark inside the room.
- Open one of the windows a little so that a streak of sunlight enters the room.
- Raise a gentle cloud of dust using a rag and observe the movement of the dust particles

Conclusion

By considering the movement of the dust particles in the air, what is your conclusion about the state of air?

Activity 1.5: Making crystals

What you need

- Sugar
- Salt
- Copper sulphate crystals
- Magnifying glass
- Three beakers
- Thread

What to do

- Using a magnifying glass, examine the shapes of grits of each of the substances you have been given.
- Draw the shapes of the grits. What is your conclusion?
- Half fill a beaker with warm water.
- Dissolve sugar in the warm water until you cannot dissolve any more.
- Carefully pour the saturated sugar solution into an empty beaker making sure to leave the un-dissolved sugar in the original beaker.
- Tie a grit of sugar at the end of a thread and lower it in the saturated solution. Make sure the grit is in the middle of the beaker.
- Repeat the procedure above for common salt and copper sulphate.
- Leave the respective grits hanging in their saturated solutions in an undisturbed place for a week
- What happens to the grits as days go by?

Learning Points

All matter is made up of tiny particles. These are either molecules or atoms. In solids, the particles are very closely bound, while in liquids, the particles are more loosely bound. In gases, the forces between the particles are very weak and the particles are very far apart. When a solid is heated, the forces between particles become very weak. In such a state, the particles become free to move about. We say the solid has melted.

When a liquid is heated further, the forces become weakened further until the liquid evaporates. This is when the particles escape into the space above the liquid. This process is called evaporation.

In a solid the particles are very close together and are vibrating about their mean positions. The extent of vibrations increases with increasing temperature. Particles in solids have fixed neighbours. Thus a solid must have a fixed shape.

In liquids, the particles are moving about randomly colliding with each other. Their speeds increase with temperature. They keep on exchanging neighbours. A liquid has a fixed volume but the shape is not fixed.

In gases, the particles are flying about in the container and exchanging neighbours. The distance between the particles is bigger than in solids and liquids.

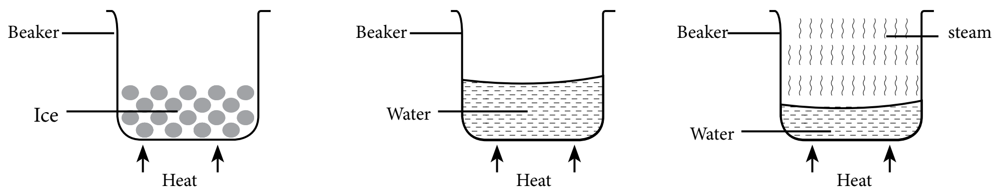


Figure 1.1

Follow-up activity

Design and carry out an experiment to obtain pure sugar crystals from sugar which has been contaminated with soil dust.

Chapter 2: Mechanics

Figure 2.1

In this chapter, you will learn about the behaviour of matter when it is in contact with matter.

Measurements

Introduction

How long, how short or how heavy! These are very important questions in our everyday life. To answer such questions, it is necessary to use a measuring instrument with a scale. In order to measure, we need to know the quantity to be measured and the unit for measuring it. A measured quantity must have a value (a number) and a unit.

Activity 2.1: Identifying and naming measuring instruments

What you need

- Metre rule
- Measuring cylinders

- Stop-clock or stop watch
- Protractor
- Scale balance
- Burette
- Pipette
- Thermometer
- Any other measuring instruments

What to do

Some of the instruments above are used to measure length, volume or mass while others measure angles or time. Classify them by filling in Table 2.1 below:

Length	Volume	Mass	Temperature	Time	Angle

Table 2.1

Activity 2.2: Measuring lengths of objects using a metre rule or tape measure

What you need

- Metre rule
- Tape measure
- Desk
- Different objects

What to do

- Measure the lengths of different objects in your classroom.
- Record your readings to one decimal place in centimetres.
- Compare your results with those of your classmates.
- Using results obtained by 9 members of your class including your own, calculate the average dimensions of 10 desks in your class.

Activity 2.3: Making a metre rule

What you need

- A long strip of wood/timbre
- Jack plane
- Saw
- Marking pens

What to do

- Cut the timber to dimensions of 100.0 cm by 5.0 cm by 0.5 cm and make it smooth.
- Using a standard ruler, calibrate (mark) the smoothened timber using a marking pen.

Learning Points

Length is the distance between two points. There are several instruments used for measuring length. The type of instrument to be used is determined by the size of the distance to be measured. You have met some of them in the activities above.

The International System (SI) unit for length is the metre (m).

Follow-up activities

- Measure the height, width and length of a building brick.
- Measure the length and width of your classroom.
- Dresses, trousers, shirts and shoes are usually marked in their sizes. Find out the sizes of members of your class.
- Using a tape measure or string, draw a design of the school compound.

Area

Activity 2. 4: Determining the cross-section area of a tin

What you need

- Tins of different diameters
- A metre-rule

What to do:

- Measure and record the diameter, d, of a tin.
- Calculate radius, *r,* from $r = \frac{d}{2}$ Calculate the area of cross-section of the tin using the formula, A = π r^2.
  (Use π = 3.14)

Learning Points

Area is a measure of the extent of a surface. This may be in form of a geometrical shape like a square, rectangle, triangle, circle or rhombus. We may sometimes be interested in the area of land, water bodies or a floor. The common units used are cm^2, m^2, acres, hectares and square kilometres. The SI unit for area is square metre (m^2).

Follow-up activities

a) Measuring the surface area of a cylinder
   - Fold a rectangular piece of paper of length, L = 29.6 cm and width, W = 21.0 cm and make a cylinder as shown in the diagram below so that the side of 21.0 cm becomes the circular end.

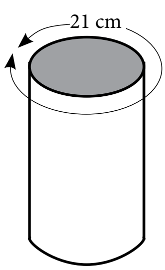


Figure 2.2

- Measure the diameter, D, of the circular end and calculate its radius, r..
- Calculate the circumference of the circular end.
- Calculate the surface area, A, of the cylinder.
- Calculate the constant, k, from the expression L x W = 2krL
- Compare your result with those of your classmates.

a) Devise a way of measuring the area of an irregular piece of land.

Volume

Activity 2.5: Measuring the volume of a rectangular wooden block

What you need

- Rectangular wooden block
- Metre-rule

What to do

- Measure and record length L, width W, and the height H, of the wooden block.
- Calculate the volume of the block from the formula, V = L x W x H

Activity 2.6: Making a suitcase

In this activity, you will make a wooden box suitable for students to carry their belongings to school.

What you need

- Saw
- Hammer
- Nails of different sizes
- Pieces of wood
- Sand paper
- 2 small hinges
- Jack plane
- Metre rule

- Pencil or pen
- Screws and screw driver

What to do

- Smoothen the pieces of wood.
- Decide on the dimensions of the box you want to make.
- Draw a diagram of the box you want to make.
- Cut the pieces of wood to the dimensions in your diagram.
- Join the pieces of wood using the nails to make a box with a cover.
- Make decorations of your choice on the box.

Note: You will need the advice of a carpenter.

Activity 2.7: Measuring the volume of a liquid

What you need

- Water
- Measuring cylinder
- Syringe
- Burette
- Pipette
-

What to do

- Using a measuring cylinder, measure the following volumes:
  1. $15cm^3$
  2. $30cm^3$
  3. $47cm^3$
  4. $60cm^3$
  5. $65cm^3$
  6. $100cm^3$
- Practise measuring different volumes using a burette, pipette and measuring cylinder.

- Describe how you would measure the volume of water which fills a tank at school.

Activity 2.8: Measuring the volume of an irregular sinking object

What you need

- Objects which sink in water
- Thread
- Measuring cylinder
- Water
- Displacement (eureka) can

What to do

- Pour some water into the measuring cylinder up to the volume, $V_{1,}$ mark.
- Tie the object on a thread and lower it into the water.
- Record the new volume V_2 of the water.

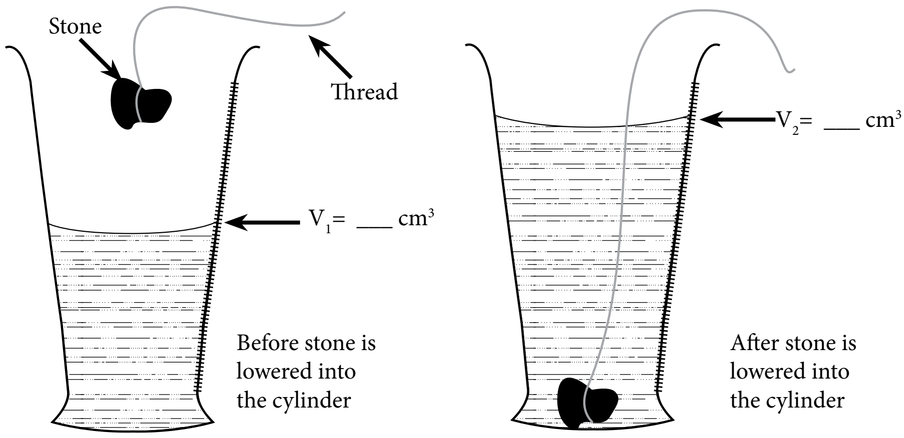


Figure 2.3

- Pour some water into an eureka can up to the brim.
- Lower the object into the water.
- Collect the water which has been displaced as seen in figure 2.3.
- Find the volume, V, of the object from $V= V_2 – V_1$

Learning Points

Volume is the space occupied by matter. The matter may be solid, liquid or gas. For a regular solid, volume is obtained by measuring its dimensions and calculating the volume using a formula.

For irregular objects, the volume of the liquid displaced is equal to the volume of the object.

When a liquid is poured into a container, it forms a curvature on the surface called a meniscus. Liquids such as water form a concave meniscus while mercury forms a convex meniscus. It is always advisable to read the lower part of a concave meniscus and the upper part of the convex meniscus.

The SI unit of volume is m^3. Other common units include cm^3, mm^3, ml and l.

Follow-up activities

- Devise ways of accurately measuring the volume of sand or sugar.
- Milk vendors normally use a mug to measure out the milk. What is the volume of a mug? Which one is more accurate, using a mug or a measuring cylinder? What are the advantages and disadvantages of using a mug to measure out milk?
- Measure the dimensions of the building bricks in your school. What instructions would you give to a carpenter to make a mould for the bricks in your school?
- Estimate the volume of air in your classroom.

Mass

All the instruments below are used for weighing. Can you name them?

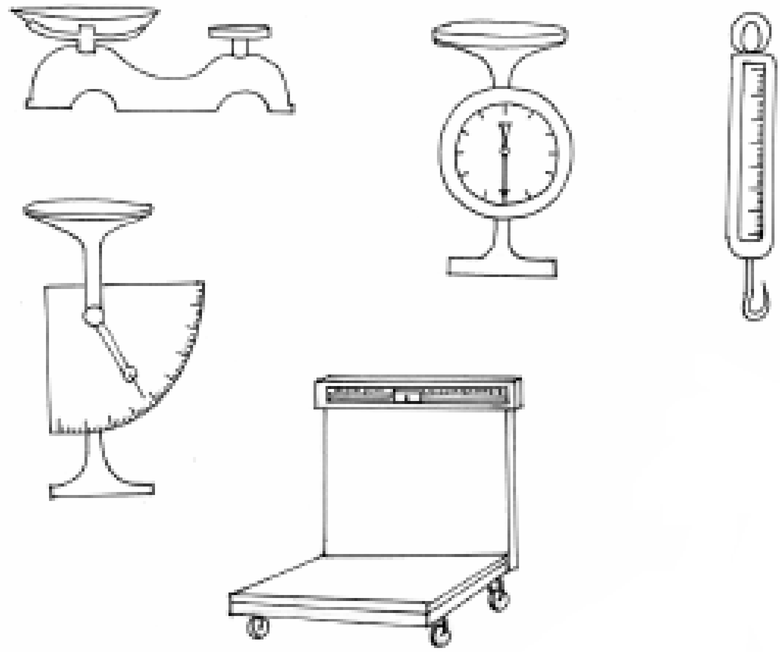


Figure 2.4

Activity 2.9: Measuring mass

What you need

Different types of weighing balances

What to do

- Practise using weighing balances by weighing different objects in your classroom.
- Weigh yourself and other members of your class.
- Calculate the average mass of students in your class.

Precaution

- Before using the balance, ensure the pointer is on the zero mark. Use the zero adjuster to bring back the pointer to the zero mark.
- After placing the object on the balance, wait for the pointer to settle down before you take the reading.

Learning Points

The heavy punching bag normally used by boxers in training is difficult to stop once it is moving and it is also difficult to start it moving. Inertia is a body's tendency to resist change of its state of motion. Mass of a body is a measure of its inertia. A body with a big mass is difficult to stop once it is moving and it is also difficult to make it move when it is stationary. The SI unit for mass is the kilogram (kg). Other common units for measuring mass include grams (g), milligrams (mg) and tonnes. One metric tonne is 1,000 kg.
Mass is a scalar quantity and does not depend on the location where the object is weighed.

Activity 2.10: Making bricks

Buildings are usually constructed using bricks. These may be made of clay, mud or concrete. The decision on which type and size of bricks to use depends on many factors. These include cost, availability of materials, weight and texture. In the following activity, you will make bricks that are used most in your locality.

What you need

- Saw
- Hammer
- Nails of different sizes
- Pieces of wood
- Sand paper
- Jack plane
- Metre rule
- Pencil or pen

What to do

- Accurately draw the mould you want to make, clearly indicating all its dimensions.
- Cut the pieces of wood to the dimensions of the mould you want to make.
- Join the pieces of wood.
- Use your mould to make bricks (you can use clay or mud).
- Cover your bricks properly and let them dry slowly in the sun.
- Find the average mass of the bricks.

Hint: Consult the local brick makers for advice on how to make strong bricks. The dimensions of the bricks will determine how heavy the bricks will be.

Follow-up activity

Estimate the masses of different objects in your classroom, and then weigh them.

Time

Activity 2.11: Timing activities

What you need

Stop watch or clock

What to do

- Time yourself while you do the following activities:
  - walking across the classroom
  - running across the field
  - walking to the staffroom
- Compare your time with the rest of the classmates.
- Calculate the average time to carry out these activities.

Activity 2.12: Timing oscillations

What you need

- Stop clock or watch
- A piece of thread about 110 cm long
- Metal bob with a hook or a stone
- Retort stand and clamp

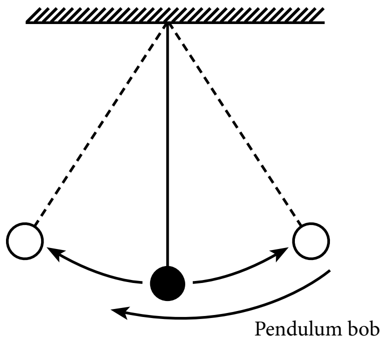


Figure 2.5

What to do

- Fix the pendulum on a fixed support e.g. on a clamp in such a way that the length, l, of the pendulum (i.e. the distance from the point of support to the centre of the bob) is 100.0 cm.
- Displace the bob slightly and release it so that it swings freely.
- Time 20 complete oscillations (an oscillation is a complete to and fro movement).
- Calculate the time,T, for one oscillation (period), T.
- Repeat the procedure for l = 90.0; 80.0; 70.0; 60.0; 50.0; 40.0 cm.
- Fill your results in the table below:

l (cm)	Time for twenty oscillations (s)	Period T (s)
100.0		
90.0		
80.0		
70.0		
60.0		
50.0		
40.0		
30.0		

Table 2.2

Learning Points

What is the time now? How much time does it take to complete a task? We always need to know the time of the day and how long it takes to carry out certain tasks. The SI unit for time is the second (s). Other units for time include hours (h), microseconds (μs) and milliseconds (ms)

Follow-up activities

a) Water clock
- Make a water clock by punching a small hole at the bottom of a can. Fill it with water and let it drip into a measuring cylinder. Mark the water level on the cylinder every 5 minutes for 20 minutes. Graduate your cylinder at these intervals and predict where the level would be in 20 minutes.
- Compare your 'clock' with the laboratory clock.
- What are the challenges you are likely to meet with this type of clock?

b) Cockcrow

Some communities use a cockcrow to estimate time. At home, record the time of the first cockcrow in the morning. Compare your results with your classmates'. Discuss with your classmates whether 'cockcrow' is a reliable 'clock'.

Conversion of Units

Activity 2.13: Converting SI units into other units

What to do

Carry out the following conversions:

a) **Length**

i) 3 km = ... m

ii) 1.5 m = ...cm

iii) 45 cm = ... m

iv) 739 mm = ... km

b) **Area**

Area is measured in square units (e.g. cm^2, m^2, km^2)

$1\ m^2 = 10000\ cm^2$

Therefore, $1 cm^2 = 10^{-4}\ m^2$

If the area of a room is $6.5 m^2$, what is it in cm^2?

c) **Volume**

Volume is measured in cubic units (e.g. cm^3, m^3, km^3)

$1{,}000{,}000\ cm^3 = 1\ m^3$

Therefore, $1\ cm^3 = 10^{-6}\ m^3$

Try out the following:

i) The volume of a box is $720\ cm^3$. Express this in m^3.

ii) A rectangular box has dimensions 15 cm, 8 cm and 5 cm.

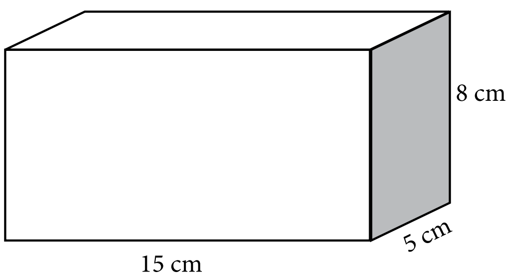


Figure 2.6

What is its volume

i) cm^3

ii) mm^3

iii) m^3?

Learning Points

Basic quantities

Scientists worldwide agreed to adopt a unified system called the International System of Measurement (SI) unit to be used in the basic measurements of length, mass and time as shown in the table below.

Basic Quantity	SI unit	Symbol
Length, l	Metre	m
Mass, m	Kilogram	kg
Time, t	Second	s
Electric current	Ampere	A
Thermodynamic (Absolute) temperature	Kelvin	K
Amount of substance	Mole	Mol

Table 2.4

You may find the following prefixes handy when dealing with smaller or bigger quantities:

mega-	1,000,000	10^6
kilo-	1,000	10^3
centi-	0.01	10^{-2}
milli-	0.001	10^{-3}
micro-	0.000 001	10^{-6}

Significant figures and standard form

A trader quoted the price of an item in her shop as Uganda Shillings 5,430,635. This figure is said to have been quoted to 7 significant figures. The number 7 is obtained by counting the digits from the extreme left to the right. The same number quoted in standard form is $5.430\ 635 \times 10^6$. The table below shows how the price can be quoted to different numbers of significant figures.

Number of significant figures	Price quoted in a given number of significant figures	Price in standard form
7	5,430,635	5.430635×10^6
6	5,430,640	5.43064×10^6
5	5,430,600	5.4306×10^6
4	5,431,000	5.431×10^6
3	5,430,000	5.43×10^6
2	5,400,000	5.4×10^6
1	5,000,000	5×10^6

Table 2.5

For a number less than one, the number of significant figures is counted from the decimal point to the right beginning with the first non zero digit. The table below shows the number 0.056,029,34 quoted to different numbers of significant figures.

Number of significant figures	Number quoted in significant figures	Number quoted in standard form
7	0.056 029 34	5.602934×10^{-2}
6	0.056 029 3	5.60293×10^{-2}
5	0.056 029	5.6029×10^{-2}
4	0.056 03	5.603×10^{-2}
3	0.056 0	5.60×10^{-2}
2	0.056	5.6×10^{-2}
1	0.06	6×10^{-2}

Table 2.6

Relationship between mass and volume

Activity 2.14: Discovering the relationship between mass and volume of an object

What you need

- Rectangular wooden blocks (labelled A, B, C and D) of the same type of wood
- Metre rule
- Weighing scale

What to do

- Measure and record the length, l, width, w, and height, h, of block A.
- Weigh block A.
- Fill your results in the table below.
- Repeat the procedure for blocks B,C and D

Block	Length l (cm)	Width w(cm)	Height h (cm)	Volume V (cm^3)	Mass m (g)	m x V (g cm^3)	$\frac{m}{V}$ (g cm^{-3})	m – V	m+ V
A									
B									
C									
D									

Table 2.7

- From your results, what do you notice?

Activity 2.15: Measuring the densities of different materials

What you need

- Rectangular wooden blocks of different materials
- Metre rule
- Weighing scale

What to do

- Measure and record length, l, width, w, and height, h, of the wooden block.
- Measure and record the mass, m.
- Calculate the volume, V, of the block.
- Calculate the ratio $\rho = \dfrac{mass}{volume}$ for the block.
- Repeat the procedure for the other blocks.

Material	l(cm)	w(cm)	h(cm)	m (g)	V (cm^3)	$\rho = \dfrac{mass}{volume}$ (g cm^{-3})
Wood						
Metal						
Rubber						
Brick (soil)						
Glass						

Table 2.7

Learning Points

Density is the ratio of mass to volume of an object,

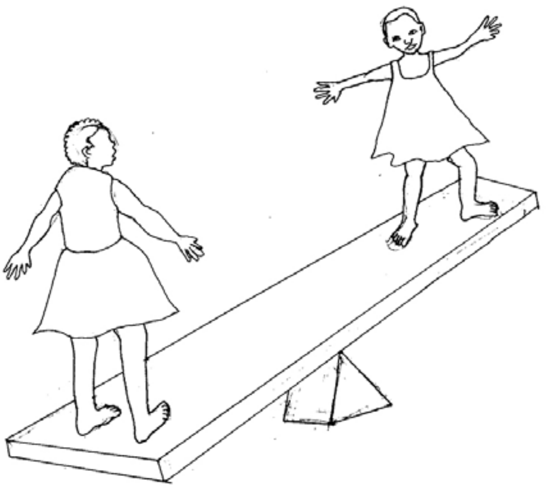
i.e. density, $\rho = \dfrac{mass}{volume} \left(\dfrac{kg}{m^3}\right)$. It is a measure of the compactness of the matter in the material. The SI unit of density is kg m^{-3}.

Follow-up activities

- Measure the density of irregular objects you can come across in the school compound.

- Devise an activity to measure the density of sugar or maize flour or foam mattress.
- Wood floats on water. Make a toy out of a piece of wood and make it to float on water.
- Describe, by giving examples, how knowledge of density may be useful in daily life.

Turning Effects of Forces



Activity 2.16: Making a see-saw

What you need

- Y- Shaped branch from a tree of diameter of about 10cm
- A straight pole of diameter about 10 cm and length about 6 m
- A 15 cm nail
- A hammer

What to do

- Dig a hole of diameter 15 cm and 50 cm deep.
- Place the Y-shaped branch with the two branches about 50 cm from the ground level.

- Add soil into the hole and compact to get the Y-shaped branch firmly into the ground.
- Balance the pole into the Y-shaped branch by adjusting so that the length on each side is almost the same and the pole balances.
- Use the 15 cm nail to fix the pole on the Y-shaped branch so that the end of the pole is free to turn about the nail.

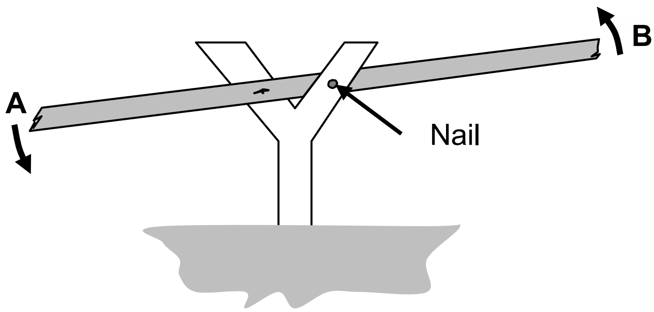


Figure 2.7

If a boy of weight 500 N sits 2 m from the pivot, find out how far another boy weighing 400 N should sit in order for the beam to balance.

Precaution

Ensure the pole can withstand the weights of those who sit on it.

Activity 2.17: Determining the centre of gravity of a uniform lamina

What you need

- Lamina of uniform thickness
- Bob with hook (or a stone) or plumbline
- Thread
- Round nail
- Clamp and stand

What to do

- Clamp a nail horizontally.
- Make several holes in the lamina.
- Hang the lamina on the nail through one of the holes. The lamina should be able to rotate freely on the nail.
- Hang the plumbline on the nail.
- Draw a line where the thread has passed.
- Repeat the procedure using the other holes.

Where all the lines meet is the centre of gravity.

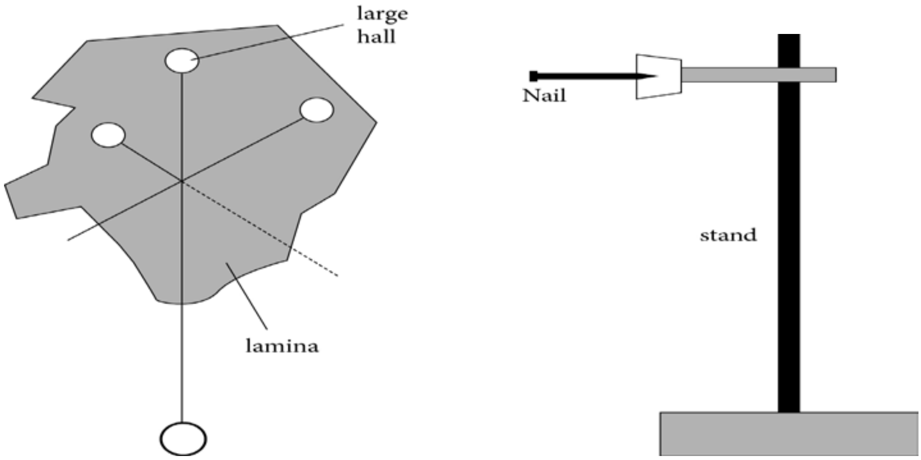


Figure 2.8

Activity 2.18: Measuring the weight of a wooden rod

What you need

- Metre rule
- Knife edge
- String
- A 500 gram mass
- A wooden rod (about 1.5 m long and not very heavy).

What to do

- Using a knife edge, determine and mark the centre of gravity of the rod.
- Tie a 500 g mass about 20 cm from the end and balance the rod on the knife edge.

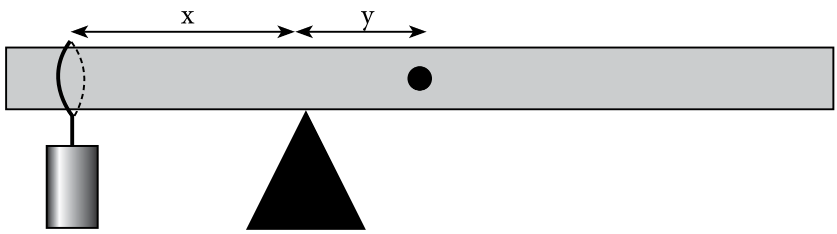


Figure 2.9

- Measure the distance, x, from the mass to the knife edge and the distance, y, from the knife edge to the centre of gravity.
- Calculate the mass of the rod using the equation $0.5x = my$, where m is the mass of the rod.

Learning Points

When a force is applied to open or close a door, it exerts a turning effect to the door. The door turns at the hinge. Such effects of forces are often experienced in daily use.

Moment (or turning effect) of force is the product of the force applied with its perpendicular distance from a turning point.
The turning point is called the pivot or fulcrum.

Moment of force is a vector quantity and its unit is Nm.

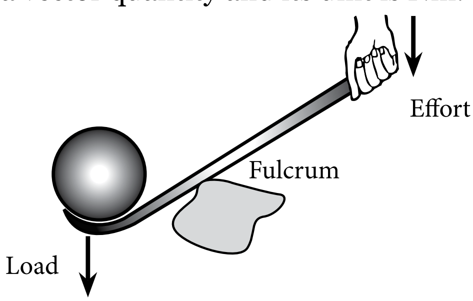


Figure 2.10

Principle of Moments

When a system is in equilibrium under the action of a number of forces, the algebraic sum of the clockwise moments about a point is equal to the algebraic sum of the anticlockwise moments about the same point.

Centre of gravity

A ruler may be considered to consist of many small particles. Each of the particles has its own weight. If the ruler is pivoted at any point, the weight of each particle exerts a turning effect (moment).
When the ruler is pivoted at its centre of gravity, the sum of the clockwise moments is equal to the sum of the anticlockwise moments. If the weight of the ruler was concentrated at the centre of gravity i.e. when all the particles were placed at the centre of gravity, the ruler would stay in equilibrium.

Centre of gravity is the point through which the total weight of a body acts.

Centre of gravity may be on the object or in space near the object. Where would you expect the centre of gravity of a ring to be?

Follow-up activities

- Design and carry out an activity to determine the centre of gravity of a bicycle rim.
- Suppose you were a potter. What factors would you consider in order to make a stable pot?

Machines

Activity 2.19: Making a cart

What you need

- Two wooden rods of diameter 8 cm and length 2 m
- Four pieces of timber of length 40 cm each
- Ten nails each of 10 cm long
- A hammer
- Machete
- A circular metal rod of diameter 3 cm and length 30 cm

What to do

- Place the two rods at a small angle to each other as Figure 2.11.
- Construct the frame of the cart (see Figure 2.11).
- Make a circular wheel with a circular hole in the middle from the wood.
- Push the rod through the wheel.
- Fix the wheel at one end of the rods.

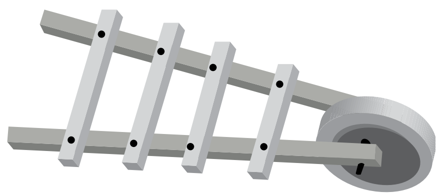


Figure 2.11

- The load can be placed near the wheel, in the middle or near the handle. Find out the most convenient place for the load and explain why the position you have mentioned is the most convenient.
- Compare a commercial cart with the one you have made.

Activity 2.20: Investigating the variation of efficiency of a pulley system

What you need

- 2 pulleys
- Strong light inelastic string
- Stand and clamp
- Masses and pan
- Spring balance or sand in a bag

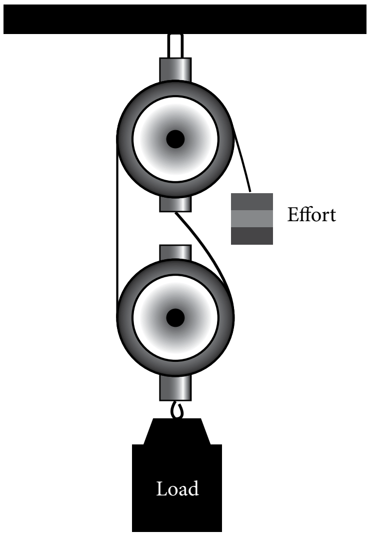


Figure 2.12

What to do

- Assemble the apparatus as shown in figure 2.12.
- Add different loads on the scale pan until the system just begins to move.
- Record the mass required for the system to move.
- Repeat the procedure for different masses.
- Tabulate your results in the table below:

Load mass (kg)	Effort mass (kg)

Table 2.8

- Plot a graph of load mass against load effort mass.
- Discuss the shape of your graph with your classmates.

Activity 2.21: Determining the velocity ratio of different machines

What you need

- Screw and screw driver
- Wedge
- Wheel and axle (or circular rod with sections of different diameters)
- String
- Suitable supports
- Inelastic string
- A metre rule

What to do

- Design and carry out experiments to determine the velocity ratio of each of the machines above.

Activity 2.22: Identifying the different simple machines on a bicycle

What you need

- A bicycle

What to do

- Examine the bicycle and identify all the simple machines on it.
- Identify parts of the bicycle where opposition to motion (friction) occurs and mention how it has been decreased.
- Identify other provisions on the bicycle that are designed to make it more efficient.
- What features on the bicycle are designed to increase friction?

Figure 2.13

Activity 2.23: Making gears

What you need

- Jack plane
- Saw
- Nails
- A log

What to do

- Make three circular wheels of different diameters.
- Drill a hole at the centre of each wheel.
- Saw teeth on each of the wheels.
- Fix three wheels on a board with nails in such a way that the teeth interlock.
- Drive the wheel at the extreme end and note the speed of the wheel at the other end.

Activity 2.24: Making charcoal/sugar tongs

What you need

- Hoop iron roll
- Metal cutter
- Pliers

What to do

- Cut about 30 cm of a piece of iron bar from a hoop iron roll.
- Fold the piece of metal into two halves and curve the ends of the metal piece as shown below:

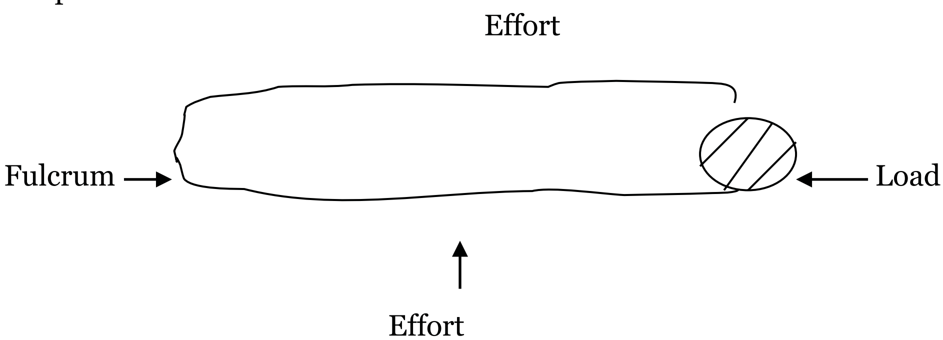


Figure 2.14

- Use the coal tong to remove red hot charcoal from a stove and place it into a charcoal flat iron, and to lift many such items.

Activity 2.25: Making a beam balance

What you need

- Pieces of wood
- Nails
- Hammer
- Jack plane
- String
- 2 plastic plates

A beam balance

Figure 2.15

What to do

- Prepare two wooden rods each of dimensions 5 cm x 5 cm x 50 cm.
- Locate the centre of gravity of one of the rods and drill a large hole at this point.
- Fix the other rod on a wooden horizontal base of dimensions 20 cm x 40 cm to make a stand.
- Make a beam balance as in figure 2.15 above.
- Use a plastic plate as a scale pan at both ends of the horizontal rod.
- Identify the difficulties of using your weighing balance.

Precaution

If the rod does not balance horizontally, you should add a few grains of sand to each of the plates until it balances.

Learning Points

We all, at one time or another, use a machine to do some work. The machine may be as small as a knife or as big as a tractor. A machine is a device which we use to simplify work. Machines do not reduce the amount of work that is to be done but they make it easier to do by making a large load to be overcome by a much smaller force. There are two kinds of machines:

a) **Simple machines**

i) Lever

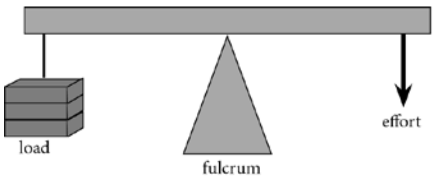
A lever is a rigid bar which can turn about a pivot (fulcrum) when a force (effort) is applied on it to move a load.

Classes of levers

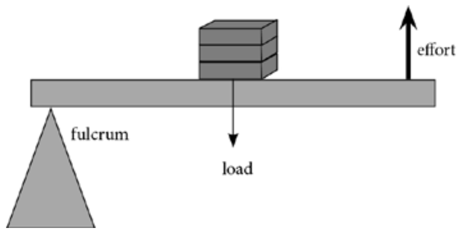
Classification of levers is based on the relative positions of the load, effort and the pivot.

1st class	Pivot is between load and effort
2nd class	Load is between effort and pivot
3rd class	Effort is between load and pivot

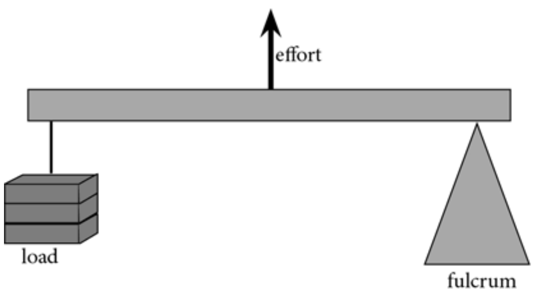
Table 2.9



First class



Second class



Third class

Figure 2.16

Characteristics of a machine

We have seen above that a machine simplifies work. We have also learnt that a machine does not reduce the amount of work to be done.

As we work with machines, the following definitions are useful:

$$\textit{Mechanical advantage (M.A.)} = \frac{load}{effort}$$

$$\textit{Velocity ratio (V.R.)} = \frac{\textit{distance moved by effort}}{\textit{distance moved by load}}$$

$$\textit{Efficiency } (\eta) = \frac{\textit{work output}}{\textit{work input}} \text{ x } 100\%$$

We can investigate the formula for efficiency further:

$$\textit{Efficiency } (\eta) = \frac{\textit{work output}}{\textit{work input}} = \frac{load}{effort} \text{ x } \frac{\textit{distance moved by load}}{\textit{distance moved by effort}} \text{ x } 100\%$$

$$\therefore \textit{Efficiency } (\eta) = M.A. \text{ x } \frac{1}{V.R.} \text{ x } 100\%$$

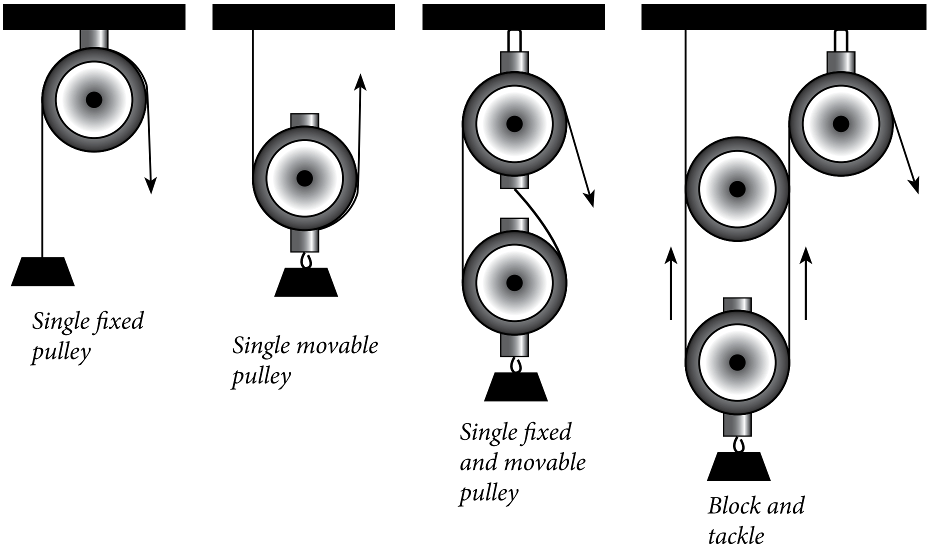
Thus, $\textit{Efficiency } (\eta) = \frac{M.A.}{V.R.} \text{ x } 100\%$

Efficiency of practical machines is always less than 100% because of the following reasons:

- **Friction between moving parts**. Work must be done to overcome this friction. The energy supplied to do the work against friction is just wasted. Friction can be reduced by greasing or making use of ball bearings between the moving parts.

- **Weight of moving parts**. Work must be done to move the parts as the load is moved when the effort is applied. Use of lighter moving parts would improve on the efficiency.

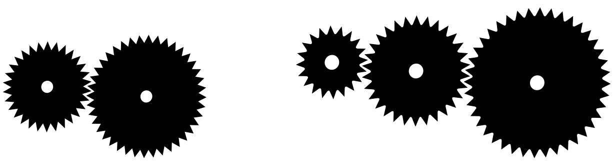
ii) Pulleys



Single fixed pulley, single movable pulley, block and tackle
Figure 2.17

- What is the velocity ratio in each of the pulley systems above?
- Mention some practical applications of pulleys.

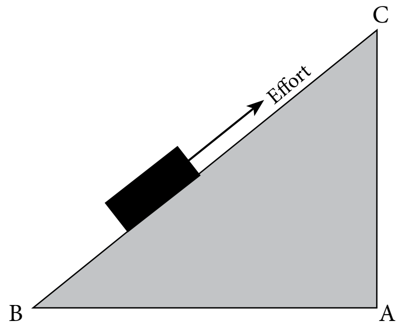
iii) Gears



Gear systems
Figure 2.18

For a gear system, velocity ratio is the ratio of the number of teeth on the effort wheel to the number of teeth on the load wheel.
For a system of gears, the overall velocity ratio is the product of the velocity ratios of the adjacent wheels.

iv) Wedges



A wedge

Figure 2.19

When an effort is applied on the load, the load moves through distance BC when the effort moves through distance AC.

Therefore

$$velocity\ ratio = \frac{distance\ moved\ by\ effort}{distance\ moved\ by\ load} = \frac{AC}{AB}$$

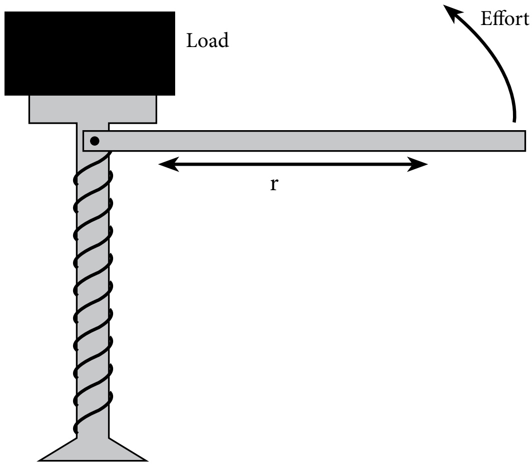
v) Screw jack

When an effort is applied on the handle (effort arm), the screw turns and the load moves up. If the handle turns through one revolution, the load moves up by a distance of one pitch, i.e. a distance between two successive pitches.

Therefore,

$$velocity\ ratio = \frac{distance\ moved\ by\ effort}{distance\ moved\ by\ load} = \frac{circumference\ of\ circle\ made\ by\ effort}{pitch}$$

$$= \frac{2\pi r}{h}$$



A screw jack
Figure 2.20

b) **Compound machines**

When you examine a bicycle, you will be able to identify the different types of machines we have mentioned above. It is a compound machine and is made by putting together different simple machines.

Follow-up activities

- Discuss with your friends the preparations you would make in order to improve the efficiency of your bicycle if you were going to participate in a cycling race.
- Friction produces a lot of heat. Find out the areas where this heat is a problem and those where this heat is useful.

Work, energy and power

Activity 2.26: Discussing the energy changes which occur in various situations

In groups of five, discuss the energy changes which occur during the following activities:

- When rat runs up a wall and on reaching the top, it loses grip and falls.
- When we eat food.
- When we burn firewood.

The secretary of the group should report to the whole class at the end of the discussion.

In all the three activities above, what is the final fate of the energy?

Activity 2.27: Investigating the efficiency of a charcoal stove

What you need

- Charcoal stoves of different designs (metallic and clay)
- Charcoal
- Saucepans of the same size with covers
- Water

What to do

Using the same amount of charcoal and water, design an experiment to test the efficiency of a charcoal stove. You should rate them on the following criteria:

- ease of lighting.
- the time it takes to boil a given amount water.
- the time it takes to burn out a given amount of charcoal.
- the amount of smoke given out by each stove.
- the amount of ash deposited by each of the stoves.

Answer the following questions

1. Name the things that you intentionally kept the same in all the investigations.
2. Which type of stove would you recommend for:

- quick cooking?
- saving on charcoal?

3. Which type of stove is most environmentally friendly?

Activity 2.28: Making a catapult

What you need

- Car tyre tube
- Y- shaped sticks
- Razor blade

What to do

- Cut strips of rubber from a car tyre tube or a bicycle tube.
- Tie the two ends of the rubber strips at the same point on a piece of wood so as to make a loop.
- Resting in a horizontal position, put a pebble in the loop and pull away until the strips stretch to a reasonable distance and release.
- Repeat the procedure for different stretched lengths and each time note the distance travelled by the stone.

There are different types of catapults. Which type is common in your area?

Precaution

Make sure the passage of the pebble is clear without a person or obstacle in its way.

Answer these questions

1. How is the maximum height related to stretch (extension) of the strip?
2. List factors which affect the extension of a strip.
3. What are the most appropriate dimensions of the strip?
4. List down the energy transformations that occur when a stretched catapult is used to project a stone.

Activity 2.29: Discussing the importance of the sun

What to do

- Without the sun all life on earth would cease to exist. Debate this motion with your classmates to find out their views.
- Discuss the importance of conserving the environment.

Learning Points

Physical work involves moving matter from one point to another. When a force acts on matter and causes it to move, work is said to have been done. When we do physical work, we normally apply a force which causes the object to move in the direction of the effort. If the object does not move, no physical work is said to have been done. If you push against an immovable wall all day , you do not do any useful work!

Work is said to be done when an applied force causes a load to move in the direction of the force.

Work = force x distance moved in the direction of the force

The unit of work is the Joule (J)

1 J = 1 N m

Work is a scalar quantity, i.e. it only has magnitude but without direction.

Energy

For a person to do work, he/she needs a supply of energy.

Energy is the ability to do work.

Types of energy

There are many types of energy which we use to do work in our daily operations.

a) **Mechanical energy**

This is the type of energy required to move objects around. There are two types of mechanical energy, namely,

i) **Kinetic energy**

Kinetic energy is the energy possessed by an object by virtue of its motion.

We can consider an object of mass, m, which is originally at rest. A constant force, F, acts on the object for a time, t, until its velocity is v. The distance travelled during this time is s.

Initial velocity is $u = 0$

Final velocity is v

Acceleration is a

Distance is s

Now, using the equations of motion,

Using the 3rd equation of motion $v^2 = u^2 + 2as$, $v^2 = 0 + 2as$

Therefore, $as = \frac{v^2}{2}$.

From $F = m\,a$, we have work $W = F \times s = m\,a\,s$

$$W = m\,\frac{v^2}{2}$$

$$W = \frac{1}{2}mv^2$$

The work done is equal to the energy supplied!

Therefore, kinetic energy, $k.e. = \frac{1}{2}mv^2$

ii) **Potential energy**

Potential energy is the energy possessed by an object by virtue of its position.

If, for example, a fruit falls from a tree, it can do mechanical work, e.g. deforming a tin on which it falls.

Suppose an object of mass, m, is lifted through a height, h, in the earth's gravitational field.

Work done, W = force x distance moved by the force

The force on the object is its weight, mg.

Therefore, $W = mg \times h$

$W = mgh$

The work done in lifting the object is converted into potential energy of the object

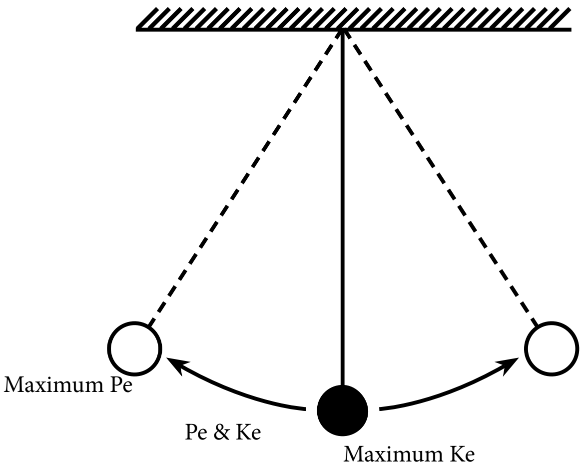
Therefore, potential energy, $p.e. = mgh$

Principle of conservation of energy

Energy can neither be created nor destroyed. It can only be changed from one form to another, i.e. total energy in a closed system is constant.

Examples

1. *Oscillating pendulum*. At the extreme ends, the bob is at rest. It only possesses potential energy. When it is moving back towards the centre of motion, its kinetic energy increases and its potential energy decreases. At the centre of motion, its potential energy is a minimum and its kinetic energy is a maximum. At every instant, however, the total energy (potential energy + kinetic energy) is constant.



Transformation of energy

Figure 2.21

2. *At the hydro electric dam*. At the top of the dam, potential energy is stored in the water. As the water falls, its potential energy decreases while its kinetic energy increases. Some of the energy is converted into electrical energy, sound energy and heat energy. The rest of the energy is maintained as kinetic energy of the water.

Other types of energy

- **Chemical energy**. This type of energy is found in chemicals, e.g. petrol, firewood and acids in a battery.
- **Heat energy.** This type of energy gives us warmth.
- **Light energy.** It enables us to see.
- **Sound energy.** This type of energy enables us to hear.
- **Electrical energy.** Electricity is used in many homes, e.g. for lighting and heating.
- **Nuclear energy.** Many countries are now using nuclear energy to make electricity.

Floating and sinking

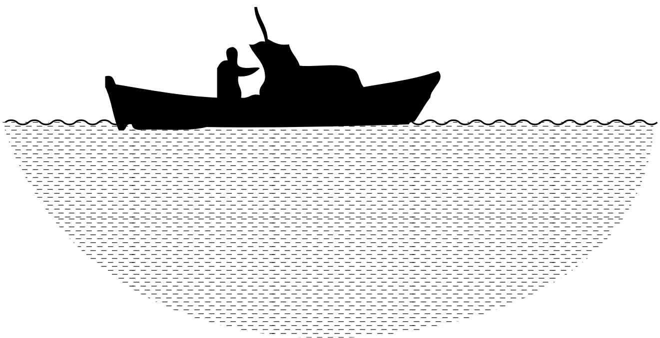


Figure 2.22

When studying density, we saw that some solids float on some liquids. For example, a log floats on water. An object floats on a liquid if its average density is less than that of the liquid in which it is floating. For example, a ship made from steel floats on water although a steel needle sinks in water. This is because a ship contains a lot of airspace. Therefore, the average density of the ship is less than that of the water on which it is floating.

Activity 2.30: Investigating the relationship between apparent loss in weight (upthrust) and weight of water displaced

What you need

- Water
- Cup
- Plate
- Spring / weighing balance
- Thread
- A stone or any other sinking object

What to do

- Weigh the stone in air (W_a)
- Fill the cup completely to the brim and place it on the plate.
- Tie one end of the thread on the stone and carefully lower the stone into the liquid until it is completely immersed. Collect the displaced liquid and weigh it (W_d)
- Record the weight of the stone when it is completely immersed in the liquid. Call this weight W_l .
- Find the upthrust W_a- $W_{l.}$
- Compare W_a- W_l with W_d.
- What is your conclusion?

Activity 2.31: Investigating the relationship between weight of an object and that of the liquid it displaces when it floats on the liquid

What you need

- Weighing balance
- Any object which floats on water
- Plate
- Bowl

What to do

- Weigh the object.
- Fill the bowel to the brim with water and place it on the plate.

- Carefully place the object on the water.
- Weigh the water which has been displaced.
- Compare the weight of the object with that of the water which has been displaced.
- What is your conclusion?

Activity 2.32: Making a buoy

What you need
- A balloon/car tube
- Metal piece or stone
- Nylon threads
- Pump
- Water source e.g. large basin or pond

What to do
- Blow air into a balloon and seal it by tying its mouth with a nylon string.
- Tie a stone at the other end of the string.
- Place the balloon on water.
- Tie more stones on the string and observe the depth to which it submerges.

Activity 2.33: Making a hydrometer

What you need
- Sand
- Drinking straw
- Cellotape
- Different liquids e.g. water, paraffin, milk and motor oil
- Graph paper

What to do
- Use cellotape to seal one end of the straw.
- Put a little sand into the straw.
- Float the straw on water.
- Continue dropping more grits of sand into the straw until it floats upright

in the water.

- Mark on the straw the point where the water level stops.
- Float the straw in pure milk and then in dilute milk. What is the difference in density between the two types of milk?
- How can you use the hydrometer to test the purity of milk?

Learning Points

Consider the following occurrences:

- A jerrycan full of water feels lighter when part of it is under water.
- It is very difficult to submerge completely an empty jerrycan.
- A large tree trunk floats on water.

When an object is partially or fully immersed in a fluid (liquid or gas), it experiences an upward force called *upthrust*. This upward force tends to make the object feel lighter.

When a body is wholly or partially immersed in a fluid, it experiences an upthrust equal to the weight of the fluid displaced. This is known as **Archimedes Principle.**

If an object is fully immersed in water, then upward force on the object (upthrust) is equal to $W_a - W_w$.

Using Archimedes Principle,

Upthrust = weight of water displaced

$W_a - W_w = W_d$.

$W_a - W_w = V \rho_w g$

$$\rho_w = \frac{W_a - W_w}{Vg} \qquad \text{(i)}$$

where V is the volume of the object (which is equal to the volume of the water displaced) and ρ_w is the density of water.

Weight of object in air, $W_a = V \rho_s g$, where V is the volume of the object and ρ_s is the density of the solid.

Relative density of the object, $\rho = \frac{\rho_s}{\rho_w} = \frac{\frac{W_a}{Vg}}{\frac{(W_a - W_w)}{Vg}}$

$$\rho = \frac{w_a}{w_a - w_w}$$

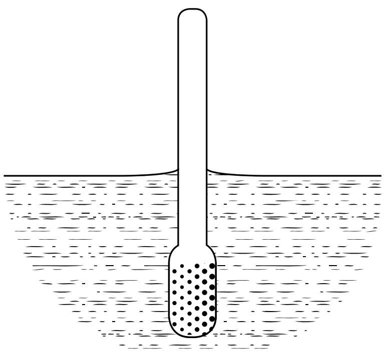
Floatation

When an object is floating on a liquid, it displaces some of the liquid and experiences an upthrust. The denser the object in comparison to the liquid, the more the object will be submerged in it. Archimedes principle can also be applied to floatation.

Law of floatation

A floating body displaces its own weight of the liquid in which it is floating.

Hydrometer



A hydrometer

Figure 2.23

This is a device used to measure relative density of a liquid**.** A dense object e.g. sand is put into a tube until it floats upright in water. The water level is marked on the tube. If it is made to float on a liquid less dense than water, it submerges deeper. Hydrometers are used to test purity of milk and battery acid.

Follow-up activity

- Make a toy which floats vertically upright on water.

Motion in a straight line

Activity 2.34: Measuring acceleration due to gravity

What you need

- String
- Meter rule
- Clock
- Availability of a tree

What to do

- Ask one of your classmates to climb a tree to a point, at least, 6 metres from the ground.
- Let him/her drop a stone while you start the clock at the same time.
- Stop the clock when the stone hits the ground and record the time it has taken.
- Measure and record the height from which the stone has fallen.
- Use the equations of motion to calculate the acceleration due to gravity by substituting the measured quantities.

Learning Points

Speed

Speed is the ratio of distance travelled to time taken (in ms^{-1}). It is a scalar quantity. The term average speed refers to the ratio of total distance travelled to the total time taken to cover the distance.

$$speed = \frac{distance}{time}\left(\frac{m}{s}\right) \qquad average\ \ speed = \frac{total\ distance}{time\ taken}$$

The SI unit for speed is $m\ s^{-1}$.

Vectors

A vector is a physical quantity with both magnitude and direction.

For example, if we say the airport is 40 km east of the Capital City, we can easily locate it because both the distance and direction have been specified. The following physical quantities are vectors: displacement, velocity, acceleration, force and weight.

Scalars

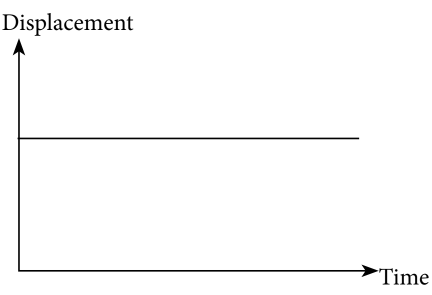
A scalar is a physical quantity with only magnitude.
Examples of scalar quantities include time, distance, speed, pressure and mass.

Velocity

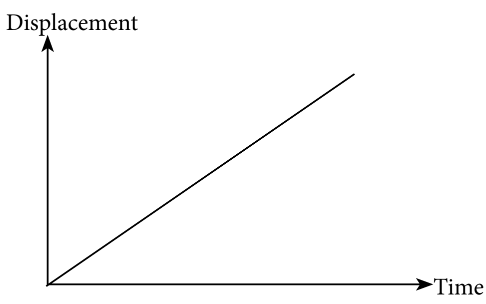
Velocity is the rate of change of displacement. It is a vector quantity.
The SI unit for velocity is the same as that for speed.

$$velocity = \frac{displacement}{time}$$

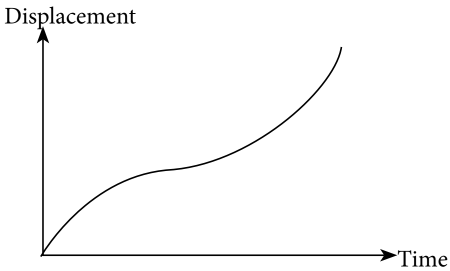
Displacement-time graphs



(i) stationary



(ii) uniform velocity



(iii) non uniform velocity

Displacement-time graphs
Figure 2.24

On the displacement-time graph shown in (a), you may note that displacement increases uniformly with time. It represents uniform velocity. The slope of the graph, which represents velocity, is constant.

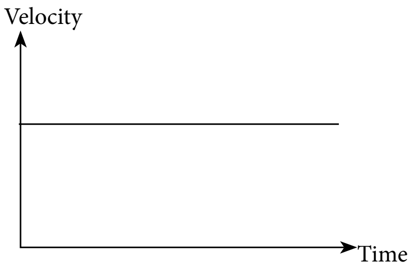
An object is moving with uniform velocity if its rate of change of displacement is constant. i.e. *the object covers equal displacements in equal times however small the displacements are.*

Acceleration
Acceleration is rate of change of velocity. It is a vector quantity.

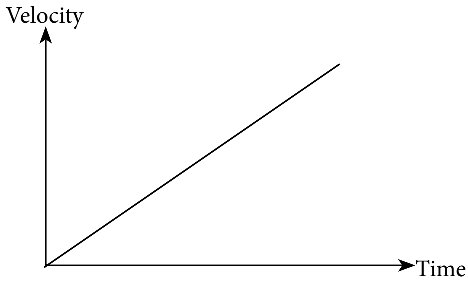
$$acceleration = \frac{change\ in\ velocity}{time}\left(\frac{m\ s^{-1}}{s}\right)$$

Note: $\left(\frac{m\ s^{-1}}{s}\right) = m\ s^{-1}\ x\ s^{-1} = m\ s^{-2}$
The SI unit for acceleration is m s^{-2}.

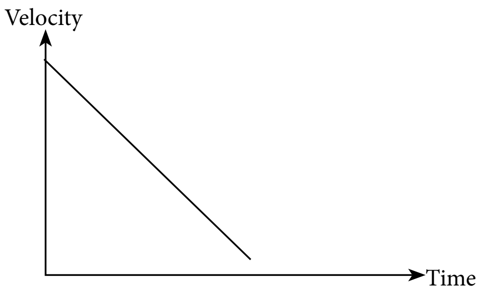
Velocity – time graphs



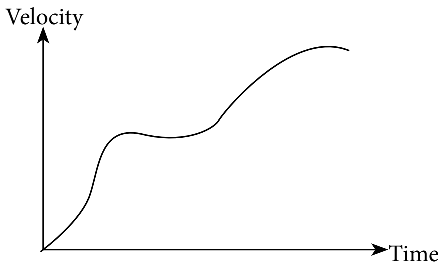
(i) uniform (constant) velocity



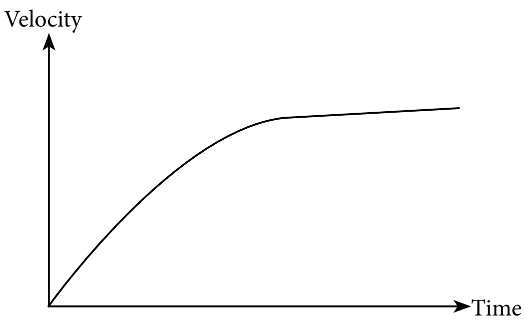
(ii) uniform acceleration



(iii) uniform deceleration



(iv) non- uniform acceleration



(v) terminal velocity

Velocity-time graphs

Figure 2.25

Discussion of the graphs:

a) *Uniform velocity*
   Velocity of a moving object is the same all the time.
b) *Uniform acceleration*
   Velocity increases with equal amounts in equal times. The slope of the graph represents the acceleration of the body.
c) *Uniform deceleration*
   Velocity decreases with equal amounts in equal times.
d) *Non-uniform acceleration*
   The slope of the graph is different at different points, i.e. the slope is not constant (non-uniform).
e) On graph (v) the slope decreases as time goes on, i.e. the acceleration decreases until it reaches zero. On the horizontal section of the graph the acceleration is zero, therefore, the body is moving with constant (terminal) velocity.

Equations of motion

Let us now consider an object initially moving in a straight line with initial velocity u. A constant force then acts upon it for time t until its velocity becomes v. During this time the acceleration, a, of the object remains constant and the object moves distance s.

The best way of sumarising the information above is as follows:
Initial velocity = $\underline{u}$
Final velocity = v
Acceleration = a
Time taken = t
Distance moved = s

First equation:

We saw above that acceleration, $a = \frac{v-u}{t}$.

When this equation is re-arranged, we get:

$$v = u + at$$

This is the first equation of motion.

Second equation:

Distance moved = average velocity x time

$$s = \frac{(u+v)}{2}t \quad \text{...} \text{ (i)}$$

$$s = \frac{(u+(a+at))}{2}t$$

Opening the brackets, we get:

$$s = \frac{2ut + at^2}{2} = \frac{2ut}{2} + \frac{at^2}{2}$$

$$s = ut + \frac{1}{2}at^2$$

This is the second equation of motion.

Third equation:

Using the first equation $v = u + at$ and making t the subject we get

$$t = \frac{v-u}{t}$$

From equation (i) $s = \frac{(u+v)}{2}t$ we can replace t by $t = \frac{v-u}{t}$ and re-arrange as follows:

$$s = \left(\frac{u+v}{2}\right)\left(\frac{v-u}{a}\right)$$

$$2as = (u+v)(v-u)$$

$$2as = v^2 - u^2$$

Hence,

$$v^2 = u^2 + 2as$$

This is the third equation of motion.

Summary

First equation $v = u + at$

Second equation $s = ut + \frac{1}{2}at^2$

Third equation $v^2 = u^2 + 2as$

Acceleration due to gravity

When a fruit falls from the branch of a tree its velocity increases uniformly. This is caused by the acceleration due to gravity. This is the acceleration experienced by a body falling freely in the earth's gravitational field. For most practical purposes the acceleration due to gravity, g, is taken to be approximately 10 m $s^{-2.}$

The ticker-timer

This is a device which is used to measure velocity or acceleration of an object. The object is tied on a strip of paper that runs under a marker. The marker makes 50 dots per second at equal interval of time on the strip, i.e. it vibrates at a frequency of 50 Hz. The time it takes to make two consecutive dots is $\frac{1}{50}s = 0.02s$, i.e. the period is 0.02s.

Measurement of uniform velocity

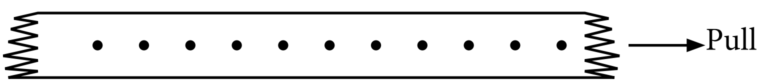
The dots for this type of motion are equally spaced. Suppose the distance between two neighbouring dots is 2.0cm, then the velocity is

$$V = \frac{2.0}{0.02} = 100\ cm\ s^{-1} = 1\ m\ s^{-1}$$

Usually, it is advisable to measure the distance between several neighbouring dots to reduce the effect of the error made in the measurement of distance. For example, in the case above the distance between 10 neighbouring dots is 18.0 cm (Note: There are nine gaps between the 10 dots.).

Then,

$$V = \frac{18}{9x0.02} = 100\ cm^{-1}$$



Ticker- timer dots for object moving with constant velocity

Figure 2.26

Measurement of uniform acceleration

The length of the first n gaps is measured (let it be x_1) and the length of the neighbouring n gaps is measured (let it be x_2). Acceleration is calculated as follows:

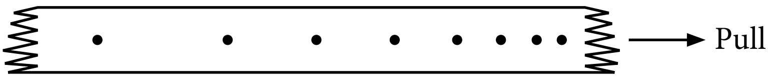


Figure 2.27

$$a = \frac{x_2 - x_1}{n \; x \; 0.02} \text{ m s}^{-1}$$

For example, if the length of the first 6 gaps (distance between 7 neighbouring dots) is 13.0 cm and the length of the neighbouring 6 gaps is 19.4 cm, the object is accelerating at:.

$$a = \frac{x_2 - x_1}{n \; x \; 0.02} = \frac{19.4 - 13.0}{6 \; x \; 0.02} = 5.3 \text{ cm s}^{-2}$$

Newton's laws of motion

Learning Points
Linear momentum

Momentum of an object is a product of the mass of a body with its velocity and it is a vector quantity.
Momentum = mass x velocity (kg x ms^{-1})
The SI unit for momentum is $kgms^{-1}$.

The principle of conservation of momentum

In an isolated system of colliding objects, total momentum is conserved.

This means that the algebraic sum of momentum before collision is equal to the algebraic sum of momentum after collision.

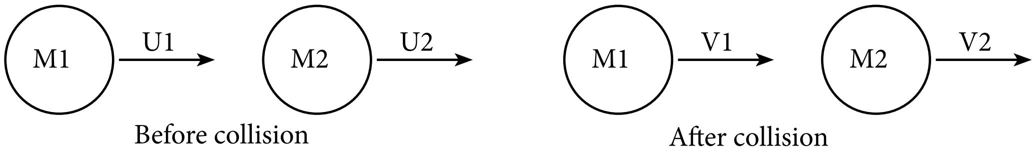


Figure 2.28

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

Applications of conservation of momentum

a) Passengers in a car will jerk forward when the diver suddenly brakes.
b) A balloon filled with air will move upwards when its mouth is untied.
c) A rocket sends fast moving air backwards in order to be able to move forward.
d) A gun recoils when it is fired.
e) When sailing on canoe water must be pushed backward by rowing for the boat to move forward.
f) When we are walking, we tend to push the earth backward in order to be able to move forward.

Indeed motion would be impossible if the principle of conservation of momentum was violated.

Newton's laws of motion

Law 1

Every body continues in its state of rest or uniform motion in a straight line unless an external force acts upon it.

Law 2

The rate of change of momentum is directly proportional to the applied force and acts in the direction of the force.

Law 3

To every action there is always an equal and opposite reaction.

Discussion of Newton's laws of motion

Law 1

This law emphasises the idea of inertia learnt earlier which is the tendency of a body to resist changes in its state of motion. Think about the following:

1) If we throw a ball up it will continue moving upwards forever! But will it?
2) A moving car will move forever unless a force acted upon it.
3) A stone rolling downwards a slope can only be brought to rest by application of a force.
4) A moving object can only change direction when a force is applied on it.
5) A stationary object cannot start moving unless a force is applied on it.

What a force can do:

It can cause a body to:

- Move faster
- Move slower
- Change direction of motion
- Start moving
- Stop moving

Law 2

Consider a body of mass m moving with velocity u. It is acted upon by a force F which changes its velocity to v in time t.

Since force is directly proportional to rate of change of momentum.

$$\Rightarrow F \propto m\frac{v-u}{t}$$
$$\Rightarrow F \propto ma$$

$$\Rightarrow F = k\ ma \quad \text{.........................} \quad \text{(i)}$$

where k is a constant.

Force is measured in Newtons.

A Newton is a force that gives a mass of 1kg an acceleration of 1ms^{-2}.

From equation (i) $F = k\ ma$

$1 = k \times 1 \times 1$

Therefore $k = 1$

F = ma ………………… (ii)
The symbol F in the equation (ii) above represents resultant velocity.

Worked examples

Weight

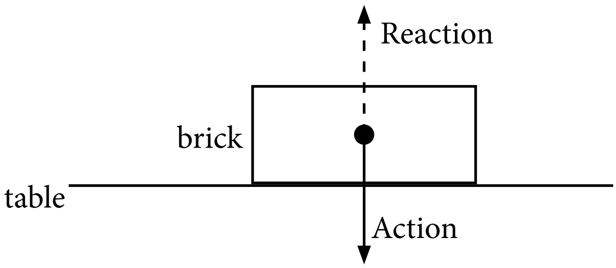
Weight of a body is the force of gravity on the body. It always points towards the centre of the earth. It is, therefore, a vector quantity.
Since weight is a force we can write it as

$W = m\ a.$
The acceleration is the gravitational acceleration, g.
Therefore,

$W = m\ g$
Weight of a body at a location depends on the value of g, therefore weight of a body changes from one location to another.

Law 3
Consider the following:
- If you hit a wall very hard using your fist you will hurt yourself.
- If you push against a wall while standing on slippery ground, you may fall.

The two examples above illustrate law 3.



Action and reaction
Figure 2.29

Weight in a lift

Consider a girl of mass m standing on a weighing balance in a lift.

a) The lift is stationary:
The reading on the weighing balance will be her true weight

$W = mg$

b) The lift is accelerating upwards:
The action of the accelerating force is upwards. Therefore the accelerating force, F, is ma. To this action there is an equal and opposite force due to the acceleration. There are two forces acting on the weighing balance: (i) the weight of the girl (ii) the force $F = ma$

The total force exerted by the girl on the weighing balance which s accelerating upwards is
$R = mg + ma$

Or $R = m(g + a)$
The girl appears to be heavier than her true weight.

c) Lift is accelerating downwards:

The accelerating force (action) is downwards.

Therefore, the reaction is $R = mg - ma = m(g - a)$

The girl appears to be lighter than her true weight.

d) **Lift is falling freely (when the cord brakes):**

The acceleration of the lift is also g

Therefore the apparent weight

$R = m(g - g)$

$R = 0$

The girl feels weightless!

Friction

This topic deals with opposition to motion between matter and matter. When one body is rubbed against another, a force tends to oppose the motion.

Activity 2.35: Demonstrating friction between surfaces

What you need

- Different objects with flat surfaces
- A wooden board

What to do

- Place a small brick on a rough board.
- Slowly, tilt the board. At a certain angle of inclination, the block slides downwards.
- Measure the maximum angle for the object to begin sliding.
- Repeat the procedure for the different objects.
- At this maximum angle, the frictional force between the block and the board has reached its maximum (limiting) value.

Activity 2.36: Investigating the factors on which friction depends

What you need

- A block of wood measuring 20 cm by 30 cm by 40 cm with a nail driven in the smallest face
- An inelastic string
- A spring balance
- A table with a horizontal flat surface
- 100 g masses

What to do

- Tie a string on the nail and on the spring balance.
- Place the block on the table lying on one of the faces.
- Slowly pull the spring balance until the block of wood just begins to move.
- Note the reading on the spring balance.
- Repeat the procedure with the block lying on the other face and note the difference between the two readings.
- Repeat the process by placing weights on the block.
- Summarise your findings.

Activity 2.37: Investigating friction on bicycle parts

What you need

- Bicycle

What to do

- Examine a bicycle and list down all the parts where friction occurs.
- Write down the parts where friction is undesirable and where it is desirable.
- Using the bicycle as an example, describe how friction is minimised where it is not desirable and how it is increased where it is desirable.
- By using a bicycle as an example, discuss with your classmates the advantages and disadvantages of friction.

Activity 2.38: Investigating factors which affect opposition to motion in liquids

What you need

- Different liquids (e.g. motor oil, water, cooking oil, paraffin)
- Metal balls of different sizes
- A tall transparent jar (tall beaker or test tube may do)
- Thermometer
- Stop clock or watch

What to do

- Fill the jar with water.
- Record the temperature of the water.
- Gently drop a metal ball into the water.
- Time the ball as it falls from the surface to the bottom.
- Repeat the procedure when the temperature of the water is 50°C.
- Investigate the effect of increasing the size of the ball.
- Repeat the procedure above for motor oil, cooking oil and paraffin.

Learning Points

Friction between solids: When you rub your palm against a coarse surface, it feels warm! A frictional force exists between your palm and that surface. It always opposes relative motion between two surfaces in contact. Work must be done to overcome friction and the energy supplied to overcome friction is converted into heat.

Friction force is a force which opposes relative motion between two surfaces in contact.

Limiting (maximum) friction: *Limiting frictional force is the maximum frictional force which prevents motion between surfaces in contact.*

Friction in fluids (viscosity): Opposition to movement also occurs in fluids (liquids and gases). Friction in fluids is referred to as viscosity. 'Thick' motor oil has a high viscosity.

Follow-up activity

- Identify parts of your body where movement occurs. Discuss how friction is minimised in these parts.
- Examine the different oils used on bicycle, motorcycle and motor vehicle parts. Write down their characteristics. Read the writing on the label.

Pressure

This is the perpendicular force acting between surfaces in contact.

Activity 2.39: Investigating factors which affect pressure exerted by solids on surfaces

What you need

- Three similar building bricks
- Soft mud on the ground

What to do

- Carefully place the bricks on the mud making sure the face on the mud is different for all the three bricks.
- Note the side which makes a deeper impression.
- Write down your conclusion.

.

Activity 2.40: Investigating the factors that affect pressure in a liquid

What you need

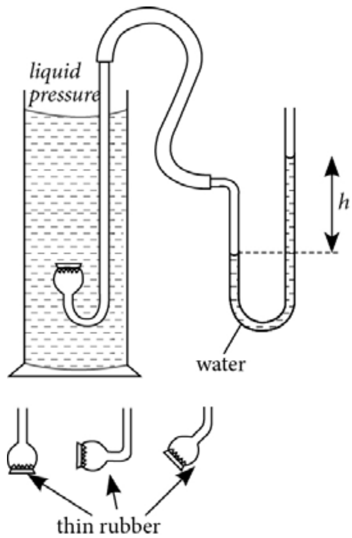
- Deep transparent vessel (e.g. A big cooking pan)
- A flexible transparent tube, X
- Water
- String
- Polythene paper
- Two cans P and Q (P has three holes at the same level and Q has three holes at the different heights from the base)
- Plasticine

What to do

Method 1

- Cover the holes of can P with plasticine and place it on a stool.
- Fill the can completely with water.
- Uncover all the holes at once.
- Measure the maximum horizontal distance covered by the water from each of the holes.
- Repeat the same procedure with can Q.
- What is your conclusion?

Method 2



Pressure in a liquid acts in all directions
Figure 2.30

- Half-fill the tube, X, with water.
- Tie one layer of polythene sheet around the mouth of the tube and assemble the apparatus as shown in the diagram.
- Measure the excess height, h, when the mouth of the tube is at:
  i) different depths below the surface of water.
  ii) the same depth but facing different directions.

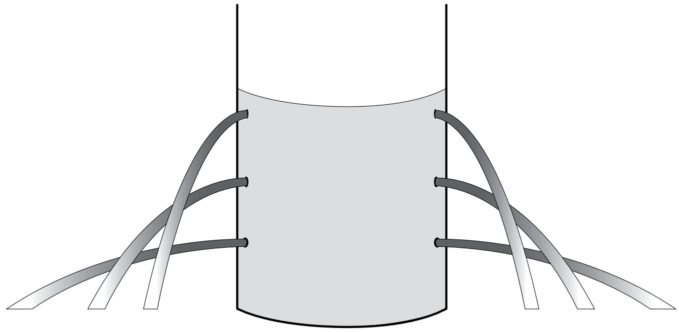


Figure 2.31

Activity 2.41: Demonstrating the existence of atmospheric pressure

What you need

- boiling tube
- Water
- A piece of paper

Method 1

The magician's trick!

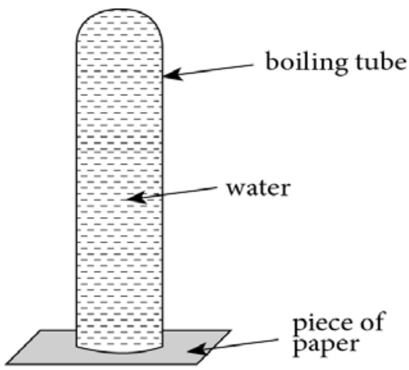


Figure 2.32

What to do

- Fill the boiling tube with water to the brim.
- Cover the boiling tube with a pa small piece of paper.
- Invert the boiling tube while holding the paper firmly over the mouth of the boiling tube

- Describe and explain what you observe.
- Now rinse the boiling tube with warm water
- invert it over cold water so that its mouth is just under the water.
- Observe and explain what happens.

Method 2

The crashing plastic water bottle!

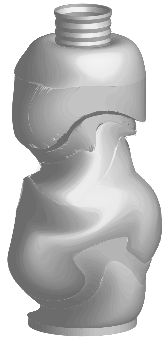


Figure 2.33

What to do

- Fill a plastic water bottle with water up to about one-eighth of its volume.
- Place the bottle in boiling water.
- Keep the bottle in boiling water for some time until all the cold air has been expelled.
- Cover the bottle with the bottle top firmly.
- Immerse the bottle in cold water.
- Explain what you observe.

Activity 2.42: Modelling a water tank

What you need

- Clay or mud
- Wooden rods of diameter 2 cm
- Flexible steel wires

What to do

- On paper, design a water tank.
- Discuss the design of the model with your group
- Make a model of the tank using clay, wooden rods and wires.

Learning Points

When you walk in soft sand, your footprints would be clearly visible. The footprints are due to the pressure your body exerts on the sand.

Pressure is the force per square metre perpendicularly exerted by a body on a surface.

$$pressure = \frac{force}{area}$$

The SI unit for pressure is Nm^{-2} or Pascals (Pa).

$1\ Nm^{-2} = 1\ Pa$

The formula $pressure = \frac{force}{area}$ suggests that the smaller the area in contact with a surface, the bigger the pressure.

Explain the following:

a) A knife should have a sharp edge to be useful.

b) Tractor tyres have a very large surface area in contact with the ground.

c) Ducks have webbed feet.

d) Elephants have very large feet.

Pressure in fluids

An object placed under the surface of a fluid experiences pressure due to fluid from all directions.

Pressure in a fluid is the force per square metre in a direction perpendicular to the surface placed inside a fluid.

Facts about pressure in fluids:

- *It acts equally in all directions.*
- *It increases with depth.*
- *It is a scalar quantity.*
- *It depends on density of the fluid.*

Pressure acts equally in all directions

This principle is used in hydraulic brakes and presses.

To illustrate how this principle is used, consider a small force f, which has been applied on a piston of a small area. The pressure is transmitted equally from the small cylinder to the big cylinder to produce a bigger force F, on the piston of a bigger area A.

Thus,

$$\text{Pressure} = \frac{f}{a} = \frac{F}{A}$$

$$F = A \times \frac{f}{a}$$

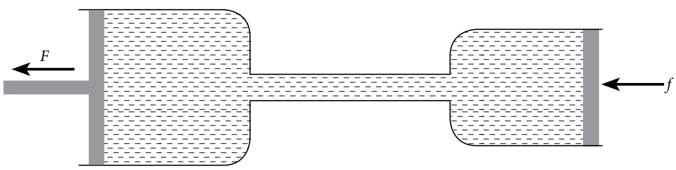


Figure 2.34

Dependence of pressure on density of the fluid

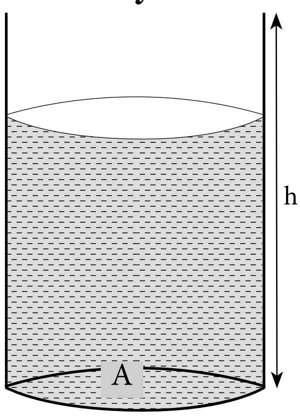


Figure 2.35

Consider a fluid of density ρ in a container of uniform cross-section area, A, and height, h, as in the diagram above.

The fluid exerts a force (thrust) on the base. This thrust is the weight of the fluid in the container.

Therefore,

$$\textit{Pressure, } P = \frac{thrust}{area} = \frac{weight}{area}$$

$$\textit{Pressure, } \mathrm{P} = \frac{mg}{A} = \frac{(volume \text{ x density})g}{A}$$

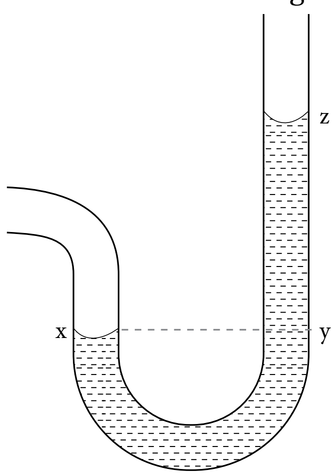
$$\textit{Pressure, } P = \left(\frac{\mathrm{A \text{ x } h \text{ x }} \rho}{A}\right) \text{x g}$$

$$\boldsymbol{P = h}\, \rho\, \mathrm{g}$$

From the equation above, it is clear that pressure in fluids increases with depth. This explains why walls of dams and water tanks should be thicker at the base and also why it is not advisable to swim in very deep waters without swimming aids.

The manometer

A manometer is an instrument used to measure gas pressure.



A manometer

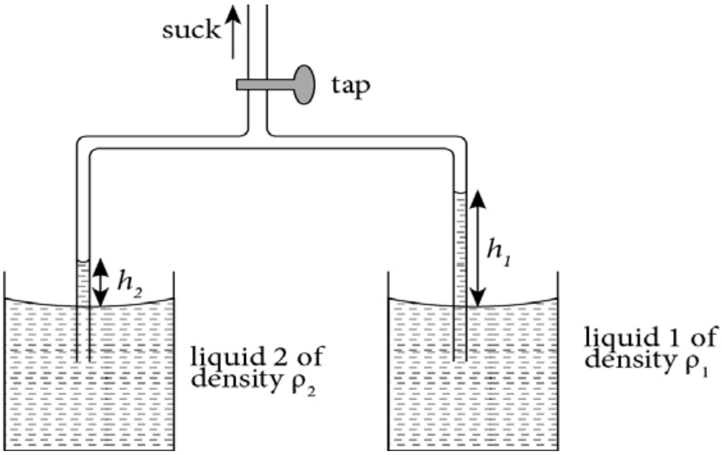
Figure 2.36

Gas pressure at X is the sum of the pressure due to the liquid column YZ (excess pressure) and atmospheric pressure.

Gas pressure = excess pressure + atmospheric pressure

Gas pressure = h ρ g + atmospheric pressure

Comparing densities of liquids



Hare's apparatus

Figure 2.37

In the diagram above, air is sucked out through tap, T, and the tap is then closed. The liquids of densities ρ_1, ρ_2 rise to heights h_1 and h_2 respectively due to the reduction in pressure above them.

Therefore,

Pressure of the air above the liquids = Atmospheric pressure - $h_1 \rho_1 g$

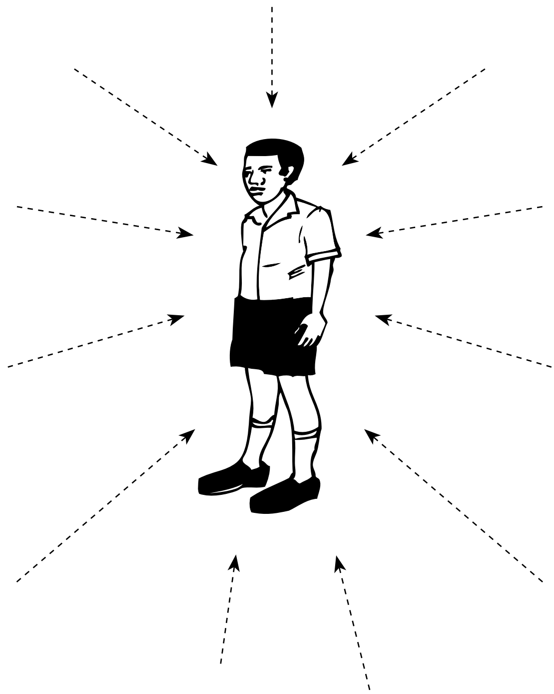
= atmospheric pressure - $h_2 \rho_2 g$

$h_2 \rho_2 g = h_1 \rho_1 g$

$$\frac{\rho_2}{\rho_1} = \frac{h_1}{h_2}$$

Atmospheric pressure

This is the pressure due to the air in the atmosphere. We normally do not feel the pressure because it acts equally from all directions, both outside and inside our bodies.



Atmospheric pressure acts on us in all directions

Figure 2.38

Measuring atmospheric pressure

A long glass tube (Approximately 100 cm) is filled with mercury to the brim. It is then covered with a glass plate and inverted over a dish of mercury while still holding the glass plate firmly over its mouth. When the mouth of the tube is under the surface of mercury, the plate is taken away.

Mercury tends to run out of the tube while at the same time atmospheric pressure is pushing it back. Equilibrium occurs when the vertical column, h, of mercury balances atmospheric pressure. For standard (normal) atmospheric pressure, h is 76 centimetres of mercury (abbreviated 76 cm Hg). Using the formula $P = h \rho g$ and taking the density of mercury to be 13,600 kg m^{-3}, the value of normal atmospheric pressure is calculated as follows:

$P = h\rho g$

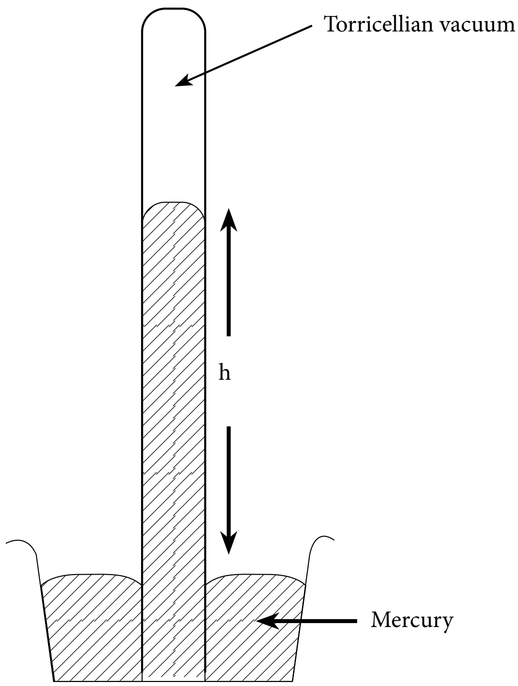
$= 0.76 \times 13{,}600 \times 10 \text{ N m}^{-2}$

$P = 103{,}360 \text{ N m}^{-2}$

Follow-up activity

Explain the following:

1. Corners of walls of buildings must not be sharp.
2. It is very painful to walk barefoot on a stony surface.
3. A hen makes deeper impression in mud than a duck.
4. An elephant has a wide foot.



A barometer

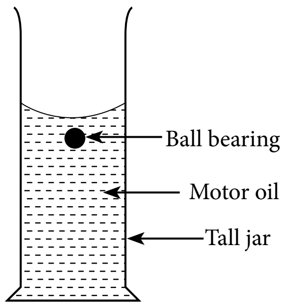
Figure 2.39

Fluid flow

Activity 2.43: Observing a bicycle ball bearing falling through a viscous liquid

What you need

- Motor oil (or cooking oil)
- Bicycle ball bearings
- A tall jar (or a big cooking can)



A ball falling through oil

Figure 2.40

What to do

- Assemble the apparatus as in Figure 2.34.
- Drop a bicycle ball bearing into the oil and observe it as it falls from the top to the bottom.
- Repeat the procedure with other ball bearings.
- Describe the motion of the ball through the oil.

Activity 2.44: Modelling a racing car

Draw on paper the design of a racing car. You should consider the following factors:

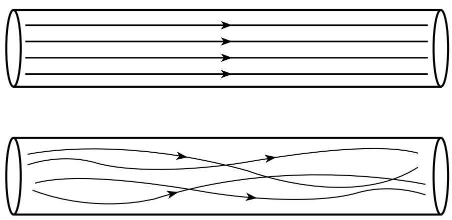
- Weight
- Shape

Justify your design and compare it with those of the other members of your class. In groups of five, discuss the advantages and disadvantages of each type of model made by each member of the group.

Learning Points

Streamline flow

This is an orderly flow of a liquid. In streamline flow, the molecules in the various layers of the liquid move at steady velocities. Molecules in a given layer do not cross to other layers. A streamline is a direction of motion of molecules in a given layer. This kind of flow occurs when a liquid is flowing slowly and steadily. Turbulent flow is the opposite of streamline flow. It is disorderly. Molecules cross from one layer to another. This kind of motion occurs when a liquid flows fast through a pipe..

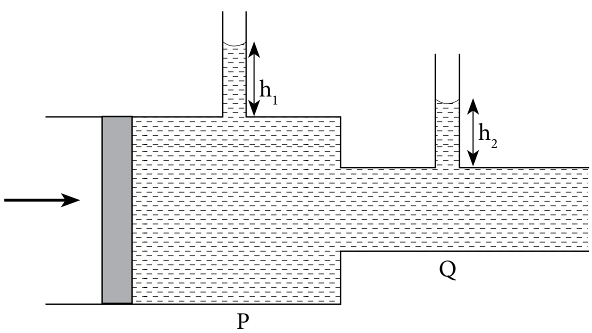


Orderly and turbulent flow through a pipe

Figure 2.41

Relationship between pressure and velocity in fluid flow

In Figure 2.35 below, the tubes connected to pipes P and Q are used to measure pressure of the liquid in the various sections of the pipe.



Dependence of pressure on velocity of a fluid

Figure 2.42

From the diagram, we can conclude that pressure of the liquid is low in narrow sections where the velocity is high and vice versa.

The higher the velocity, the lower the pressure.

The above can be summarised in the table below:

	Wide section	**Narrow section**
Streamlines	Far apart	Close together
Velocity	Low	High
Pressure	High	Low

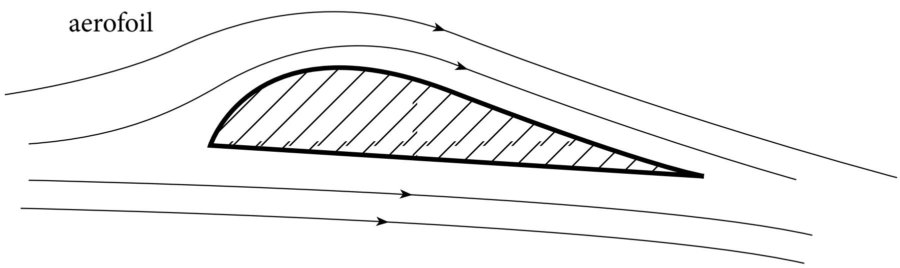
Table 2.10

Applications

1. **The suction effect**

The low pressure effect experienced by a person standing by the roadside when a fast moving bus passes and the rising of a piece of paper when air is blown above it can be explained by the summarised notes in the table above.

2. **The aerofoil lift**



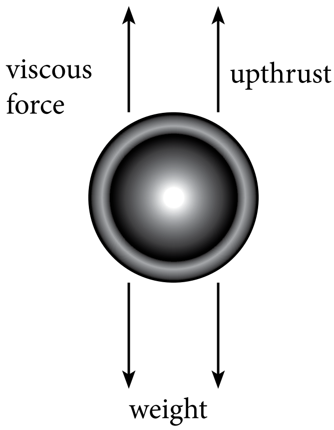
A cross-section of a wing of a plane moving through wind

Figure 2.43

Above the plane: streamlines are closer, velocity of wind is high and pressure is low.
Below the plane: the streamlines are farther apart, velocity of wind is low and the pressure is high.
The resulting pressure difference between the top and lower surfaces of the wing provide the lifting effect on the airplane.

Motion of an object falling in a viscous fluid

Forces acting on an object in a viscous medium:



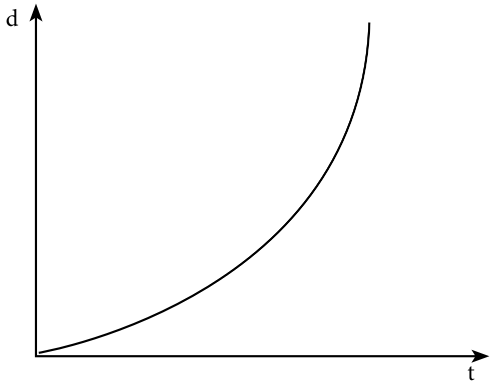
Forces acting on an object falling through a medium

Figure 2.44

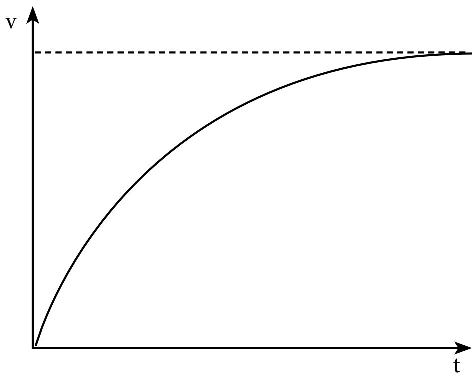
The viscous force is a frictional force opposing motion of an object in a fluid. Viscous force increases with speed of the object. For example, it becomes increasingly more difficult to ride against wind as the speed of the bicycle increases.

At the beginning of motion:
Weight > Upthrust + Viscous force.

The resultant force between the downward force (weight of the object) and upward forces (upthrust and viscous force) makes the object accelerate.
As the object accelerates, the viscous force on it increases and the resultant force between the downward force and upward forces decreases leading to decreased acceleration.
Acceleration gradually decreases as the speed of the object increases.
After some time, *Weight = Upthrust + Viscous force.*
The resultant (net) force and acceleration of the object becomes zero. The object then moves with constant (terminal) velocity.



(i) Displacement – time



(ii) Velocity – time

Figure 2.45

Graphs of (i) displacement against time (ii) velocity against time for an object falling through a viscous medium are shown above.

A parachutist jumping to the ground from a plane experiences the same forces described above. His velocity will not perpetually increase. After some time, his velocity becomes constant.

Mechanical properties of matter

Activity 2.45: Investigating the behaviour of a spring under a force

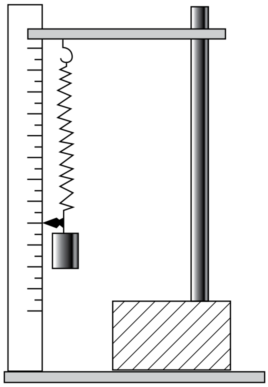


Figure 2.46

What you need

- Helical spring (Nuffield type) with a pointer
- Six 100 gram masses
- Metre rule
- Retort stand and clamp

What to do

- Assemble the apparatus as shown in Figure 2.40 above.
- Note the initial pointer reading.
- Hang 100 g on the spring.
- Note the new pointer reading.
- Calculate the extension.
- Repeat the procedure above for 200, 300, 400, 500 and 600 g.
- Plot a graph of extension against mass
- What conclusion can you draw from the graph you have plotted?

Activity 2.46: Making a rubber balance

What you need

- Rubber strips cut from a car tube or bicycle tyre tube
- 100 g mass

- Small nails
- Spring balance
- Pieces of wood
- Jack plane
- Saw

What to do

- Make a piece of wood measuring 5cm by 30cm.
- Fix a small nail of about 2cm from one end of the wood.
- Cut a rubber strip of about 10cm x 2 cm (you can change the dimensions if the dimensions are not suitable).
- Fix a hook and pointer on one end of the rubber strip and fix the other end of the strip to the nail.
- Make the wood stand vertically upwards and mark the pointer position. Assign it value “0 g”.
- Hang a known mass (100g) on the hook and mark the new pointer position on the wood. Assign it value of “100 g”.
- Remove the standard mass.
- Draw a vertical line between the two pointer positions.
- Sub-divide the interval between the two pointer positions into ten equal divisions.
- Mark the divisions from the 0 g mark in increasing values of 10 g to 100g.

Precaution

Ensure that the rubber strip is not overstretched (i.e. its elastic limit is not exceeded).

Activity 2.47: Finding out uses of brittle and ductile materials

What to do

- Observe the floors, roofs, ceilings, walls, windows, doors, etc of the buildings in your school.
- Write down the different materials used on the buildings.
- Write down the property of the material that made it suitable for the purpose it was used.

Learning Points

Relationship between extension and pulling force

When a wire or a string is subjected to a pulling force its length increases with the size of the force.

For a spring loaded vertically with a mass at the end, the pulling force increases when the weight loaded on the spring is increased.

Provided proportional limit is not exceeded, force applied is directly proportional to the extension produced.

This is known as Hooke's Law.

Therefore,

Force is directly proportional to extension

Thus,

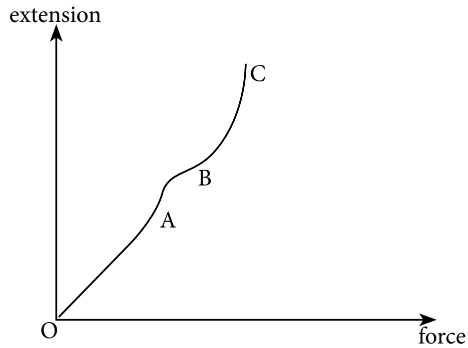
$F \propto e$

$\Rightarrow F = k\,e,$

where k is a constant of the spring. The SI unit for k is Nm^{-1}.

The same results would be obtained if a copper wire was loaded with small masses.

Behaviour of a copper wire loaded with increasingly bigger masses



A graph of extension against force for a constantan wire

Figure 2.47

The graph above was plotted using results obtained when a constantan wire was loaded with increasingly bigger masses.

- From O to A, the graph is a straight line. Extension is directly proportional to the applied force.
- A is the proportional limit.
- B is the elastic limit. When the wire is pulled up to B, it recovers its original length when the pulling force is removed.
- Between O and B, the wire is said to be elastic.
- When the wire is pulled beyond B, it does not regain its original length. Beyond B, the wire undergoes plastic deformation. Extension is not directly proportional to applied force.
- At C, the wire breaks.

Brittle materials cannot be stretched beyond the elastic limit. When an attempt is made to stretch them beyond the elastic limit they snap or break easily. Examples of brittle materials include china clay, building bricks, concrete and window glass. This type of material breaks or cracks easily when a large stress is applied on them. It cannot bend easily **stiffness** (rigidity) is inability of a material to bend easily.

Ductile materials are those that can undergo plastic deformation. Examples of ductile materials include copper wire, and most plastics. This type of material bends easily when under stress.

Concrete can withstand large compression forces but cracks easily under large tensional forces. It also cracks easily when it dries or when temperature changes substantially. It is normally reinforced using steel bars which allow some little expansion to take place. This also minimises the effect of cracks.

Both brittle and ductile materials have numerous applications in daily life.

Tensile stress is the ratio of force to cross-sectional area of a material.

$$tensile\ stress = \frac{force}{area}$$

Tensile strain is the ratio of extension to the original length of a material.

$$Tensile\ strain = \frac{extension}{original\ length}.$$

$$Young's\ Modulus = \frac{stress}{strain}$$

Tensile strain and Young's modulus have no units.

Effect of forces on beams, shapes and structures

Activity 2.48: Constructing a model of a roof frame

What you need

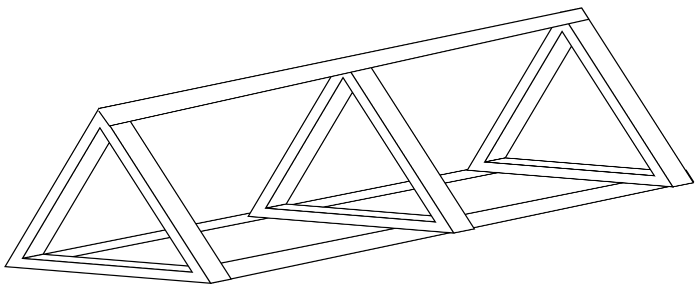
- Planks of wood of different dimensions
- Nails (varied sizes)
- Jack plane
- Saw
- Hammer
- Measuring tape
- Plumb line
- A builder's square

What to do

- Draw to scale a frame of a model house measuring 1 m by 0.5 m.
- Construct a roof frame for the model house
- Explain the choice of the planks and the shapes on the structure of the frame.

Struts and ties

A strut is a beam in a structure which is under compression. It should be able to resist the strong compressive forces of the structure.
A tie is a beam in a structure which is under tension.



A frame of a roof support

Fig 2.48

On the roof structure of your classroom, identify struts and ties.

Follow-up activity

Visit a building site to study how buildings are made strong.

What to do

- Visit a building site and talk to the Site Engineer.
- Ask them how they ensure the frame of the building is made strong to withstand the huge forces.
- Find out how the types of building materials are suited for the purpose they are used for.

Activity 2.49: Identifying shapes and structures on a bicycle which make it strong

What you need

- Bicycle

What to do

- Examine the bicycle and identify struts, ties and other features which make it strong.
- Explain why the structures you have identified on the bicycle were used in those locations.

Activity 2.50: Constructing a support structure for a water tank

What you need

- Planks of wood
- Nails of different sizes
- Jack plane
- Saw
- Hammer

What to do

- On paper, draw a model of a support structure for a water tank.

- Make a model of the structure measuring not more than 1 m high.
- Explain the choice of the planks and nails you have used in each section of the structure.

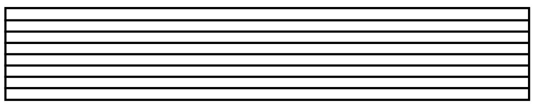
Learning Points

Stress lines in beams

When a beam is under stress, the stress appears to concentrate along lines known as stress lines. Beams break easily at the point where there is a high concentration of stress lines.

1) **Straight beam**

Stress lines are parallel



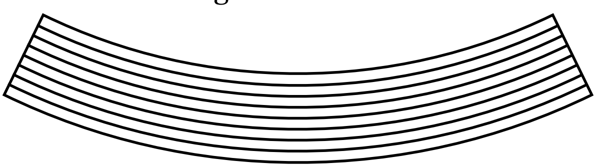
A straight beam showing parallel straight line

Figure 2.49

2) **Bending beam**

Stress lines on the side under compression are shorter than stress lines on the side under tension.

Neutral axis. This is the central line of the beam. Its length remains constant when the beam is bent. In the diagram below XY is the neutral axis.



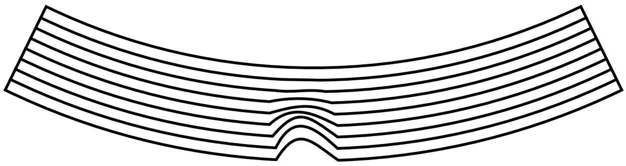
A bent beam

Figure 2.50

Notch

This is a crack in a beam.

At the notch, there is a high concentration of stress lines. The beam can easily break at this point. A notch on the side under tension spreads easily and therefore weakens the beam more than a notch on the side under compression.



A diagram showing a notch

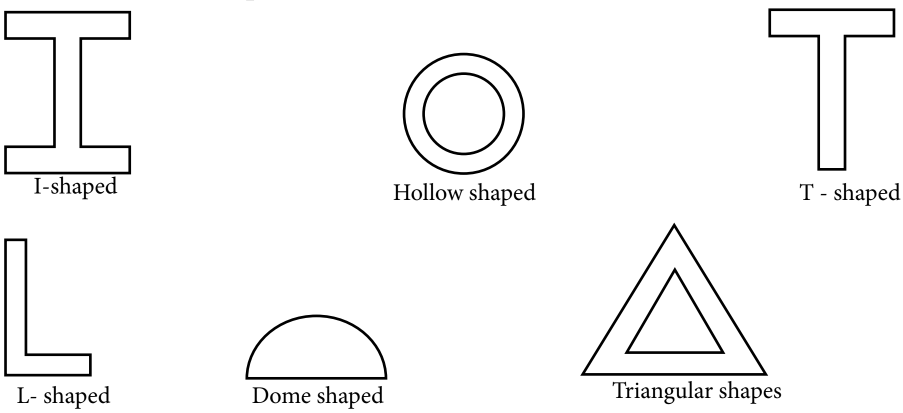
Figure 2.51

The effect of a notch can be minimised by drilling a circular hole at its tip. This distributes the stress over a wider region.

Shapes

In engineering, the following shapes have been found to resist very high stresses:

- Triangular shapes
- Dome shaped
- T-shaped
- I-shaped
- L-shaped
- Hollow shaped



Shapes of strong structures

Figure 2.52

Mention some structures where these shapes are commonly used.

Chapter 3: Light

Introduction

Light is a form of energy which enables us to see. We need it in photography. Plants need it to make food. It has no shape and no weight but illuminates the whole world and it is the fastest of all things! It is a form of energy. When light comes into contact with matter, it may be reflected, absorbed, transmitted or refracted.

Sources of light include artificial e.g. light bulbs, fires, and natural e.g. sun and fire flies. The moon is not a natural source of light. It just reflects light from the sun.

Rectilinear propagation of light

Activity 3.1: Investigating motion of light through air

Method 1

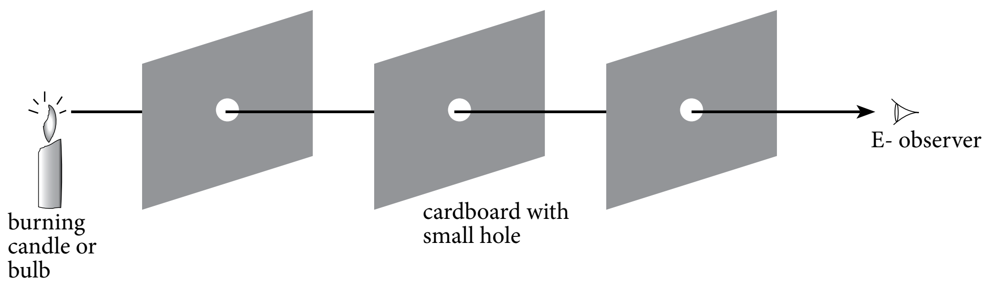


Figure 3.1

What you need

- Source of light e.g. Candle
- 3 Cardboards each with a hole at the centre
- String
- A flexible tube

What to do

- Assemble the apparatus as in Figure 3.1 above.
- Using blocks of wood, make the cardboards stand up vertically.
- Try to find out whether you can see the light from the candle with the holes in different positions.
- Use a string through the holes to ensure the holes are in a straight line and again try to see the light from the candle.
- What is your conclusion?
- The principle of reversibility of light says that light rays are reversible. Investigate the reversibility of light by placing the candle where the eye previously was and make the observations from where the candle was.

Method 2

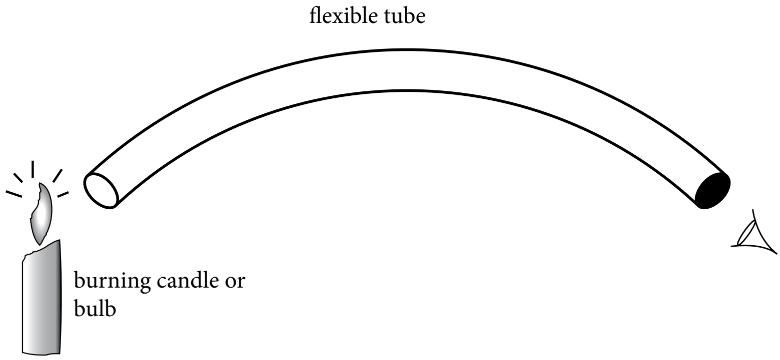


Figure 3.2

What you need

- A flexible tube
- candle or any source of light

What to do

- View the light when the tube is bent and when it is straight.
- What is your conclusion?

Activity 3.2: Forming shadows (umbra and penumbra) on the screen

What you need

- Lamp holder
- Electric / torch bulb
- Screen with a hole in the centre
- Switch
- 4 connecting wires
- 2 dry cells
- Holders
- White screen
- Pendulum bob

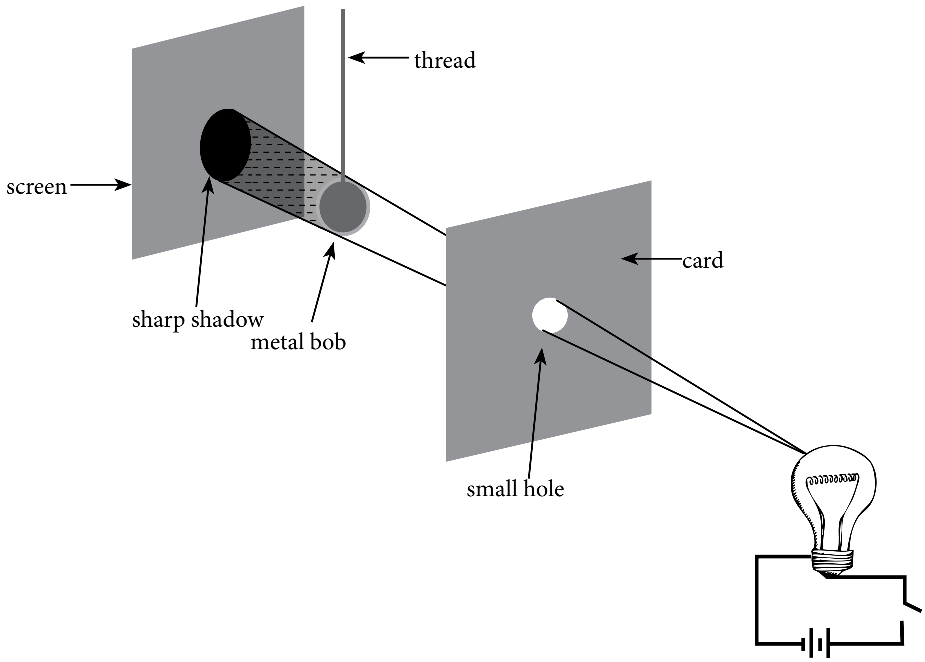


Figure 3.3

What to do

- Place a card board with a small hole in front of a light bulb.
- Place a metal bob in the way of light as in Fig 3.3.
- Identify the umbra and penumbra.
- Investigate the effect of:

a) using a small source of light and a large obstacle.
b) a large (extended) source of light and a small object on the relative sizes of the umbra and penumbra

Activity 3.3: Making a pin-hole camera

What you need
- Glue
- Cardboard paper
- White sheet of paper
- Cooking oil (or fat)
- A pin

What to do
- Make two open cylinders out of the cardboard (the diameter of one of them should be slightly smaller than that of the other and the smaller cylinder should be able to move in and out of the bigger cylinder).
- Glue an opaque cardboard (with a very small hole) on the mouth of the bigger tube and a white sheet of paper smeared with fat on the mouth of the smaller tube.
- Use your camera to view different objects around you.
- Focus the objects by increasing or decreasing the length of your camera.
- Find out the effect of enlarging the pin-hole.

Activity 3.4: Classification of materials basing on their behaviour towards light

What you need
- Glass beaker
- Source of light
- Clear glass, frosted glass
- Milk
- Tracing paper
- Wood

What to do

- Place each of the materials/objects above in turn between a source of light and your eye
- Write down how each of them affects the amount of light reaching your eye.

Answer this question

Different types of window glasses are suitable for different places on the house. Where would each of the above qualities be best suited?

Learning Points

Behaviour of different materials towards light

- Opaque – they do not allow any light to pass through them.
- Transparent – they allow light to pass through them.
- Translucent – they allow only little light to pass through them e.g. frosted glass.

Speed of light

The speed of light in air is approximately 300,000,000 m s^{-1} (or 3×10^8 m s^{-1} in standard form).

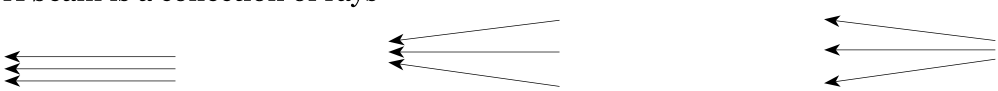
Rays and beams

A ray is a direction (or a path) taken by light.

A ray

Figure 3.4

A beam is a collection of rays



Parallel **Convergent** **divergent**

Diagrams of parallel, convergent and divergent beams

Figure 3.5

Propagation of light

Light travels in a straight line.

Shadows

A shadow is a dark region formed when an opaque object is placed in the path of light. The formation of a shadow with sharp edges is clear indication that light travels in a straight line.

Types of shadows

Umbra – this is a region of complete darkness.
Penumbra – this is a region of partial shadow. It is formed around the umbra.

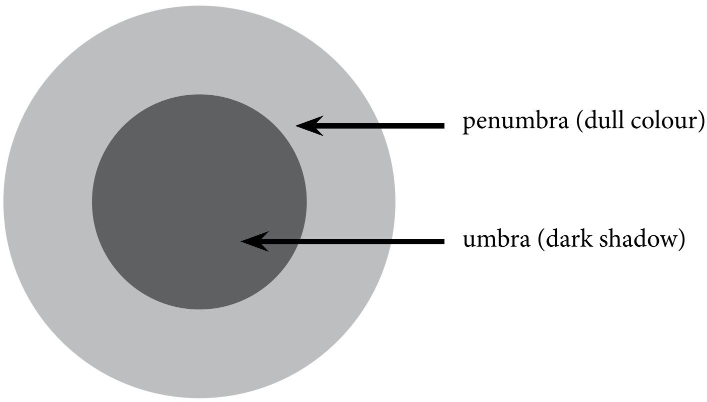


Figure 3.6

Eclipses

Eclipse is the obstruction or blocking of light. There are two types of eclipse: eclipse of the sun (solar eclipse) and eclipse of the moon (lunar eclipse). These types of eclipse take place when the sun, moon and earth are in a straight line.

Eclipse of the sun

The moon lies between the sun and the earth.

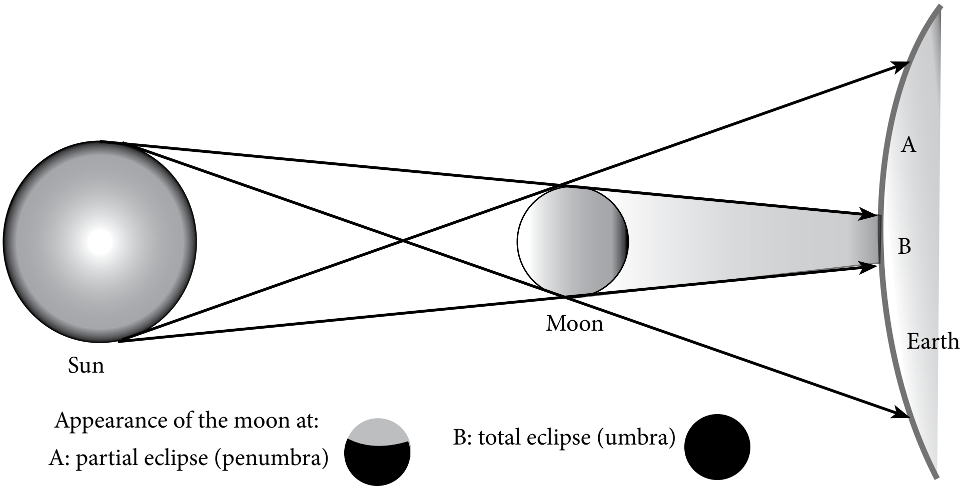
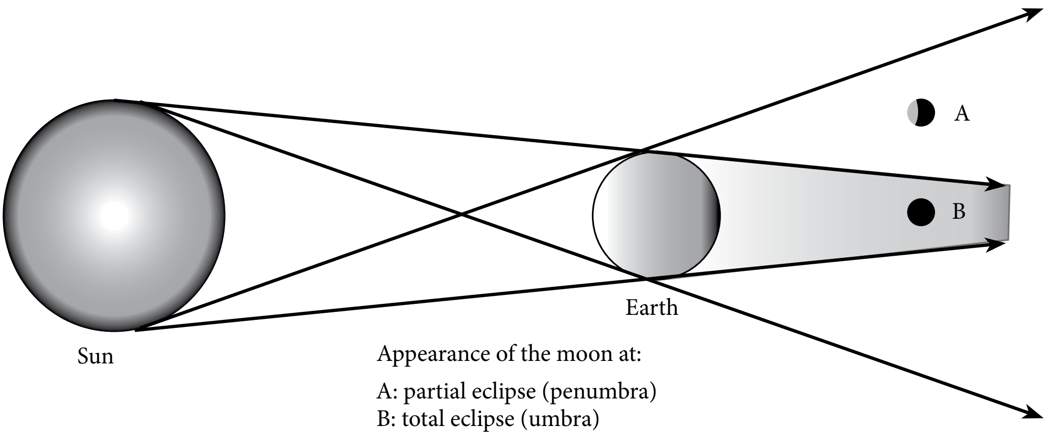


Figure 3.7

Eclipse of the moon

The earth lies between the sun and the moon.



Eclipse of the moon

Figure 3.8

The pin-hole camera

This is a dark hollow box with a translucent sheet at one end and a small hole (the size of a pin) at the other.

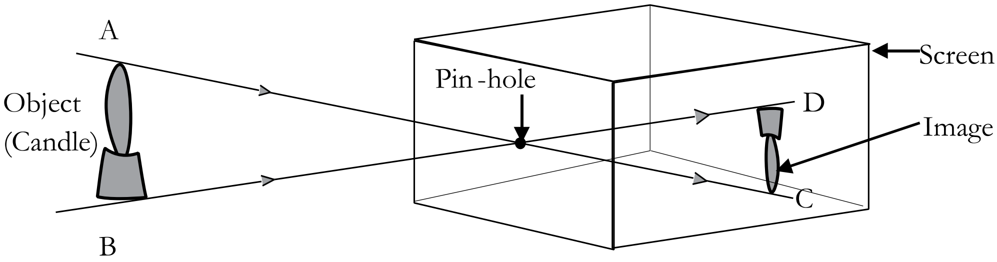


Figure 3.9

The image is inverted and real (because it forms on a screen). The size of the image depends on the length of the camera and the distance between the camera and the object.

A larger 'pin-hole' behaves as if it consisted of many 'pin-holes'. Each of the pin-holes forms its own image on the screen. When all the images overlap, a blurred image (one with unclear boundary) is formed.

Reflection of light from a plane surface

Activity 3.5: To investigate the reflection of light from a plane surface

What you need

- A set of geometrical instruments
- White plane sheet of paper
- Plane mirror mounted on a vertical piece of wood
- 4 optical pins
- Soft board
- 4 drawing pins
- Foot ruler

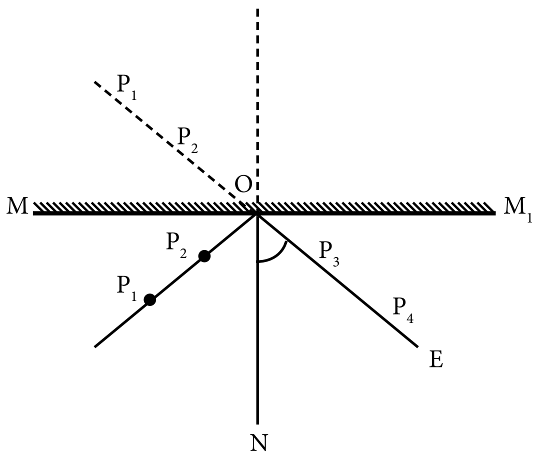


Figure 3.10

What to do

- Using 4 drawing pins, fix the white sheet of paper on a soft board.
- Draw a line MM′ across the paper.
- Place the mirror on the line with the reflecting surface facing you.
- Draw a perpendicular 0N
- Draw angle P_1ON = **i** = 20º.
- Fix pins P_1 and P_2 into the board along the line drawn.
- While looking in the mirror fix pins P_3 and P_4 into the board in such a way that they appear to be in one straight line with the images of P_1 and P_2 .
- Remove the mirror and draw a line joining O, P_3, P_4.
- Measure angle **r**.
- Repeat the procedure for angles of i= 30°, 40°, 50°, 60° and 70°.
- Record the values obtained in the table 3.1.
- What do you notice?

i (°)	r (°)
20	
30	
40	
50	
60	
70	

Table 3.1

Learning Points

Laws of reflection

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

Activity 3.6: To investigate the relationship between angle of rotation of mirror and angle of rotation of reflected ray

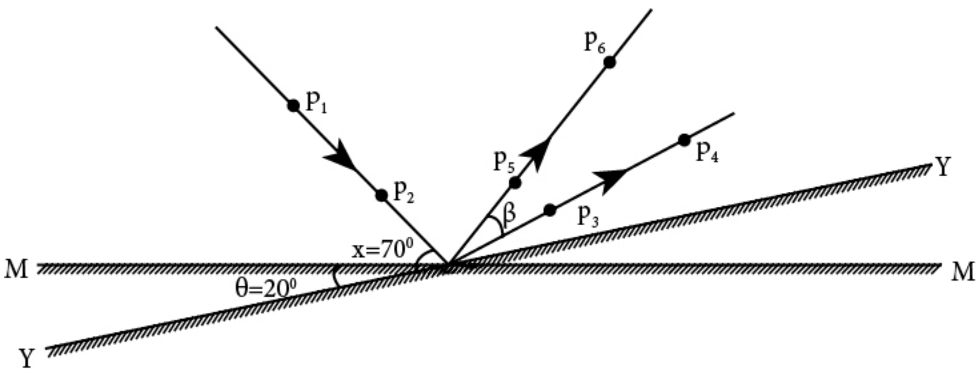


Figure 3.11

What you need

- A set of geometrical instruments
- White plane sheet of paper
- Plane mirror mounted on a vertical piece of wood
- 4 optical pins
- Soft board
- 4 drawing pins

What to do

- Using 4 drawing pins, fix the white sheet of paper on the soft board.
- Draw a line MM′ across the paper.
- Mark a point O on MM′.
- Draw angle x = 70°.
- Place the mirror on the line with the reflecting surface facing you.

- Fix pins P_1 and P_2 into the board along the line drawn.
- Fix pins P_3 and P_4 into the board so that all the four pins appear to be in one straight line.
- Remove the mirror and draw a line joining O, P_3 and P_4.
- Draw another line XY through O making an angle of 10° with MM′ and place the mirror on the line.
- Fix pins P_5 and P_6 to be in a straight line with the images of P_1 and P_2 without changing the positions of P_1 and P_2.
- Remove the mirror and pins P_5 and P_6.
- Draw a line joining O, P_5 and P_6.
- Measure the angle between line P_3P_4 and P_5P_6.
- Repeat the procedure for values of θ = 20°, 30°, 40° and 50°.
- Record the values of θ and β in a suitable table.
- What the relationship between angle of rotation of mirror and angle of rotation of ray?

Learning Point

The angle of rotation of the reflected ray is twice the angle of rotation of the incident ray

Activity 3.7: To show how the eye sees the image

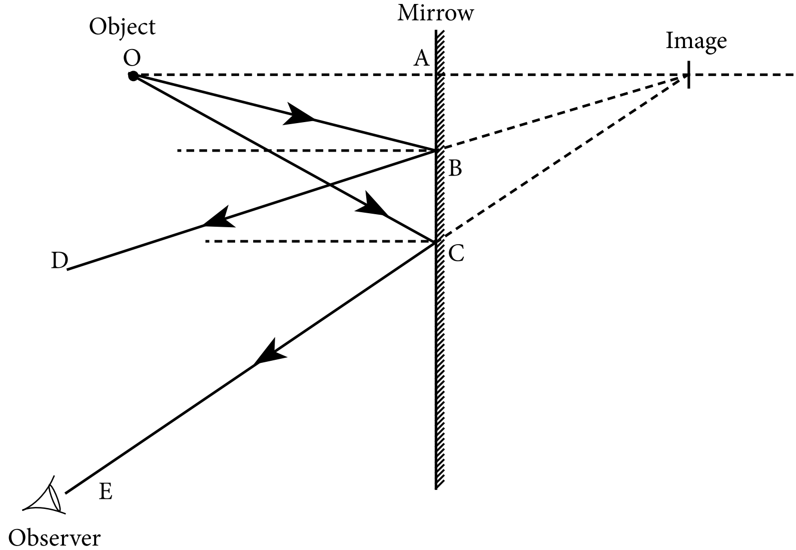


Figure 3.12

What you need

As in activity 3.4

What to do

An observer views an object when rays of light from the object are reflected from the mirror to the eye (s) of the observer.

- Draw ray OB.
- Construct a normal at B.
- Draw the reflected ray BD (use a protractor to ensure **i** and **r** are equal).
- Extrapolate DB behind the mirror.
- Repeat the procedure with another ray OC.
- The two extrapolated rays meet at I where the image appears to be.
- Join O to I.
- Measure OA and AI.
- What do you notice?
- Measure the angle between OI and the mirror.
- Write down the properties of the images formed in a plane mirror.

Activity 3.8: Constructing a periscope

What you need

- A large piece of manila paper
- 2 plane mirrors (4 cm x 4 cm)
- Cellotape
- Protractor
- Razor blade or pair of scissors
- Plasticine

What to do

- Roll a manila paper to make a tube of diameter 3 cm.
- Cut a hole near each end to fit the mirrors at 45° as shown in Figure 3.13 below.

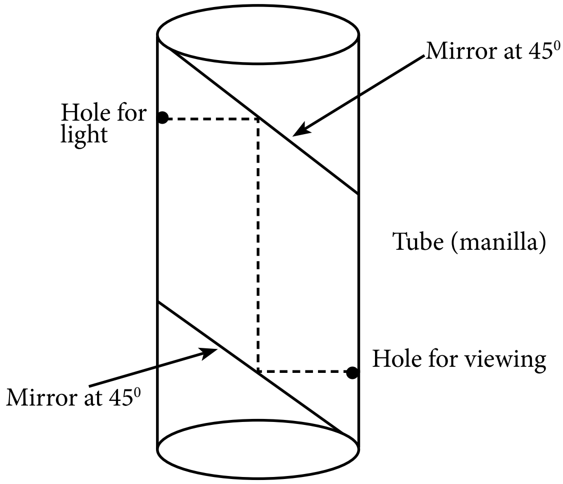


Figure 3.13

Observation

Use the periscope you have made to enjoy the view around you. Mention practical applications of a periscope.

Activity 3.9: Counting the number of images of an object placed between two plane mirrors inclined to each other

What you need

- Two plane mirrors
- Protractor
- A small coloured object

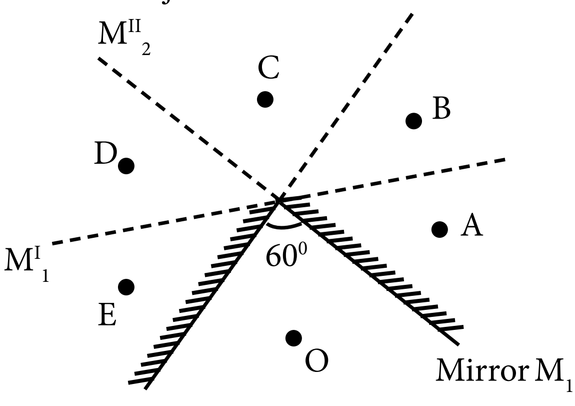


Figure 3.14

What to do

- Place a small object between two plane mirrors inclined to each other at 90°.
- Count the number of images in the mirrors.
- Repeat the procedure for 30°, 40°, 60°, 120°and180°.

Deduce the formula for determining the number of images for an object placed between two plane mirrors inclined to each other.

Activity 3.10: Making a Kaleidoscope

When an object is placed between two plane mirrors facing each other in a tube, a repeated pattern of images is formed. This is called a kaleidoscope.
In this activity, you will make your own kaleidoscope.

What you need

- Pieces of wood
- Two plane mirrors
- Glue

What to do

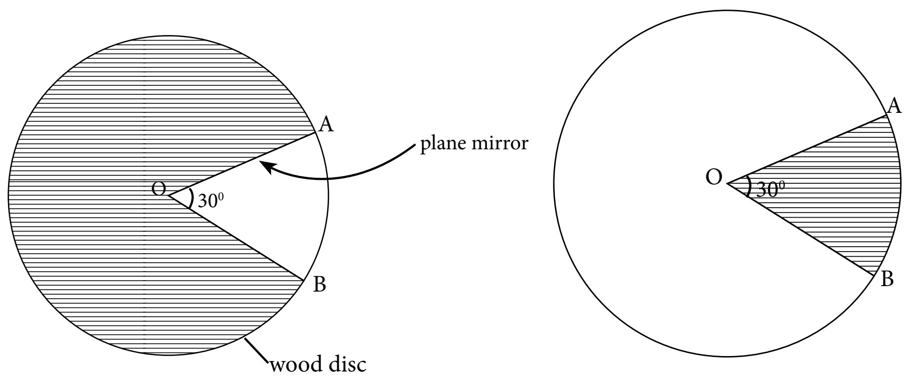


Figure 3.15

- Cut several circular discs of wood.
- Using a protractor, mark out shaded sector AOB, with angle AOB = 30°.
- Carefully cut out the shaded sector.
- Using wood glue, fix plane mirrors along OA and OB.

- Repeat the procedure by changing the angle to 20°, 40°, 50°, 60°, 90° and 120° using cardboard.
- Place one of the discs you made above at the bottom of the tube.
- You can now drop flowers or other small coloured objects into the tube.
- For each coloured flower you drop into the tube, apparently many others are "produced". Using discs with mirrors at different angles, you can enjoy this effect. This effect can be used to develop patterns for decorations.

Activity 3.11: Making reflective materials

What you need

- Paints of different colours
- Brushes
- Cardboard paper each of dimensions 20 cm x 20 cm

What to do

- Colour each of the cardboard papers with a different colour paint.
- View the cardboards in light at night to find out the best reflecting colours.
- Select three best reflecting colours and use them as warning signs on your compound.

Learning Points

When light is incident on a plane mirror (or any other smooth reflecting surface), it bounces back (gets reflected). Look at objects around you to see the different objects reflecting light.

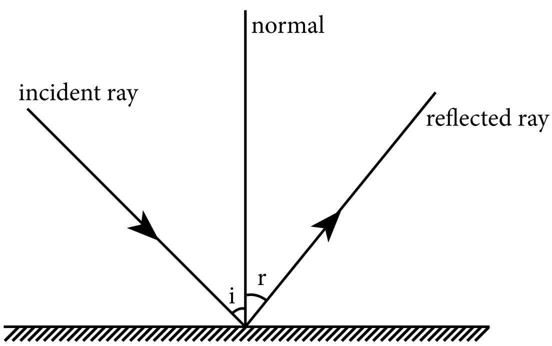
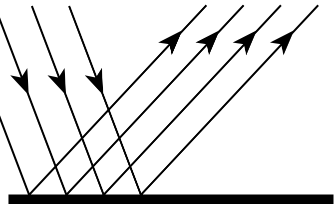
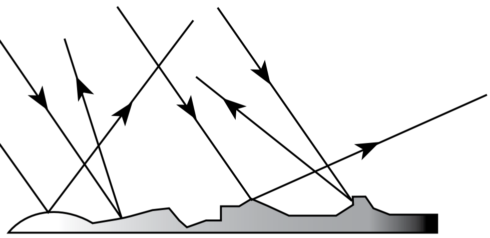


Figure 3.16

Types of reflection - Regular and irregular (diffuse) reflection



Regular reflection



Diffuse reflection

Figure 3.17

In order to see an object, light must be reflected from it first. In regular reflection, a parallel beam incident on a smooth plane surface is reflected as a parallel beam. The reflected beam is very bright and this makes it difficult to recognise details on the reflecting surface.

In irregular reflection, a parallel is incident on an irregular (rough) surface. The reflected rays are scattered in many directions. However, at each point where reflection occurs, the laws of reflection are obeyed. In this type of reflection, we are able to recognise the details of the reflecting surface because the reflected beam is not very bright.

The periscope

A periscope consists of two parallel plane mirrors facing each other. Light from the object is reflected from the first mirror and then from the second mirror before entering the viewer's eye.

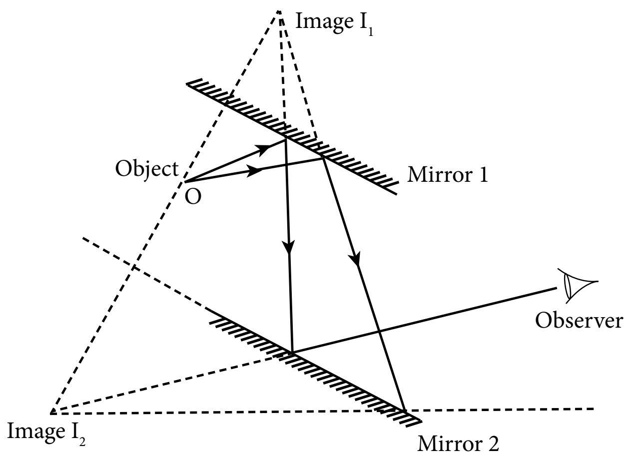


Figure 3.18

Mirror 1 forms image I_1
Mirror 2 views I_1 and forms image I_2
The observer sees I_2.
To draw this diagram accurately, you should note the following:

(i) The two mirrors must be parallel to each other.
(ii) A line joining I, O, I_2 is perpendicular to both mirrors.
(iii) $OI = OI_2$
(iv) You can now use the positions of I_1 and I_2 to complete the diagram.

Reflection of light from curved surfaces

Activity 3.12: Studying the properties of images formed in a concave mirror

What you need

- Concave mirror
- Screen

What to do

Method I

- Place the mirror very close to your face.
- Describe your image in the mirror.

- Move the mirror a short distance away from your face. What happens to the image?
- Repeat the process until when the mirror is very far away from your face.

Method II

- Point the mirror toward a distant object.
- Position the screen between the mirror and the object in such a way that you do not obstruct the line of view between the mirror and the object.
- Write down the properties of the image.
- Gradually increase the distance between the screen and the mirror, each time noting the properties of the image.

Precaution

Avoid pointing the mirror towards the sun.

Activity 3.13: Determination of the focal length of a concave mirror (illuminated object method)

What you need

- Concave mirror
- Bulb and holder
- Connecting wires
- Cells and cell holder
- Cardboard with a small hole in the middle
- Metre rule
- Screen
- Wire gauze
- Cello tape

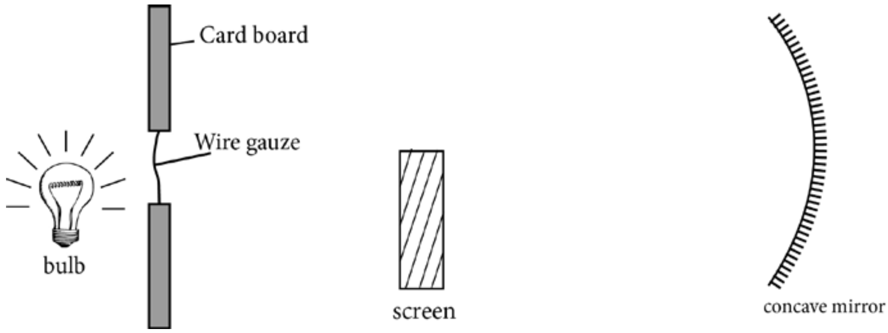


Figure 3.19

What to do

- Focus a distant object onto a screen.
- Measure the distance, f, between the mirror and the screen.
- Fix a wire gauze in the hole in the cardboard.
- Arrange the apparatus as in Figure 3.19.
- Light the bulb and place it behind the wire gauze.
- Adjust the distance, x, between the wire gauze and the screen to about 1.5 f.
- Move the screen until you obtain a focused image of the wire gauze.
- Measure the distance, y, between the screen and the wire gauze.
- Repeat the procedure for distances, x, of about 2.0 f, 2.5 f, 3.0 f, 3.5 f and 4.0 f
- Tabulate your results including values of x, y, x + y and xy.
- Plot a graph of xy against x + y
- Find the slope of the graph.
- The slope of the graph is equal to the focal length of the mirror.

Learning Points

Principal focus of a curved mirror is a point on the principal axis through which all rays originally parallel and close to the principal axis converge (for a concave mirror) or diverge from (for a convex mirror) after reflection from the mirror.

The principal focus for a concave mirror is real and for a convex mirror is virtual.
Focal length is the distance from the principal focus to the pole of the mirror.
It is positive for convex lenses and negative for concave lenses.

Symbol for focal length is f.

From knowledge beyond the scope of this book, it can be proved that
Radius of curvature = 2 x principal focus
r = 2f.

Activity 3.14: Making a solar cooker

What you need

- Silvery cigarette papers (or Aluminium foil)
- Glue
- Thin metal sheet 1m x 1m

What to do

- Fold the metal sheet into a semi-circular shape.
- Glue the silvery paper on the inner surface of the metal and ensure a clean unravelled finish.
- Point your curved surface towards the sun at mid-day.
- Test the hotness of the reflected heat from the sun.
- Adjust the curvature of the metal until a good reflector is obtained.
- Find out:
    - how much time your heater takes to boil one litre of water in a kettle
    - the best time of the day to use your heater
- Calculate the cost of your cooker.
- Calculate the savings in a month which would be made by a family which changes from charcoal stove to your solar cooker.

Activity 3.15: Making headlamp reflectors

What you need

- Aluminium foil
- Glue
- Thin metal sheet 30 cm x 30 cm
- Bulb
- Connecting wires

- Cell
- Cell holders

What to do

- Glue the aluminium sheet onto the metal sheet.
- Fold the metal sheet into a parabolic surface.
- By trial and error, locate the principal focus to the mirror (this can best be done at night) using a lit bulb.

Activity 3.16: Designing a security surveillance system

What you need

- Several convex mirrors
- Masking tape

What to do

- Design a security surveillance system using a number of convex mirrors for the school laboratory.
- Hang the mirrors in the pre-determined positions in the laboratory to test how the system works.

Learning Points

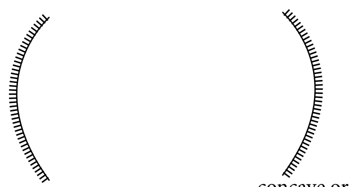


Figure 3.20

Terminology used

- **Pole** is the central point on the mirror.
- **Centre of curvature, C** is the centre of the sphere which the mirror makes part of**.**
- **Radius of curvature**, **r,** is the distance between the centre of curvature

and the pole.

- **Principal axis** is a line which goes through the pole and the centre of curvature.

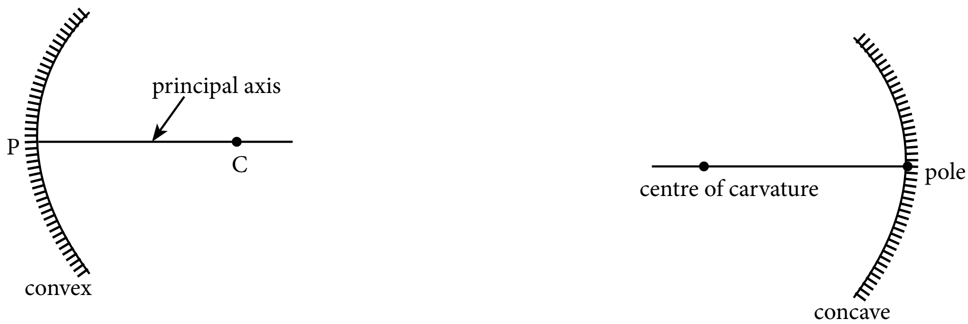


Figure 3.21

Reflection of rays originally parallel and close to the principal axis

Figure 3.22

As you may notice all incident rays originally parallel and close to the principal axis are reflected through single point (for a concave mirror) or seem to be coming from single point (for a convex mirror) after reflection. This point is called the principal focus (F).

Wide beams

When a wide beam of light is incident on a concave mirror of wide aperture (curvature), the reflected rays do not pass through the same point. The reflected rays seem to touch a curve called the **caustic curve** (or caustic surface). The tip (apex) of the caustic curve is at the principal focus. This surface may be seen in the cup of tea in a brightly lit room.

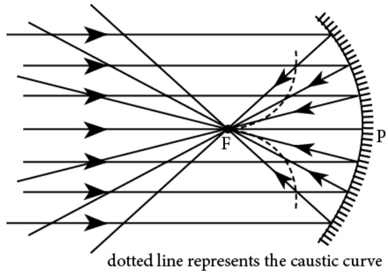


Figure 3.23

Concave reflectors

Consider a small bright bulb placed at the principal focus of a concave mirror. The reflected rays will be scattered in many directions. Only a small fraction of the reflected rays at the centre of the mirror will be reflected as parallel rays.

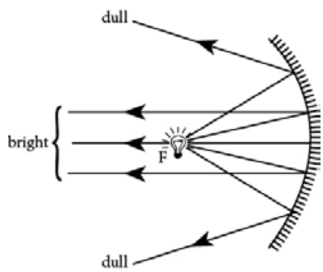


Figure 3.24

This type of reflector will be useless for a torch or a car headlamp because only the middle of the reflector will produce bright light.

Parabolic mirrors

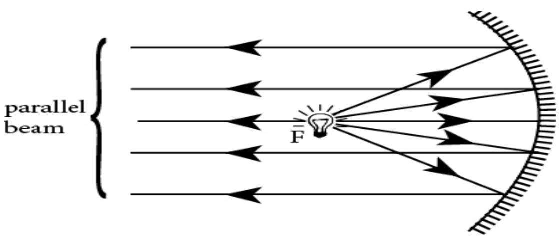


Figure 3.25

A parabolic mirror produces a wide parallel beam of light. The beam is bright even at the edges.

Images formed by curved mirrors

When drawing diagrams to obtain images formed by curved mirrors, we make use of four very useful rays:

1. All rays originally parallel and close to the principal axis converge to the principal focus for a concave mirror or appear to diverge from the principal focus after reflection for a convex mirror.
2. All rays through the centre of curvature are reflected back along their original path. This is because the centre of curvature is a centre of a sphere.
3. All rays incident through the principal focus are reflected parallel to the principal axis.
4. All rays incident at the pole are reflected at the same angle, i.e. the angle of incidence must be equal to the angle of reflection.

Note: The mirror is represented by a straight line because we are only treating rays close to the principle axis. This is a small section of the mirror which may be represented by a straight line.

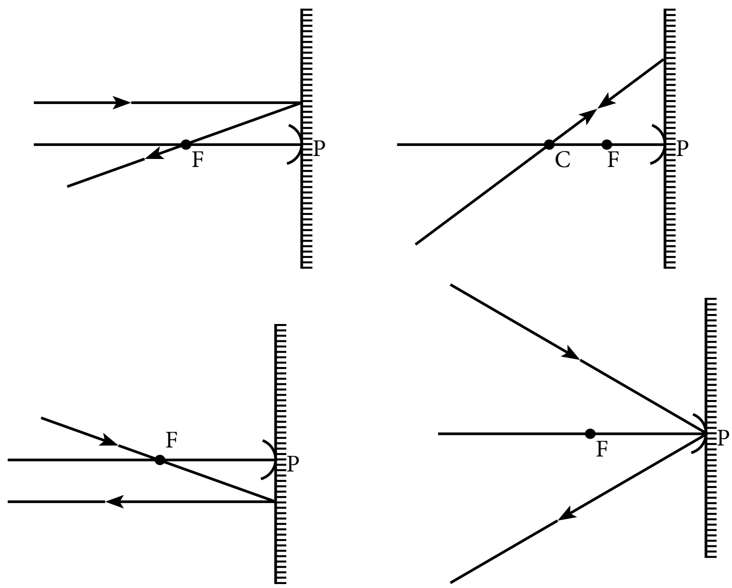


Figure 3.26

In the proceeding treatment we shall consider only those rays incident very close to the pole. Therefore the mirror shall be represented as a straight line with a small sign to indicate whether it is a concave or convex mirror.

In order to draw accurate ray diagrams,

a) All incident rays must originate from the same point on the object.

b) All real rays are drawn as full lines and all virtual rays are drawn as broken lines.

c) The image is formed where the reflected rays meet or seem to meet.

d) Always ensure that r = 2f

e) Always ensure that the mirror, object and image are perpendicular to the principal axis.

Images formed by concave mirrors

Concave mirrors

1. Object between F and P

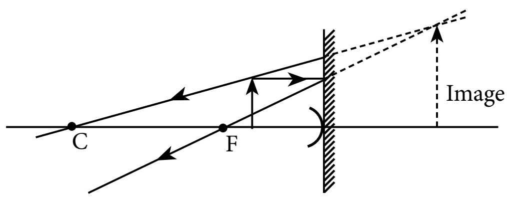


Figure 3.27

The image is

i) virtual

ii) upright

iii) magnified

iv) behind the mirror

2. Object at F

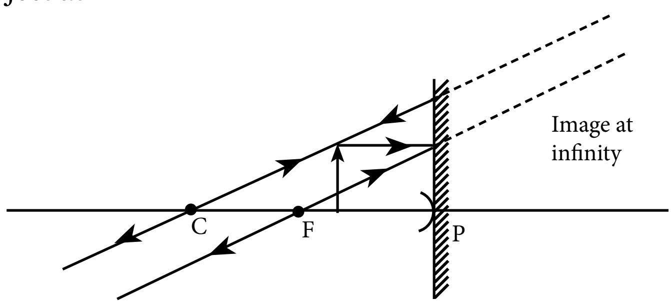


Figure 3.28

The image is at infinity (because parallel lines appear to meet at infinity).

3. Object between F and C

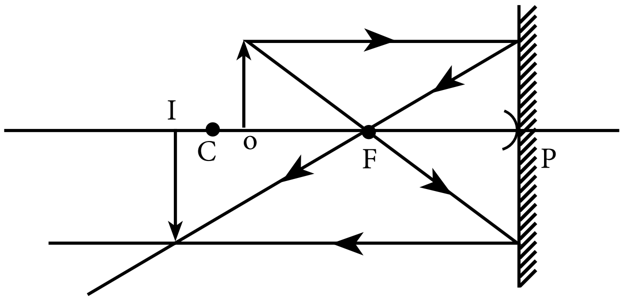


Figure 3.29

The image is

i) real
ii) inverted
iii) magnified
iv) beyond F

4. Object at C

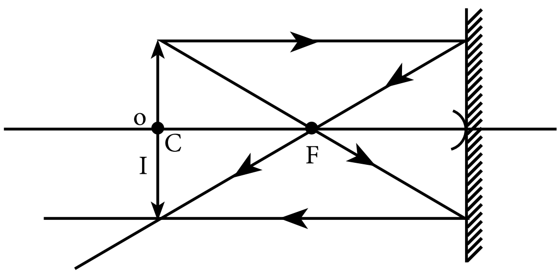


Figure 3:30

The image is

i) real
ii) inverted
iii) same size as the object
iv) at C

5. Object beyond C

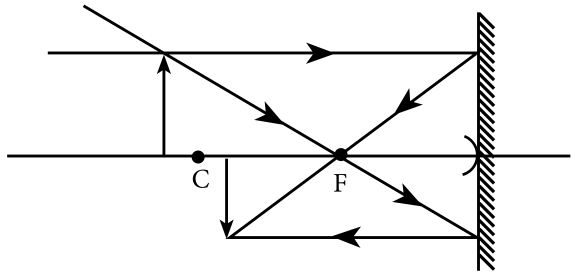


Figure 3.31

The image is

i) real
ii) inverted
iii) diminished
iv) between F and C

6. Object at infinity

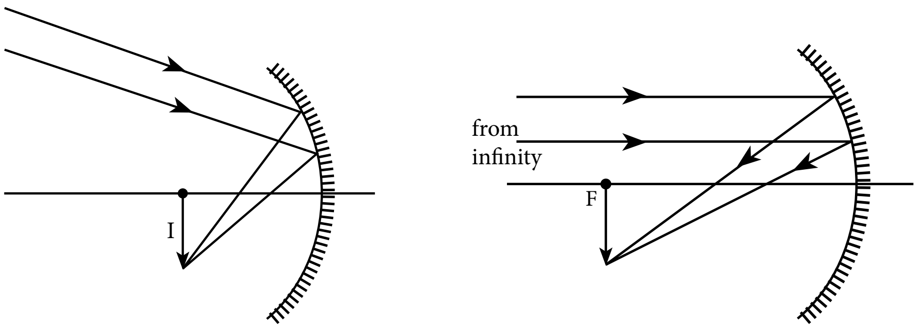


Figure 3.32

The image is

i) real
ii) inverted
iii) diminished
iv) at F

Indeed the focal length of a concave mirror can be roughly obtained by focusing a distant object on a screen, the distance between the screen and the mirror is the focal length.

Images formed by convex mirrors

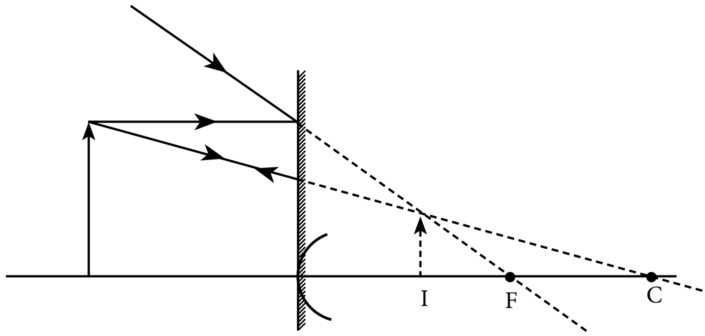


Figure 3.33

Wherever the object is placed the image is always;

i) virtual
ii) upright
iii) diminished, and
iv) behind the mirror,

Sometimes the diagrams may not be able to fit on the page of your book. In this case, it is advisable to work using a scale.

Magnification

When the mirror is used, sometimes the images may look bigger than the object (magnified) or smaller than the object (diminished).

$$magnification = \frac{size\ of\ image}{size\ of\ object}.$$

Magnification has no units and cannot be negative.

Uses of curved mirrors

(a) Concave

They are used as

i) Dentist's mirror
ii) Solar concentrators
iii) Shaving mirrors

iv) Torch reflectors

v) In car headlamps (these are largely parabolic)

(b) Convex mirrors

i) They are placed in corners for motorists to see oncoming vehicles.

ii) They are used in large shops to monitor activities of customers.

iii) They are used as driving mirrors (side mirrors). The major advantages of convex mirrors as driving mirrors are that they form diminished, upright images and they give a wide field of view and its disadvantage is that it is difficult to estimate the distance and speed of a vehicle coming from behind.

iv) "Under car" surveillance mirrors

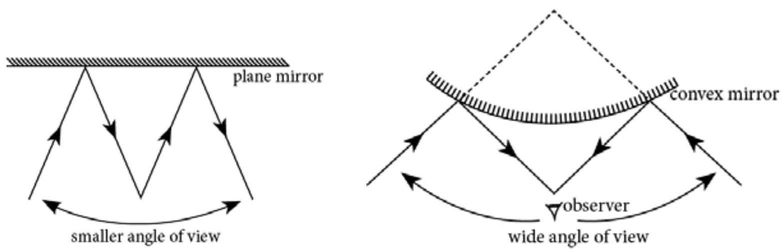


Figure 3.34

Refraction of light at a plane surface

When light is incident on a boundary between two optical media, it changes its direction and speed. This is because light moves at different speeds in media of different optical densities.
When a ray is incident normally at a boundary between two optical media it goes through undeviated (without change of direction) although its speed changes.

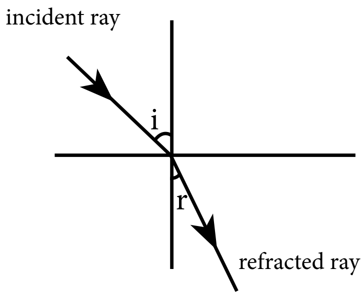


Figure 3.35

Activity 3.17: Investigating the passage of light through a glass block

What you need

- A set of geometrical instruments
- White plane sheet of paper
- Glass block
- 4 optical pins
- Soft board
- 4 drawing pins
- Foot ruler

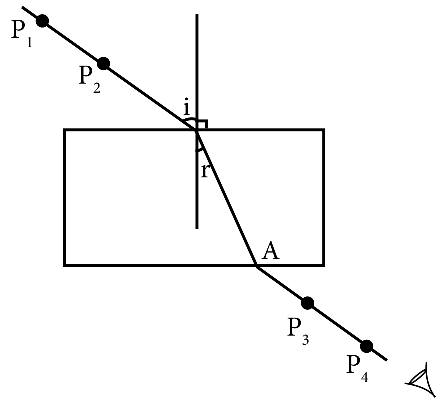


Figure 3.36

What to do

i) Using 4 drawing pins, fix the white sheet of paper on a soft board.

ii) Draw the outline of the glass block.

iii) Draw a normal ON about 2cm from the edge of the outline (on the longer side).

iv) Construct an angle of incidence i = 10° from the normal.

v) Place back the glass block on the outline so that it fits exactly.

vi) Fix pins P_1 and P_2 into the board on the line representing the incident ray as in figure 3.36

vii) Looking through the glass block as in Figure 3.36, fix the pins P_3 and P_4 into the board so that P_1, P_2 P_3 and P_4 lie in a straight line.

viii) Join P_3 and P_4 to meet the outline of the glass block at A.

ix) Join O to A.

x) Measure the angle of refraction, r.

xi) Calculate sin i and sin r and the ratio $\frac{\sin i}{\sin r}$

xii) Repeat the procedure (iv) to (xii) above for angles of incidence i = 20°, 30°, 40°, 50° and 60° and fill your results in the table below.

i(°)	r(°)	sin i	sin r	$\frac{sin\ i}{\sin\ r}$
10				
20				
30				
40				
50				
60				

Table 3.2

What do you notice?

xiii) Plot a graph of sin i against sin r and find its slope.

Glancing angle is the angle between the incident ray (or emergent ray) and the refracting surface. What can you say about the incident ray and emergent ray?

Activity 3.18: Investigation of refraction through a glass prism

What you need

- Glass prism
- Soft board
- White sheet of paper
- 4 optical pins

What to do

- Place the white sheet of paper on the soft board.
- Place the triangular face of the prism on the paper and trace its outline ABC as shown below.

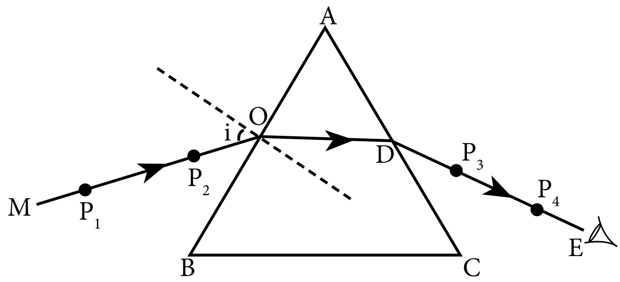


Figure 3.37

Improve this diagram

- Draw a perpendicular line NO to the side AB.
- Draw a line MO at an angle i = 20° to NO.
- Fix two points P_1 and P_2 along the side AC and move your head until pins P_1 and P_2 appear to be in line.
- Fix pins P_3 and P_4 so that they appear to be in line with P_1 and P_2 as seen through the prism.
- Remove the optical pins and the glass prism.
- Draw a line through the holes made by P_3 and P_4 to meet the side AC at D.
- Join O to D.
- Explain the bending of the ray at O and D

Learning Points

Refractive index

The ratio $\frac{\sin i}{\sin r}$ is the refractive index, n, of the material for light entering the material from air, i.e. $n = \frac{\sin i}{\sin r}$

The refractive indices of glass and water are approximately 1.5 and 1.3 respectively.

Laws of refraction

For two media in contact;

1. The incident ray, refracted ray and the normal at the point of incidence lie in the same plane.
2. The ratio of the sine of angle of incidence to the sine of angle of refraction is constant (Snell' law).

Principle of reversibility of light in refraction

Consider light was travelling from glass to air

Then, according to Snell's law $n' = \dfrac{\sin\ r}{\sin\ i}$.

You may notice that $n' = \dfrac{1}{n}$

Effects of refraction

Consider a coin O placed at the bottom of a tank of water.

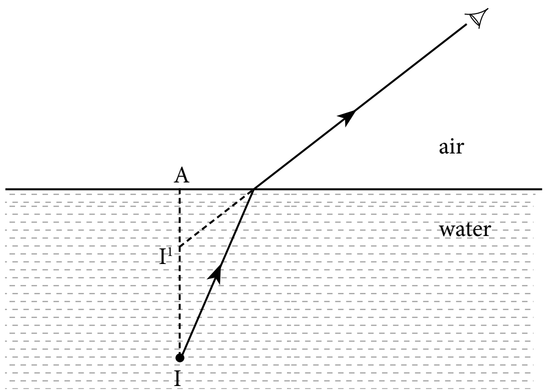


Figure 3.38

When light is moving from water to air (i.e. from a medium of high density to a medium of low density), it is refracted away from the normal as in figure 3.38 above. When the refracted ray is extrapolated (extended) backwards, it meets the normal which passes through the coin at I. The observer sees the coin is at position I. The coin appears to have been displaced to I.

OI = displacement

AI = apparent depth

OA = real depth

Theory beyond the scope of this book shows that

$$refractive\ index,\ n = \frac{real\ depth}{apparent\ depth}$$

Thus the tank;

- Appears shallower (AI is less than OA).
- Wider at the bottom (because the refracted ray ‘is coming from the side of the tank instead of coming from the bottom).

Total internal reflection

Consider a monochromatic (single colour or single wavelength) ray moving from glass to air (from a more dense to a less dense medium). For a small angle of incidence, some light is refracted into air and the rest is internally reflected in the glass. When the angle of incidence is increased, the angles of refraction and reflection both increase. At a particular angle of incidence, called the critical angle, *c*, the refracted ray grazes the surface (is along the surface of the glass).

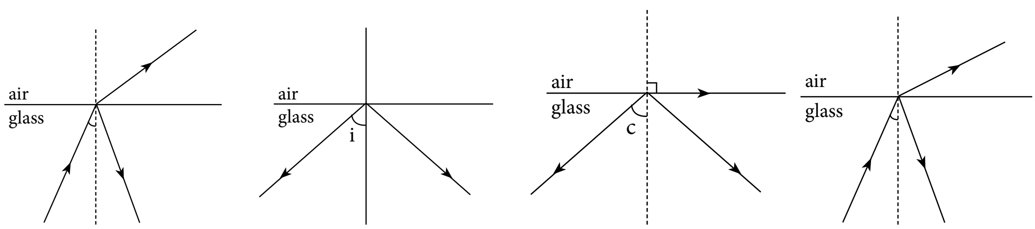


Figure 3.39

In this case, the angle of refraction is 90°. When the angle of incidence is increased beyond the critical angle, all the light is totally internally reflected.

Thus for total internal reflection to take place,

- Light must be travelling from a denser medium to a less dense medium.
- The angle of incidence must be greater than the critical angle.

Mathematically, from glass to air, we may write the following:

$$n' = \frac{\sin\ c}{\sin\ 90°} = \frac{\sin\ c}{1},$$

where n' is the refractive index of the glass-air boundary for light travelling from glass to air.

From the principle of reversibility of light,

$$n' = \frac{1}{n}$$

where *n* is the refractive index of the glass-air boundary for light travelling from air to glass.

Therefore the refractive index, n, of the glass is given by:

$$n = \frac{1}{\sin\ c}$$

Thick plane mirrors

When light is incident on a thick plane mirror, some of the light is refracted and some is reflected. In addition, some of the light energy is absorbed. The refracted light is totally internally reflected at the back of the mirror. The light which is totally internally reflected undergoes further refractions, reflections and absorptions. Thus the emergent rays become progressively fainter.
The brightest image is the one which is as a result of reflection from the back (silvered surface) of the mirror. It is the second image.

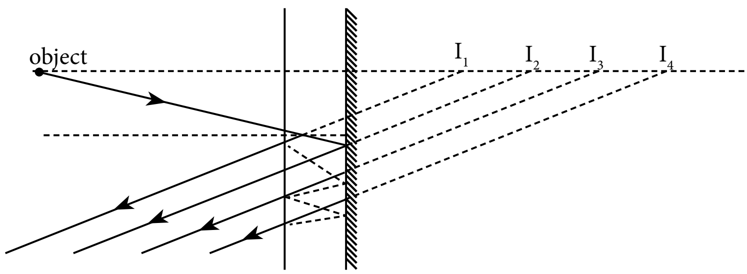


Figure 3.40

Natural phenomena exhibiting total internal reflection

The mirage

On a hot day, the air near the ground is hot and its density is low. The density of the air progressively decreases upwards, away from the ground. Light from the sky is progressively refracted away from the normal as it approaches the ground. At the ground, the light is totally internally reflected. Thus the ground acts as a mirror. The image of the sky appears on the ground. This gives the impression of the presence of water on the ground.

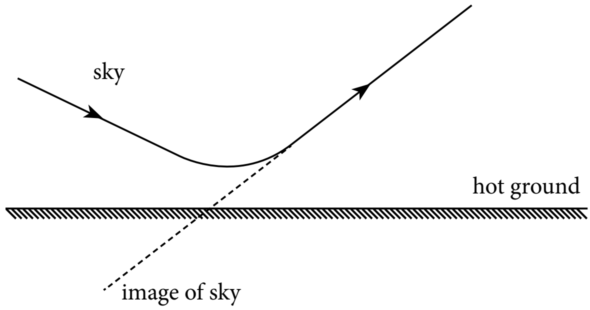


Figure 3.41

Applications of total internal reflection

Total internal reflecting prisms

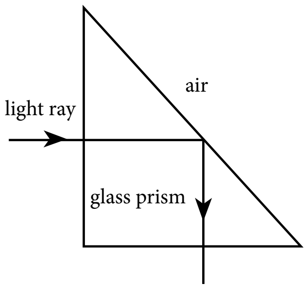


Figure 3.42

If the refractive index of glass is 1.5. Then from the formula, $n = \frac{1}{\sin\ c}$, the critical angle of glass is 41.8°.

Light which enters normally on the edge of a right angled glass prism is totally internally reflected in the prism. The side of the prism where total internal reflection takes place acts as a plane mirror.

This type of prism is used in prism binoculars and prism periscopes. They are preferred to the plane mirror because the images formed are bright and free from distortion. In plane mirrors, incident light rays are refracted and reflected many times leading to loss of energy, leading to decrease in brightness and distortion of the image.

Follow-up activity

Bicycle reflectors are very important for keeping safe on the road at night. Find out how they work.

Dispersion and colour

Passage of white light through a prism

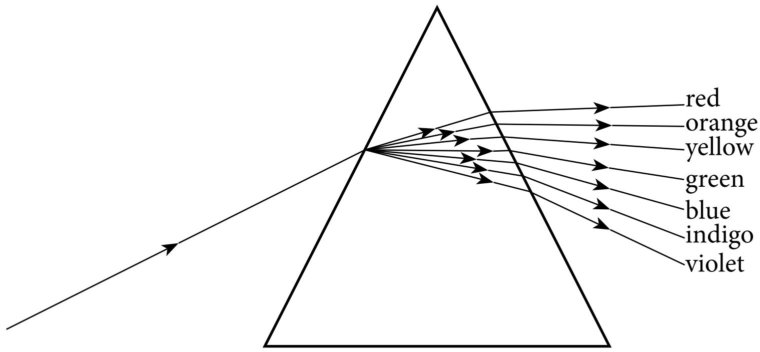


Figure 3.43

The prism splits the white light (day light) into a spectrum of colours, the components of white light are violet, blue, green, yellow, orange and red taken in that order. This process is called **dispersion** of white light. Dispersion occurs because the different components in white light move at different speeds through the glass.

Dispersion is the splitting of white light into its component colours.

The boundaries between the different components are not clearly defined. This type of spectrum is an impure spectrum.

Production of a pure spectrum

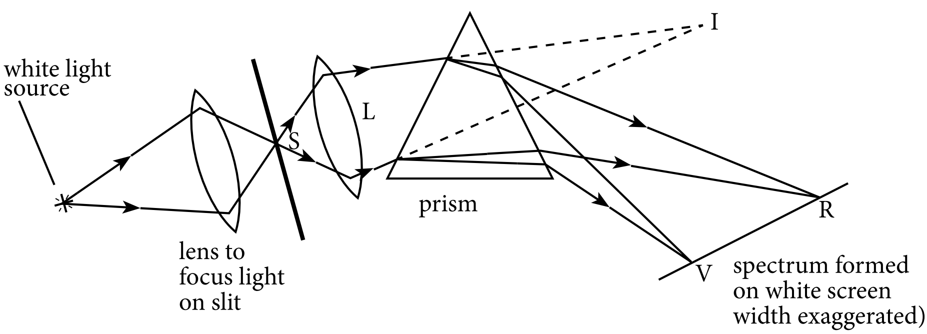


Figure 3.44

The collimator contains a special lens which produces a parallel beam of white light which is directed towards a prism placed on a rotating table of the spectrometer. This beam of white light is then dispersed. The dispersed light falls on a special lens which focuses rays of coloured light on the same position on the screen (see diagram). This arrangement produces a spectrum with sharp boundaries between the adjacent components of white light..

Mixing coloured lights

Interesting results are obtained by mixing different coloured lights.

Primary and secondary colours

Red, green and blue are called primary colours because they cannot be obtained by mixing any other coloured lights.

Secondary colours are the colours obtained by mixing two coloured lights. They are yellow, magenta and cyan.

Red +Green = Yellow

Green + Blue = Cyan

Red + Blue = Magenta

Red + Green + Blue = White

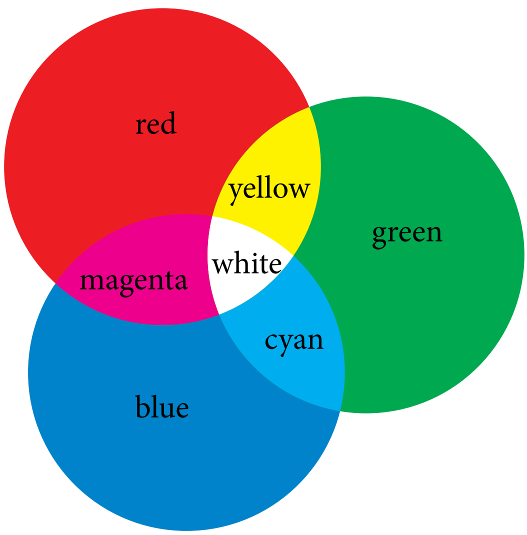


Figure 3.45

Complementary colours

Any two coloured lights which combine to give white light are called complementary colours. One of them must be a secondary colour and the other one a primary colour.

Yellow + blue = white
Magenta + green = white
Cyan + red = white

Appearance of objects in coloured lights

The colour of an object is the colour of the light it reflects, for example

- a blue object absorbs all colours and reflects only blue light.
- a red object absorbs all colours and reflects only red light.
- a yellow object reflects only yellow, red and green, and absorbs all other colours.
- a black object absorbs all colours and reflects none
- a white object reflects all colours and absorbs none.

Note:
Mixing of coloured paints is different from mixing coloured lights and is beyond the scope of this book.

Light filters

The colour transmitted by a filter is the same colour it reflects. The filter absorbs all the other colours, for example:

- a green filter absorbs all colours and transits only green light.
- a red filter absorbs all colours and transmits only red light.
- a yellow filter transmits yellow, red and green and absorbs all other colours.
- a black filter absorbs all colours and transmits none
- a white filter transmits all colours and absorbs none.

Infra-red and ultra violet radiation

The mercury column of a thermometer whose bulb is blackened rises when the thermometer is placed just beyond the red patch. This would mean that there is some invisible radiation there. This radiation is called infra-red radiation (IR). When the bulb of the thermometer is placed just beyond the violet again it is able to detect some other invisible radiation. It is called ultraviolet radiation (UV).

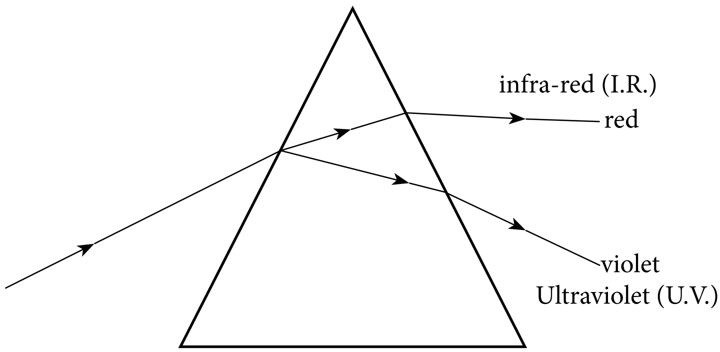


Figure 3.46

The complete electromagnetic spectrum

Visible light, UV and IR are part of a wider spectrum. The complete electromagnetic spectrum consists of many components. All the components are transverse waves traveling at a speed of 3 x $10^8 ms^{-1}$ in air. Electromagnetic waves can also travel through a vacuum.

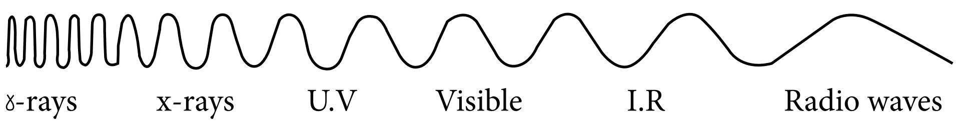


Figure 3.47

Properties and uses of components of the complete electromagnetic spectrum:

	Component	Property / use
1	Radio waves	• Very long wavelength • Very low frequency • Used in radio communications
2	Microwaves	• Used in microwave cookers and in communication between satellites
3	Infrared	• This is the heat we experience in our everyday life. • Absorbed by some types of glass • Used by cameras when taking photographs at night and in bad weather conditions. • Affects photographic plates • Used in short range remote control operations
4	Visible light	• This is the light which enables us to see.
5	Ultraviolet	• Initiates some chemical reactions • Affects photographic plates • Sunlight and the welders flame contain a lot of it.
6	X-rays	• Very short wave length • Very high frequency (See X-rays for a more detailed treatment)
7	Gamma rays (γ-rays)	• Very short wave length • Very high frequency (See radioactivity for a more detailed treatment)

Table 3.3

Refraction through thin lenses

Types of lenses

Figure 3.48

Passage of a beam of light through a lens

Consider a beam of rays parallel and close to the principle axis which is incident on the lenses as in Figure 3.49. The refracted rays converge at the principal focus, F (for a convex lens) or diverge from F (for a concave lens).

Common lens terminology

The principal axis is a line which runs through principal foci of the lens (a lens has two principal foci).

Principal focus of a lens is a point on the principal axis through which all rays originally parallel and close to the principal axis converge (for a convex lens) or appear to diverge from (for a concave lens) after refraction through the lens.

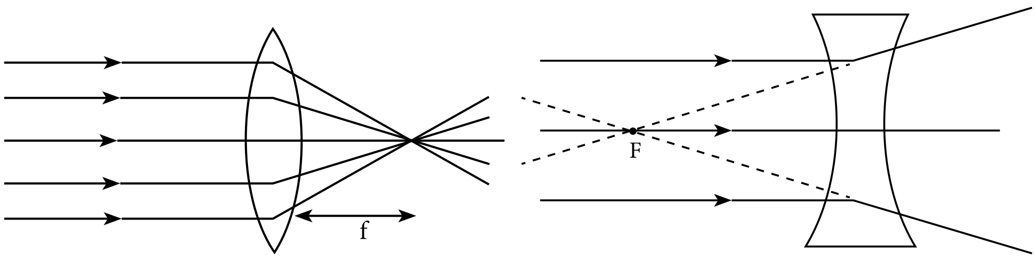


Figure 3.49

The principle foci for a convex lens are real and for a concave lens they are virtual.

Focal length is the distance from the principal focus to the point where the principal axis meets the lens (optical centre).

Symbol for focal length is *f*.

Focal length, f, is positive for convex lenses and negative for concave lenses.

Activity 3.19: Determination of the focal length of a convex lens

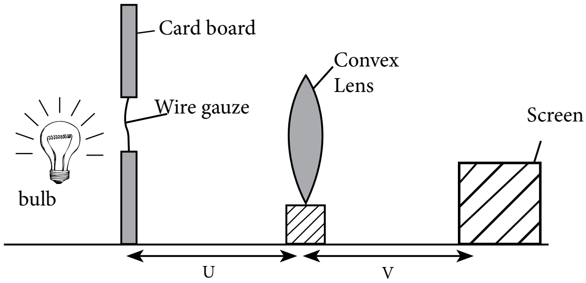


Figure 3.50

What you need

- Convex lens
- Bulb and holder
- Connecting wires
- Cells and cell holder
- Screen
- Metre rule
- Wire gauze
- Lens holder
- Cellotape
- Cardboard with a hole in the centre

What to do

- Focus a distant object onto a screen.
- Measure the distance, f, between the lens and the screen.
- Fix a wire gauze in the hole in the cardboard.
- Assemble the apparatus as in Figure 3. 50.
- Light the bulb and place it behind the wire gauze.
- Adjust the distance, x, between the wire gauze and the lens to 1.5 f.
- Move the screen until you obtain a focused image of the wire gauze.
- Measure the distance, y, between the screen and the lens.
- Repeat the procedure for distances, x, of about 2.0 f, 2.5 f, 3.0 f, 3.5 f and 4.0 f
- Tabulate your results including values of x, y, x + y and xy.
- Plot a graph of xy against x + y

- Find the slope of the graph.

The slope of the graph is focal length of the lens.

Follow-up activity

What you need

- Manila paper
- 2 convex lenses (f = 10 cm and f = 15 cm)
- 2 concave lenses (f = 10 cm and f = 15 cm)
- Glue

What to do

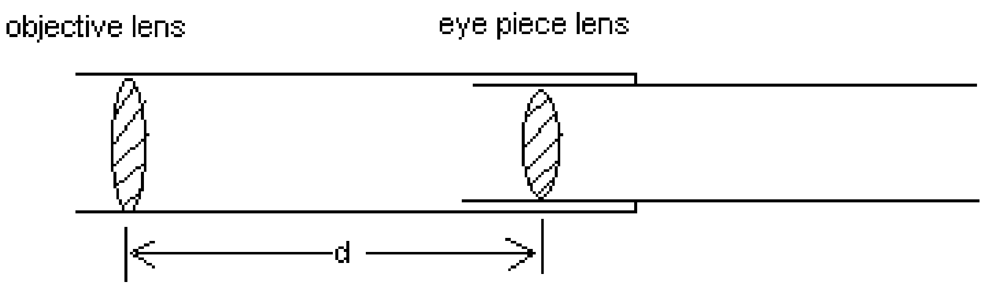


Figure 3.51

- Make two cylindrical tubes using the manila paper of diameter equal to that of the lenses.
- Fix a lens in each tube so that the diameter is perpendicular to the length of the tube.
- Make sure that one tube just fits into the other as in Figure 3.51.
- Adjust the distance, d, between the lenses by pushing or pulling the inner tube.
- By looking through one open end, focus at a distant object.
- Repeat using both concave and convex lenses until you get the most effective and convenient telescope.
- Measure the separation of the lenses.
- Use lenses of different focal lengths for the eye piece to study the effect on the magnification of the telescope.

- Replace the eye piece lens with a concave and note the effect (Note: the eye piece is the lenses nearest to the eye).

Learning Points

The power of a lens is the reciprocal of its focal length in metres. The unit of power of a lens is dioptres (D)

For example if the focal length of a lens is 20cm, its power, $P = \frac{1}{0.4} = +2.25D$.

If the focal length is -20cm (for a concave lens), then power is $P = \frac{1}{-0.2} = -5D$

Passage of rays through a lens

All rays originally parallel and close to the principle axis are refracted through the principal focus (for a convex lens) or diverge from the principal focus after refraction (for a concave lens).
All rays incident through the principal focus are refracted parallel to the principal axis.
All rays incident at the point where the principal axis meets the lens (optical centre) go through the lens un-deviated.

Images formed by lenses

Convex lenses
We shall only consider those rays incident close to the principal axis. The lens therefore can comfortably be drawn as a straight line. Real rays shall be represented by unbroken lines and imaginary (virtual) rays be represented by broken (dotted) lines.

Object between F and lens

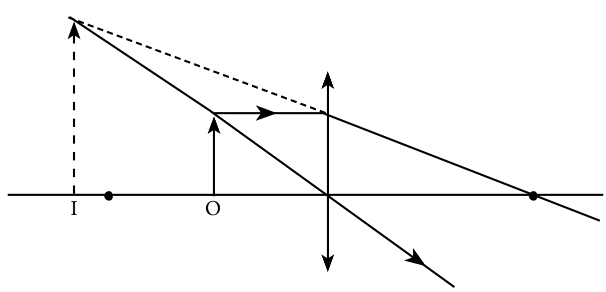


Figure 3.52

The image is

i) virtual
ii) upright
iii) magnified
iv) same side as the object

1.Object at F

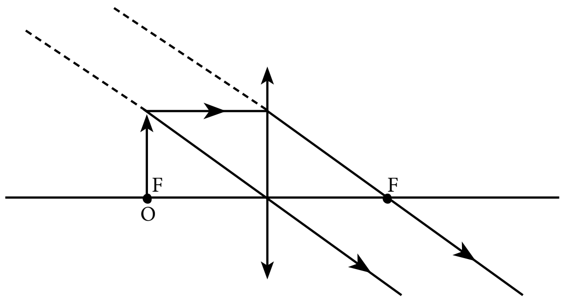


Figure 3.53

The image is at infinity (because parallel lines appear to meet at infinity).

2. Object between F and 2F

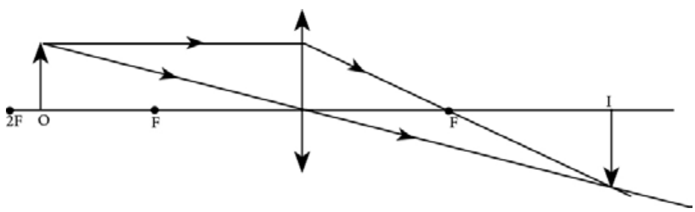


Figure 3.54

The image is

i) real
ii) inverted
iii) magnified
iv) beyond F

3. Object at 2F

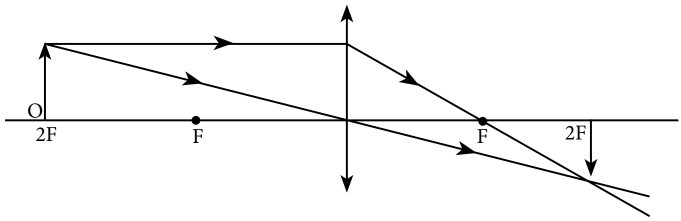


Figure 3.55

The image is

i) real
ii) inverted
iii) same size as the object
iv) at 2F

4. Object beyond 2F

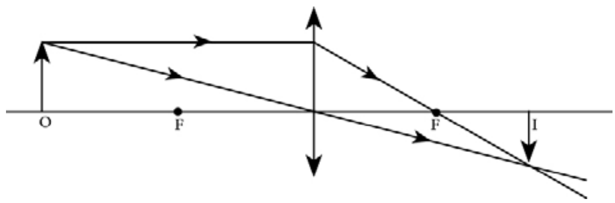


Figure 3.56

The image is

i) real
ii) inverted
iii) diminished
iv) between F and 2F

5. Object at infinity

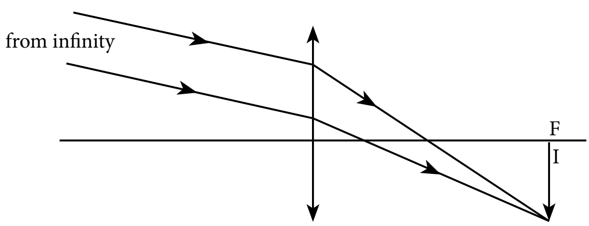


Figure 3.57

The image is

i) real
ii) inverted
iii) diminished
iv) at F

Indeed, the focal length of a convex lens can be roughly obtained by focusing a distant object on a screen, the distance between the screen and the lens is the focal length.

Concave lenses

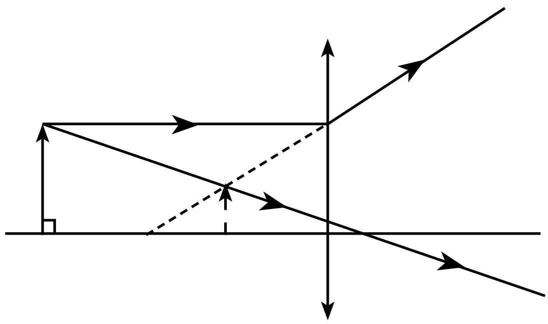


Figure 3.58

Wherever the object is placed, the image is always

(i) virtual
(ii) upright
(iii) diminished
(iv) between the principal focus and the lens.

Sometimes, the diagrams may not be able to fit on the page of your book. In this case, it is advisable to work using scale diagram.

Applications of lenses

The magnifying glass

As we saw earlier, an object placed between the principal focus and a convex lens always produces a magnified image. Magnifying glasses find many uses in science and industry.

The projector

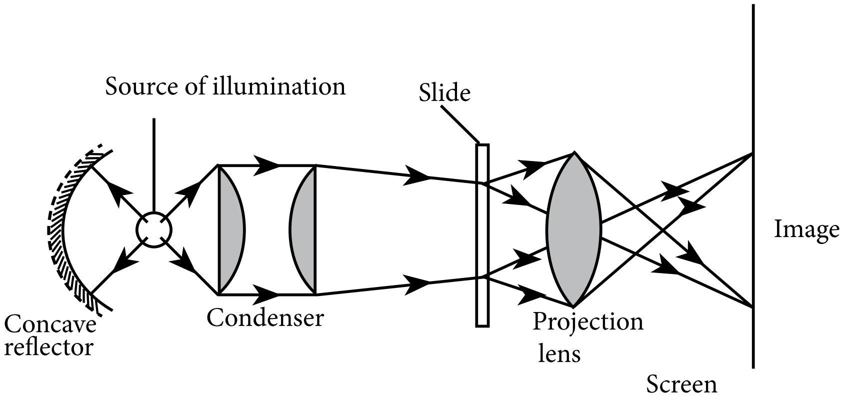


Figure 3.59

A very bright bulb is positioned at the centre of a curvature of the concave mirror. The concave mirror reflects all the light back. This reduces loss of light. Again the bulb is positioned at the focal point of the combination of the plano-convex lenses. This combination is called the condenser. It brings the rays close together and concentrates the light to make it brighter. A film containing images to be screened is placed immediately after the condenser. A projection lens is positioned between the film and the screen in such a way that a magnified real image is projected on a screen several metres away.

The human eye and the lens camera

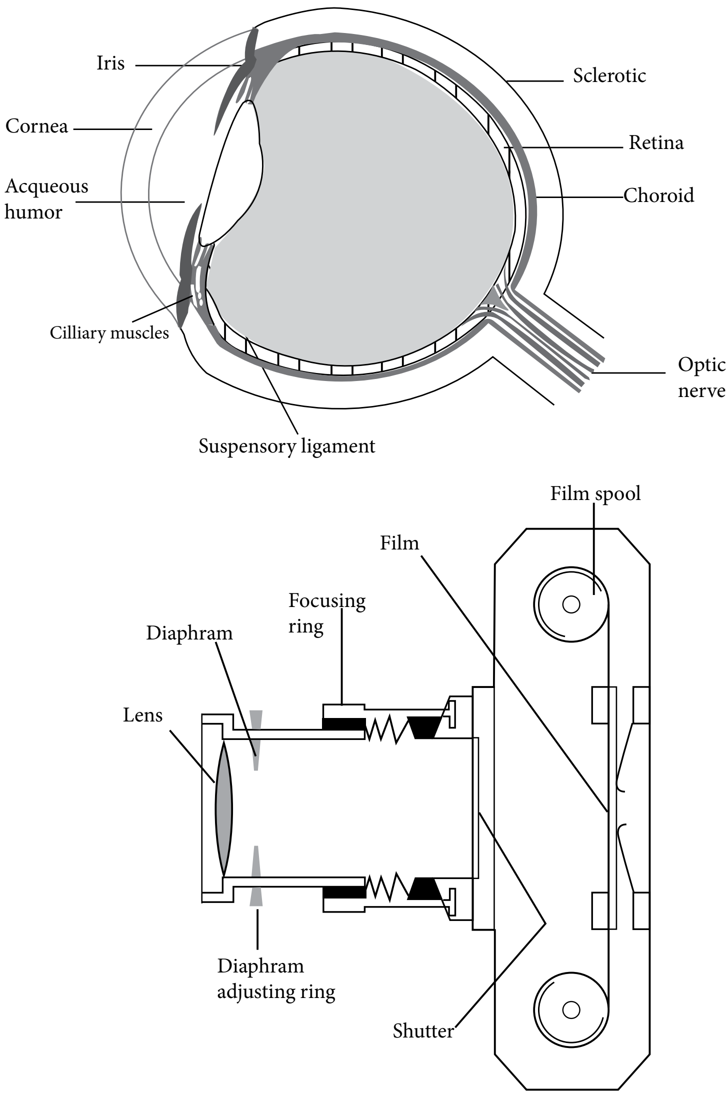


Figure 3.60

The human eye is a natural optical 'device' while a lens camera is an artificial optical device. Light must be reflected from an object in order to be able to see it. The lens refracts and projects the light rays on a screen.

- Images form on a 'screen' called the retina in the eye or a film in a lens camera. The images are real and inverted but in the human eye the brain turns them round so that they appear upright.

- Ciliary muscles pull (increase the focal length of lens) or relax (decrease the focal length of lens), whereas in a lens camera, a focusing ring is used to vary the distance between the lens and the camera in order to focus the image on the screen. Accommodation is the ability of the eye to focus objects at different distances from it.
- The pupil is an opening into the inner eye. It controls the amount of light entering the eye. When there is too little light, for example, at night the pupil is wide open and vice versa. In a lens camera, the diaphragm carries on this purpose.
- The eyelid opens to allow light enter the eye while in a lens camera, the shutter opens to allow in light when capturing an image. The eye is constantly 'taking photographs'!

Comparison of the human eye and a lens camera

	Purpose	**Lens camera**	**Human eye**
1	Refraction and projection of image	lens	eye lens
2	Screen where images form	film	retina
3	Focusing	focusing ring	Ciliary muscles
4	Regulating amount of light entering	diaphragm	pupil
5	Allowing light to enter	shutter	eyelid

Table 3.4

What are the major differences between a human eye and a lens camera?

Chapter 4: Waves

Introduction

A wave on the pond, waves on the lake, waves everywhere! The earthquake shakes the whole world and waves sink ships! Every day we experience waves in one form or another. Remember the devastating tsunami wave.
Sound waves, water ripples, waves on strings and in pipes are the common examples of waves. Many waves are invisible but have visible effects. In this chapter, you will study the properties and characteristics of waves and their effects on matter.

Wave motion

Introduction
A wave is a periodic disturbance of a medium. There are many examples of waves. You have made or seen waves on water (called water ripples) and on strings.

Activity 4.1: To demonstrate wave motion

Part I
What you need
- A long string
- A large surface of water, e.g. A pool
- Coloured objects like pieces of plastic or empty jerry cans
- A large surface of water, e.g. a pool
- Coloured objects like pieces of plastic

What to do
Method I
- Tie the coloured objects at equal distances on the string.

- Place the string on the surface of water in such a way that the objects lie in a straight line.
- Generate a wave at the beginning of the string.
- Observe the motion of the objects.
- What happens to the objects as time passes?

Method II

- Place the coloured objects on water in such a way that they lie in a straight line.
- Generate a wave at the end of the rope.
- Note how the displacement of the object changes with time.

Activity 4.2: Making wavelike models

What you need

- Flexible wires of diameter 1 mm
- Beads of different colours with holes
- Glue
- Coloured pieces of paper
- A razor blade

What to do

- String the beads on the wires making sure a particular colour is repeated after a regular interval (use as many colours as possible).
- Glue the beads onto the wire.
- Bend the wire to make a wavelike pattern.
- Combine several wavelike patterns to make an interesting art piece.
- You can also cut out wavelike patterns from a manila paper.
- Glue the differently coloured wavelike pattern to come up with an interesting art pattern.

Learning Points

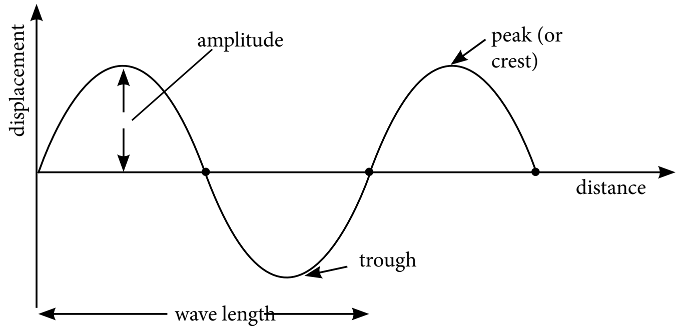


Figure 4.1

General properties of waves

Terminology used

- **Amplitude** is the maximum displacement of a particle from the equilibrium position. It is measured in metres (m).
- **Wavelength** (λ) is the distance between two successive crests or troughs. It is measured in metres (m).
- Equilibrium position is the undisturbed or rest position.
- Displacement is the distance the object or particle is displaced from the undisturbed position.

Figure 4.2 below shows how the displacement of a single object (or 'particle') varies with time.

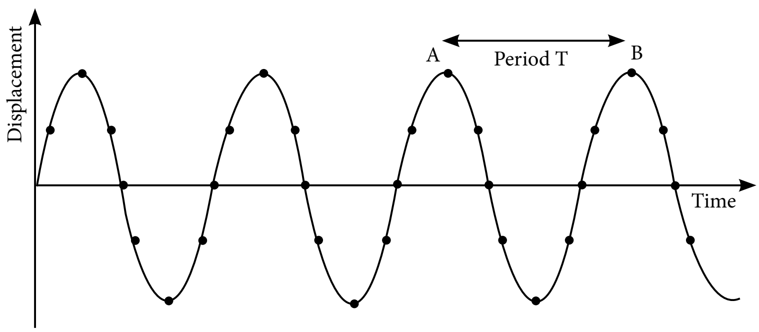


Figure 4.2

The positions of the object also trace out a wave with time as the object (particle) oscillates up and down.

Terminology used in waves

- A full oscillation or a full wave is called a **cycle**.
- **Period T**, is the time taken to complete one full cycle. It is measured in seconds (s).
- **Frequency f**, is the number of cycles made in one second. It is measured in Hertz (Hz) or cycles per second (s^{-1})

Relationship between period and frequency

- It takes T seconds to complete one cycle.
- The number of cycles completed in one second is therefore $\frac{1}{T}$.
- This is the definition of frequency, f.

—

Velocity of a wave

The wave moves a distance, **λ,** in T seconds at a speed v.
Using the expression *Distance = velocity x time.*
We have $\lambda = v \times T$.

But $T = \frac{1}{f}$
Therefore,

$\lambda = v \times \frac{1}{f}$
$\boldsymbol{v = f\lambda}$.

- **Ray:** A ray is a direction or a path taken by a wave. It is represented by a line with an arrow pointing in the direction of the wave.

- **Phase:** This is the state of vibration of a particle in a wave. Two particles are said to be vibrating in phase if their state of vibration is the same.
- **Wavefront:** This is a line through an advancing wave in which all the particles in that line are vibrating in the same phase.

Straight wavefronts

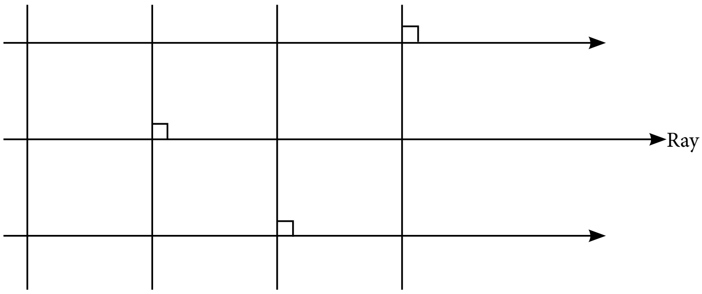


Figure 4.2

Circular wavefronts

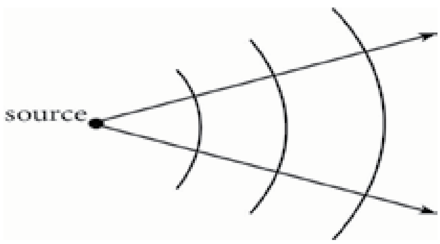


Figure 4.3

From Figure 4.3 above, you can note that the rays are perpendicular to the wavefronts. This knowledge will be useful in future.

How would you generate both types of wavefront on the surface of water?

Types of waves:

We can classify all waves into two categories:

1. Mechanical waves

   This type of waves requires a medium for propagation. Examples of mechanical waves include water ripples, sound waves, waves on strings and ultrasonic waves.
2. Electromagnetic waves

This type of waves does not require any medium for propagation. Examples of electromagnetic waves include light waves, infra-red rays and ultra-violet rays
Note: All waves are as a result of vibrations caused in the medium.

Transverse waves

In a transverse wave, the particles oscillate (move to and fro) perpendicular to the direction of the wave.

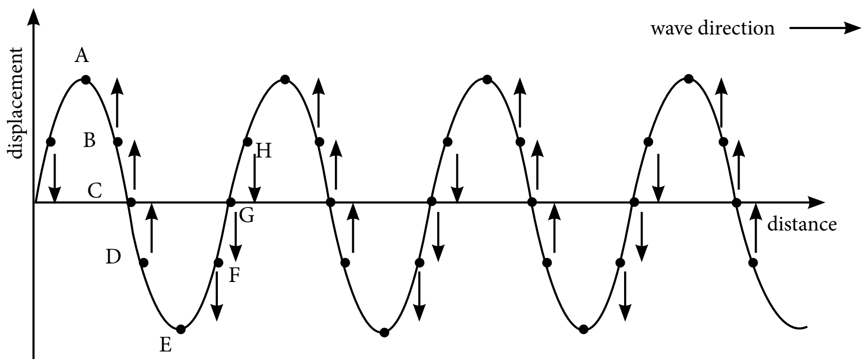


Figure 4.4

The diagram above shows the relative positions of the objects at a given time.

- Object A has reached the maximum possible position (**peak or crest**). It is about to start going down.
- Objects B, C and D are still going up. After some time they will also reach the peak and start going down. B will reach first, then C and D in that order.
- E is at the lowest possible position called the **trough**.
- Objects F, G and H are still going down. After some time, they will also reach the peak and start going down. F will reach first, then G and H in that order.

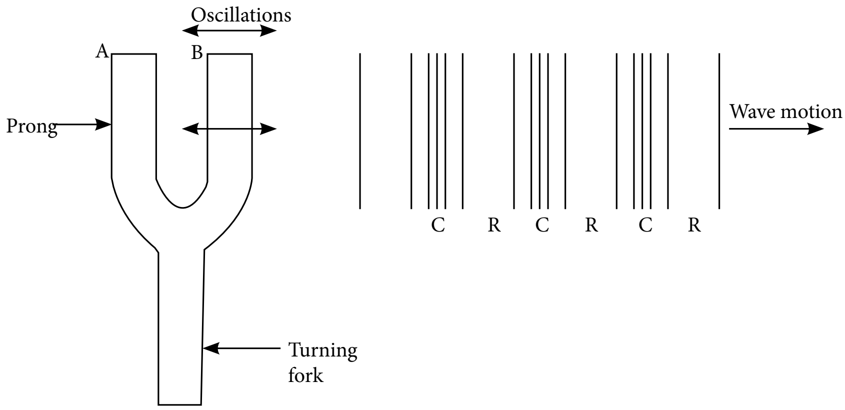
Note

- The objects (particles) are moving to and fro (vibrating or oscillating) perpendicular to the direction of the wave. This type of wave is called a **transverse wave**. Examples of transverse waves are water ripples and electromagnetic waves.

- All the particles will achieve the same maximum displacement as the wave advances. For example, the peak of the wave moves in the direction of the wave. This type of wave is called a **progressive wave**.

The positions of the objects (particles) form a wavelike pattern. This type of a wave is called a **sinusoidal** wave. It traces out a **sine curve**.

Longitudinal waves



C = Compression R = Rarefaction

Figure 4.5

The tuning fork is made to vibrate by hitting it on the table. If you look at the prongs carefully, you would see them vibrating. The sound you hear is due to this vibration. When a prong such as B is moving to the right, it compresses the air in that direction. This results into a region of high density called the **compression**. The compression pulse moves on in this direction.

When the prong moves to the left, it leaves a region of low density called the **rarefaction**.

Therefore, as the prong vibrates, it sends out compressions and rarefactions in the direction of the wave.

In a longitudinal wave, the particles oscillate parallel to the direction of wave motion.

Examples of longitudinal waves are sound and ultrasonic waves (very high frequency waves not detectable by a human ear, i.e. above the audible range).

Stationary waves

These are waves formed when two progressive waves of nearly the **same amplitude and frequency** moving in **opposite directions** meet e.g. when an incident wave meets its own reflection from a barrier. Stationary waves are formed in pipes and on stretched strings.

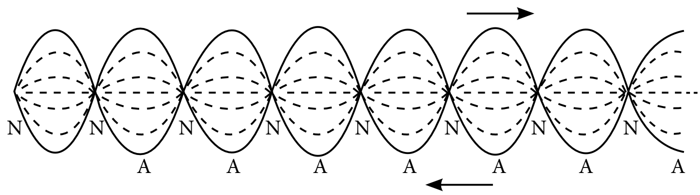


Figure 4.6

The distance between two neighbouring nodes is $\frac{\lambda}{2}$.

Characteristics of stationary waves

- The stationary wave comprises points where the displacement of particles is permanently zero. They are called nodes (N).
- Between the nodes, particles are vibrating in phase, but they do not attain the same amplitude.
- Particles half-way between the nodes attain maximum amplitude. They are called antinodes (A). (The broken lines show how the displacements of individual particles vary with time.)
- The peaks are always at the same position.

Properties of waves

Learning Points

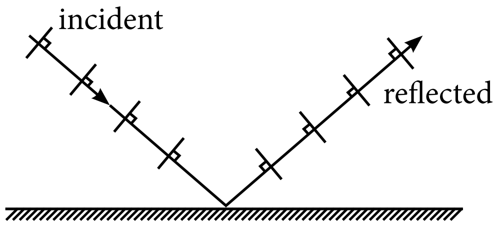
When waves are incident on a surface they get reflected and when incident at a boundary between two media of different refractive indices they get refracted. These two properties are also displayed in reflection and refraction of waves. The laws of reflection and refraction we met when studying light are all obeyed. An important point to remember when treating reflection of waves is that rays are always perpendicular to the wavefronts

Note:

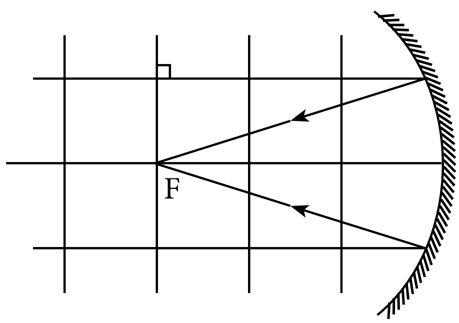
The effects below can easily be observed on a large body of water e.g. a pond or a lake. (Alternatively, you can view them using a ripple tank if there is one in your school.)

(a) **Reflection of waves**

Reflection of straight wavefronts



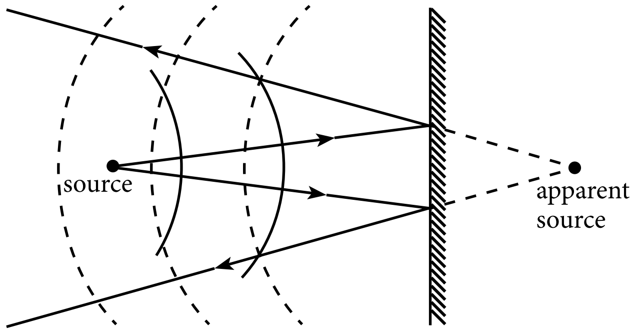
(i) **reflection of straight wavefronts from a plane surface**



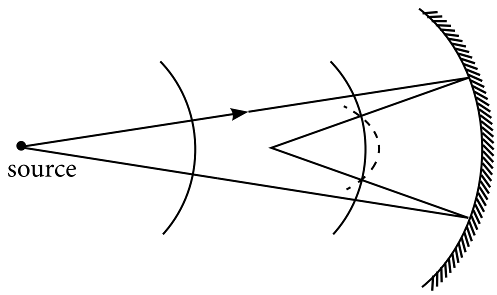
(ii) **reflection of straight wavefronts from a concave surface**

Figure 4.5

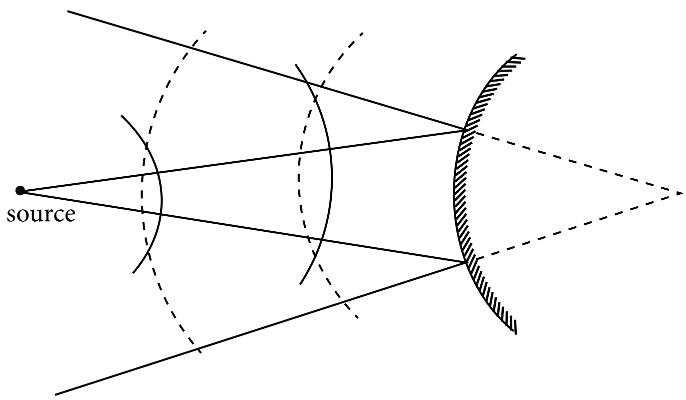
Reflection of circular wavefronts



(i) from a plane surface



(ii) from a concave surface



(iii) from a convex surface

Figure 4.6

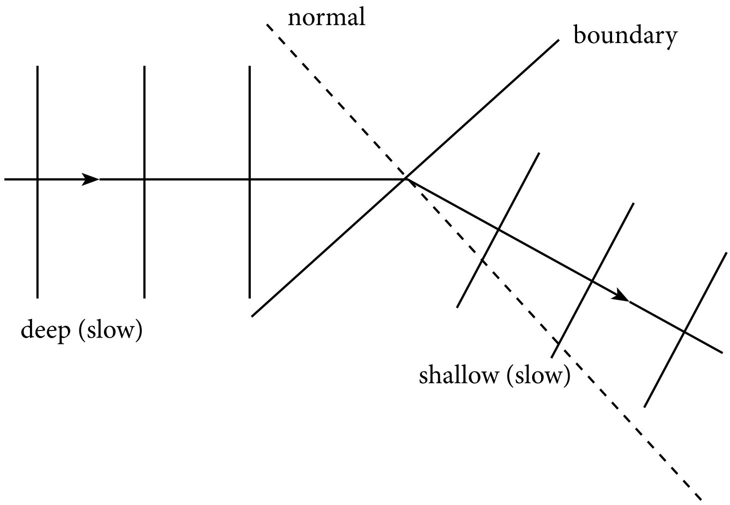
ARROWS

(b) **Refraction of waves**

Refraction is the bending of the direction of waves as they cross form one medium to another of different refractive index.

***Points to note when drawing refracted waves*:**

- Waves move faster in deep than in shallow water.
- The wavelength of waves is longer in deep than in shallow water.
- The frequency of the waves does not change when they are refracted.
- Waves bend towards the normal when they move from a medium where they are fast to where they are slow e.g. when light crosses from air to glass.
- Begin by drawing the incident and refracted rays and the fit in the wavefronts.
- Wavefronts must be perpendicular to the rays.



waves crossing from a deep medium to a shallow medium

Figure 4.7

The refracted waves bend towards the normal and have a shorter wavelength.

(c) Interference of waves

Imagine you are a sailor in a canoe and two waves meet at a point where your canoe is located. The following may happen:

- Your canoe may be raised very high; higher than the height to which only one of the waves would have raised your canoe.
- Your canoe may be lowered by the waves to a level below its original level.
- Your canoe may neither be raised nor lowered.

The principle of superposition of waves states that:
When two waves of the same frequency and amplitude meet at a point, the resulting effect is the ***algebraic sum*** *of all the effects due to the individual waves.*

The phrase 'algebraic effect' means that the displacements above the equilibrium line are taken as positive and those below are taken as negative.

Interference is the overlapping of progressive waves of the same frequency and amplitude.

Constructive interference

This is when the peaks of both waves meet at a point. The resulting displacement is the sum of the amplitudes of both waves.

Destructive interference

This is when the peak of one of the waves meets the trough of another wave at a point. The displacements cancel out making the net effect to be zero.

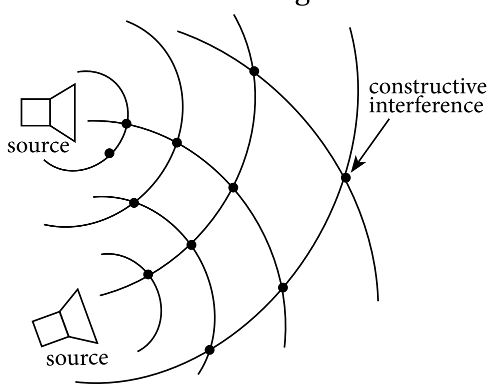
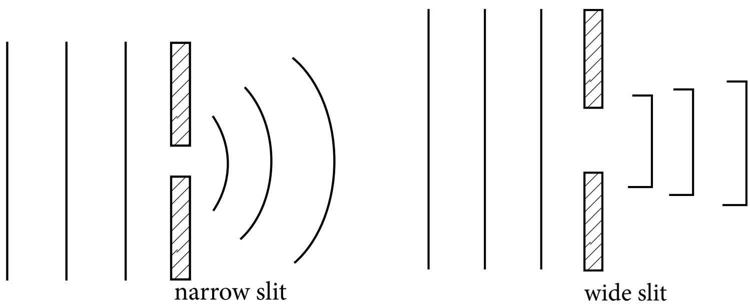


Figure 4.8

The energy of the wave depends on the amplitude. The bigger the amplitude the more the energy (and therefore, the louder, in case of sound waves) a wave possesses. When waves interfere constructively at a point the total energy due to the resulting effect is far more than the energy due to either of the waves alone.

(d) **Diffraction of waves**

This is the spreading or bending of waves as they pass through narrow openings (apertures) or round the edge of an obstacle.



Diffraction of waves going through a narrow opening and through a wide opening

Figure 4.9

From the diagrams above you can notice that the narrower the opening compared to the wavelength of the wave, the bigger the diffraction effect.

Diffraction effects of waves of longer wavelengths are more easily observable than those of shorter wavelengths. The wavelength of sound is much longer than that of light. Diffraction effects of sound waves are more noticeable than those of light. For example, you may not see an object which is around a corner but you can hear somebody talking around a corner.

Your teacher will demonstrate the above properties of waves using a ripple tank.

Short range FM radio transmission

Radio receivers that are a few kilometers away and behind the hills can easily receive FM signals from a local radio station. This is because waves of long wavelength are easily diffracted around the hills. The problem with FM signals is that they cannot be received by listeners a long distance away from a transmitting station. The strength of the signals quickly weakens with distance from the transmitting station.

Sound waves

Activity 4.3: Determination of the velocity of sound in air

What you need

- Stop clock / stopwatch
- Long open space (about 200 m long) infront of a high wall
- Tape measure (or string or a meter rule)

What to do

Method I

- Stand at one end of an open space with a stop clock while a colleague stands at the other.
- Measure the distance x, between the two of you using a tape measure.
- Signal to your colleague to clap while you simultaneously start the stop clock.
- When you hear the sound, stop the clock immediately and note the time, t, taken for the sound to reach you.
- Calculate the speed v, of the sound from $v = \frac{x}{t}$.

Method II (echo method)

- Let both of you stand at the edge of the open space in front of the high wall.
- Signal to your colleague to clap while you simultaneously start the clock.
- Stop the clock immediately you hear the echo.
- Record the time t, taken for the echo to come.

- Calculate the speed *v*, of the sound from $v = \frac{2x}{t}$

You may not have been able to record the time accurately because it is very short.

Now do the following to improve the accuracy of your results:

- Let your colleague practise clapping continuously and regularly.
- When you are ready, start the clock and record the time, t', for 10 echoes.
- Calculate the time taken for one echo to come back using the formula

  $t = \frac{t'}{10}$.
- Calculate the speed *v*, of the sound from $v = \frac{2x}{t}$

Explain the following:

- During a storm, lightning comes first then sound comes a few seconds later. How would you attempt to establish the location of the storm?
- When a worker at a distance is splitting firewood, you can see him do it but you hear the sound later.

Precaution

There should be no wind blowing during the time you are doing the experiment. Wind quickens the sound when both are moving in the same direction and slows it when they are moving in opposite directions.

Activity 4.4: To show that sound travels faster in solids than in air

What you need

- Hammer (or any other hard object)
- A barbed wire fence
- A colleague

What to do

- Let your colleague stand at a far end of the fence while you are at the other end.
- Put your ear on the fence.
- Signal to him/her to tap on the fence using the hammer.

Observation

Describe what you hear. What is the explanation to your observation?

Activity 4.5: Making a room to be soundproof

What you need

- As many sheets of cloth as possible (or blankets)
- Adhesive tape
- Nails or any other objects to support the blankets and sheets
- A radio
- A small room or a large cardboard box

What to do

- Cover the walls and the ceiling or cardboard box with as many bed sheets and blankets as possible. (You can use adhesive tape or nails to hang them up).
- Switch on the radio and place it inside the room or box.
- Go out of the room and close the door.

Observation

Compare the loudness of the sound from the radio when you were inside the room and when you are outside the room (or when the box is open and when it is closed).

Learning Points

Sound is a longitudinal wave of long wavelength. It is caused by mechanical vibrations of particles in the medium. Therefore sound requires a medium to be propagated. The sounds we hear are due to the mechanical vibration of the air close to our eardrums. Sound is a form of energy which affects our ears and enables us to hear.

Sound does not travel through a vacuum

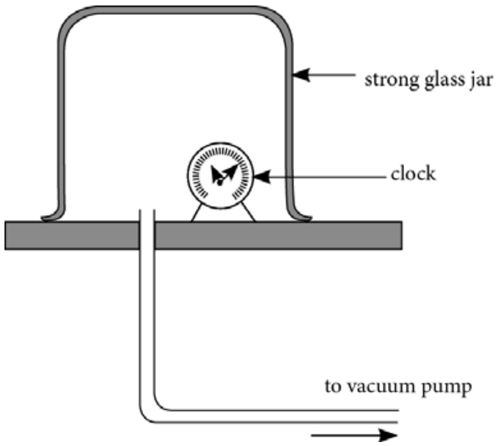


Figure 4.10

The ticking of the clock dies away as air is gradually evacuated.
The frequency of the vibrations detectable by a human ear ranges from 20Hz to 20,000Hz.

Speed of sound

The speed of sound in air is about 331 ms^{-1}or 1191 kilometres per hour. There are many factors which affect the speed of sound in a medium.

Factors which affect the velocity of sound in air

- Sound travels faster on a hot day than on a cold day.
- Pressure does not affect the velocity of sound in air.
- The speed of sound in a medium depends on its density. The denser the medium, the faster the sound travels in the medium. Thus, sound travels faster in solids than in gases.

Echoes

Sound bounces back (is reflected) when it is incident on a hard surface. An echo is reflected sound. Some people call it a ghost!
Where have you experienced echoes?

Uses of echoes

1. For determining the velocity of sound in air. (see above)
2. Blending music: Mixing musical notes with their echoes produces a pleasant effect.
3. Echo sounding: In this technique, a signal is sent down to the bottom of the sea from a boat floating on the water. The time taken for the echo to be received back is measured and the depth, *h*, is calculated from the formula $v = \frac{2h}{t}$, where *v* is the velocity of the wave signal in the water.
4. Radar detection: This is a technique used to detect the position, speed and direction of aircrafts and ships. A signal is sent out and its reflection is received . The time it takes to come back gives information on the position of the reflecting object.

Reverberation

When the reflecting surface is very close to a source of sound, the echo comes back before the original sound dies away. This produces a prolonged sound. This effect is experienced in large halls and plastered rooms.

Echelon echo

When there are many reflecting surfaces lactated at different distances from a source of sound, the echoes also produce a prolonged effect of the original sound.

Music and musical instruments

Figure 4.11

Activity 4.6: Investigating the factors that affect the pitch of a note produced by a vibrating wire/string

What you need

- Wires (different thicknesses, different materials)
- Slotted masses (small stones may do)
- A pulley fixed on a table edge (a round empty tin may do)
- Two wedges

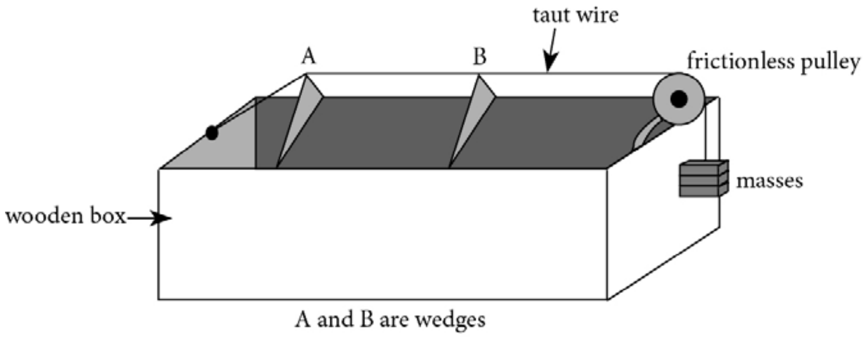


Figure 4.12

What to do

- Fix end A of the wire tightly on the wood.
- Hang a mass at end B of the wire.
- Strike the wire in the middle and record the pitch of note produced.
- Investigate the effect of increasing the mass on the pitch produced.
- By adjusting the positions of the wedges, investigate the effect of increasing length of wire on the pitch produced.
- Also investigate the effect of increasing the diameter of the wire by using a thicker wire (same length and mass hanged at the end).
- Finally, investigate the effect of using another type of wire (i.e. made from a different material (same thickness, length and mass hanged at the end).

Activity 4.7: Making a stringed musical instrument

What you need

- Pieces of wood
- Jack plane
- Wires of different thickness
- Nails
- Hammer

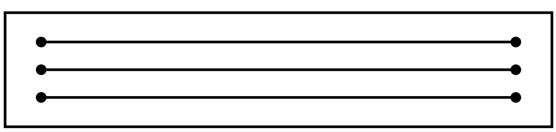


Figure 4.13

What to do

- Make a closed wooden box of a sizeable length (25cm by 25cm by 100cm).
- Firmly fix three nails on the shorter sides of the top surface of the box.
- Tie three different sizes of strings on the nails as shown above and stretch the strings. Make sure they are taut.
- Drill some holes on the sides of the box.
- Pluck on each string to check the sound produced and adjust to a new sound by tightening the string further.

Activity 4.8: Producing music using bottles

What you need

- 8 empty soda bottles of the same size
- Water
- Nail

What to do

- Fill the bottles with water to different increasing heights.
- Arrange the bottles in a row starting with one with the least amount of water to the most full.
- Gently hit the bottles with a nail one after another.
- You have made a musical instrument.

Activity 4.9: Making xylophones

Making xylophones is a very old tradition. It would be wise to consult an expert in your village on how to do it

What you need

- Pieces of wood (ask the elders to show you the right type)
- Machete

What to do

- Find out the effect of increasing (a) the size (b) the length of the xylophone rods.

- Consult on how best to vary the pitch of the note.
- Try playing a local tune using your xylophones.

Learning Points

We all enjoy listening to some kind of music! Music may provide a relaxing effect to the listener or it may cause the exact opposite if it is not regulated. Many people have earned money out of playing music.

A **tone** is an audible note (wave) of regular frequency. It is in a form of a sinusoidal wave of constant wavelength. The **pitch** of a tone is its sharpness or its position on a musical scale. A high pitched note has a high frequency.
Music is a combination of tones of regular frequencies whereas 'noise' is a combination of notes of irregular frequencies.
The higher the frequency, the higher the pitch of a tone.

Intensity

As we mentioned above, sound is a form of energy. Intensity is a measure of the quantitative effect of the sound we hear, i.e. how much vibration effect the sound produces on the eardrum.
*Intensity is the rate of flow of sound **energy per second** perpendicular to a surface per square metre of the surface.*
*The underlined phrase is an expression for **power** of the sound.*

To understand this definition better, we may consider a source of sound being surrounded by a spherical surface with the source at the centre.

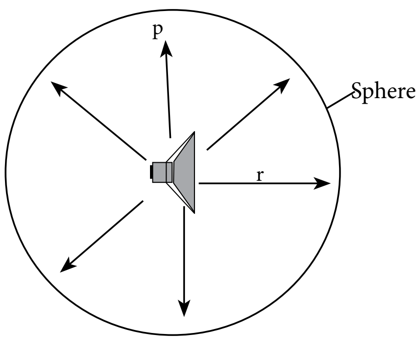


Figure 4.14

Sound travels from the source in all directions to the sphere.

Below is a summary of the factors which affect the intensity of sound;

1. ***Distance from the source***. Intensity reduces with distance.
2. ***Frequency.*** Intensity is higher for notes of higher frequencies at a given distance from a source.
3. ***Amplitude.*** The higher the amplitude, the higher the intensity.
4. ***Density of the medium.*** The higher the density of the medium through which the sound travels, the higher the intensity.

Generally, the energy of a wave depends on the amplitude of the wave. Waves whose amplitudes are big have more energy than those whose amplitudes are small.

Loudness of sound

This is a sensation of the ear of the person who is hearing the sound. It depends on the state of health of the ear of the individual. What appears loud to one person may appear faint to another person.
Normally, the more intense a sound is, the louder it sounds. All the factors which affect the intensity of sound equally affect the loudness of sound. A Loud note has bigger amplitude than a soft note.

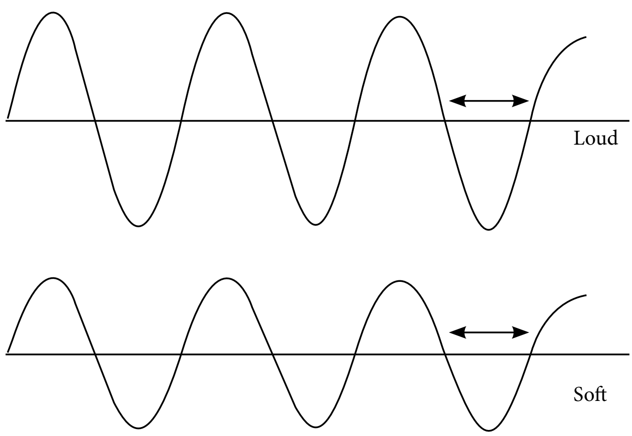


Figure 4.15

Another factor that affects loudness of a note is the amount of air which is set in vibration. The bigger the amount of air set in vibration the louder the sound produced. For example, placing a drum on a table top makes it sound louder. Another example is the sound box mounted on guitars for the same purpose.

Vibrating wires/strings

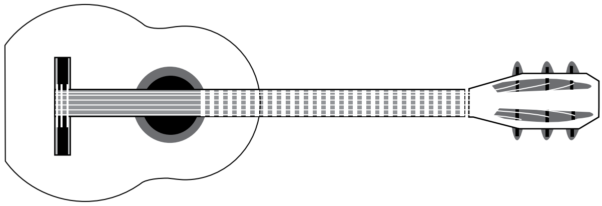


Figure 4.16

Factors that affect the pitch of a vibrating string/wire

Factor	**How it affects frequency**
Length	Frequency is lower for longer wires
Thickness	Frequency is lower for thicker wires
Tension	Frequency is higher at higher tension
Nature of material of wire	Frequency depends on nature of material of wire

Table 4.1

Resonance

Activity 4.10: Investigating the relationship between length of pendulum and its period

What you need

- Bob (a stone will do)
- A thread

What to do

- Tie the pendulum from a fixed support. It is better to start with a long pendulum of about 1 m.

- Displace the bob slightly and let it swing freely.
- Time twenty oscillations.
- Calculate the period.
- Repeat the procedure for different decreasing lengths of the pendulum.
- Record your results in the table below.
- Repeat the procedure with bigger bobs.

Length of pendulum (m)	**Time for twenty oscillations (s)**	**Period, T (s)**

Table 4.2

Observation

- What is the relationship between length of pendulum and period?
- What is the effect of changing the mass of the bob on the period?
- Investigate the effect of wind on the period.

The word 'period' is used in many instances in daily use. Mention some.

Activity 4.11: Demonstrating resonance

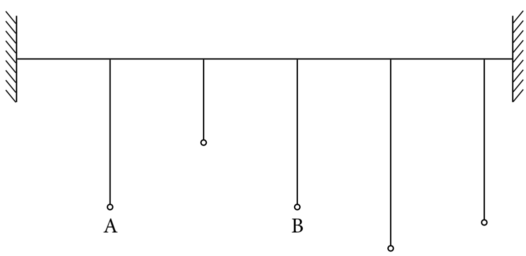


Figure 4.17

What you need

- Two fixed support about 1.5m apart
- an inelastic string
- bobs (small pieces of stone will do)

What to do

- Arrange the apparatus as in Figure 4.14. Ensure that two of the pendulum have the same length (call them A and B).
- Pull A aside through a small angle and release it so that it swings freely.
- Observe what happens.

Hint

Pendula of the same length have the same frequency.

Questions

1. What does the period of a pendulum depend on?
2. Why does B swing with the maximum amplitude?

Learning Points

Free oscillations

A free oscillation is one whose amplitude remains constant.

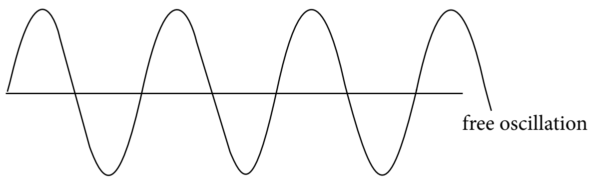


Figure 4.18

Free oscillations are desirable in systems like the ones used in clocks.

Damped oscillations

In some oscillations, the amplitude of the oscillations gradually reduces and finally dies away due to loss of energy. These oscillations are said to be damped. Damping is due to loss of energy of the system. For example, a swinging pendulum will eventually come to rest due to friction at the support and between the bob and the air. Damped oscillations are desirable, for example, in shock absorbers normally found on motorcycles.

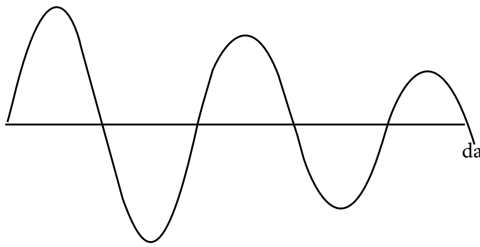


Figure 4.19

Forced oscillations

In order to keep a system which has some degree of damping in continuous oscillation, a periodic external force must be applied to it. For example, in order to keep a children's swing in continuous oscillation, the arm of the person pushing the swing must also be swinging. The arm must move with a **forcing frequency** in order to keep the swing in regular motion. The forcing frequency must be equal to the swing's own frequency called the **forced or natural frequency**.

In order to achieve maximum amplitude of the swing, the **forcing frequency** must be equal to the **forced or natural frequency.** In this case, **resonance** is said to have occurred**.**

Resonance is when a forcing frequency is equal to the forced or natural frequency of an oscillating system.

Or

Resonance occurs when a system is forced to oscillate at its natural frequency.

Fundamental note and overtones

Consider a string tied taut between two fixed supports. When it is struck in the middle, it vibrates with more than one mode as shown in the diagrams below.

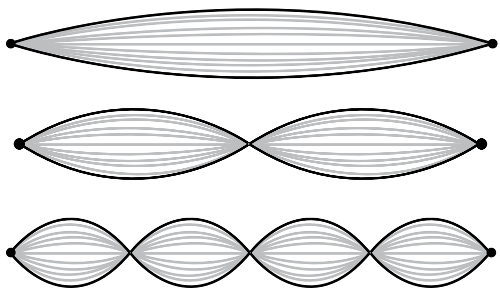


Figure 4.20

In the first diagram, both ends of the string are fixed and cannot move. They are both nodes. The distance between these two nodes is a half of a wavelength. Therefore, the length of the string, l, is a half a wavelength λ_o.

$$l = \frac{\lambda_0}{2}.$$

The frequency, f_o, associated with this wavelength is obtained using the formula
v = fλ
where *v* is the velocity of sound in air.

Hence, $v = f_0\lambda_0$

$v = f_0 \ x \ 2l$

$$f_0 = \frac{v}{2l}$$

This is the lowest possible frequency when the string is struck. It is called the fundamental frequency.
Fundamental frequency is the lowest audible frequency obtained when a musical instrument is sounded.
Apart from the fundamental mode of oscillation, there are other modes as shown in the figure 4.17 above.

In figure 4.17 you can notice that other waves of higher frequencies can also fit in the length of the wire. The only condition is that ends of the wire must always be nodes.
In the figure
$l = \lambda_1$

$$or\ l=2\ x \frac{\lambda_1}{2}$$

The frequency, f_1, due to this mode of oscillation is obtainable from the equation of motion of waves as follows

$v = f_1 \ x \ \lambda_1.$

$$v = f_1 \ x \ 2 \ x \ \frac{l}{2}$$

Hence, $f_1 = \dfrac{2v}{2l}$

Working in the same way we can prove that the other higher frequencies are, respectively,

$f_2 = \dfrac{3v}{2l}, f_3 = \dfrac{4v}{2l}, f_4 = \dfrac{5v}{2l}$ and so on. These frequencies are called overtones. f_1 is the first overtone, f_2 is the second overtone and so on.

An overtone is a note whose frequency is higher than the fundamental obtained when a musical instrument is sounded.

- Overtones determine the **quality** of music from a musical instrument.
- A **harmonic** is a note whose frequency is a full number multiple of the fundamental frequency. Thus, the fundamental frequency f_o, is the first harmonic, f_1 is the second harmonic and f_2 is the third harmonic and so on.

OCTAVES

Two musical notes mix best if the frequency of one of them is double or half that of the other, i.e. when they are an **octave** apart.

Follow-up activities

Make a study of various musical instruments available locally to find out the following:

- how the pitch is varied
- how mixing of notes is done
- how it is played
- how music from different musical instruments is blended together to produce a pleasant effect

Chapter 5: Heat

Introduction

We use heat to cook our food. We get it from the food we eat and we feel it when we rub our hands together.

When matter and energy interact, some of the energy is absorbed and some may be transmitted. In this chapter, you will study some ways of measuring the degree of hotness and quantifying heat energy. You will also study about some effects of heat energy on matter.

Temperature and thermometers

Activity 5.1: Calibrating a thermometer
What you need

- Thermometer
- Funnel
- Retort stand
- Beaker
- Round bottomed flask
- Ice
- Cork with 2 holes
- Stove

What to do

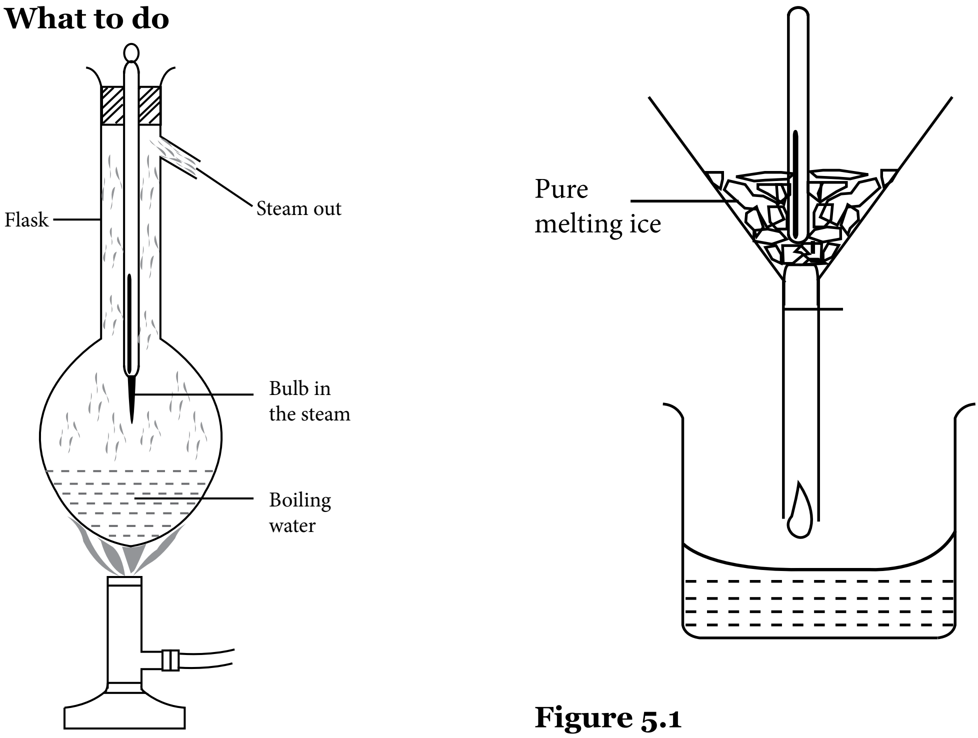


Figure 5.1

What to do

- Assemble the apparatus as in Figure 5.1 above.
- Place a thermometer in the pure melting ice.
- Hold the funnel just above a beaker using the retort stand to hold the funnel.
- Let the apparatus stand for some time.
- Mark the level of the liquid on the thermometer. This is the lower fixed point.
- Insert the thermometer into a cork.
- Firmly fix the cork containing clean water. Ensure the thermometer is just above the water level.
- Heat the water to boiling point.
- Mark the level of the liquid on the thermometer. This is the upper fixed point.
- Mark (calibrate or graduate) the interval into 10 equal divisions and then subdivide the ten divisions into smaller equal divisions.

Note that the boiling point of water may be slightly below 100°C because the atmospheric pressure may also be below normal atmospheric pressure. The upper fixed point may require a slight adjustment because boiling point of a liquid is dependent on the pressure above its surface.

- Use the thermometer you have made to measure your body temperature and room temperature.

Precaution

Careless handling of the apparatus may lead to serious scalding.

Activity 5.2: Making an air thermometer

What you need

- A used ball point pen
- Graph paper
- Thermometer
- Stove
- Water
- Cellotape

What to do

- Remove the inner tube from a ball point pen.
- Pull out the writing tip of the tube.
- Using your mouth, suck a small drop of coloured water into the tube.
- Plug the end of the tube again without letting the water run out.
- Using cello tape, fix the tube on to a strip of graph paper.
- Hold the 'bulb' of your thermometer in water which is being heated slowly.
- Calibrate your thermometer against commercial thermometer as the water is being heated using a graph paper.

Learning Points

A person with fever normally feels hot. Temperature is a degree of hotness of a body. We can get some idea of how hot or cold a body is using our hands but this method is not accurate because different individuals might not give exactly

the same values. In laboratories, hospitals and in our homes, we can measure temperature more accurately using thermometers.
The most common type of thermometers in school is the liquid-in-glass type.

Thermometric liquids

The liquids most commonly used in thermometers are alcohol and mercury.

Advantages of mercury

- It is opaque.
- It expands uniformly.
- It does not evaporate easily.
- It has a high boiling point.
- It has a low freezing point.
- It does not stick to glass.

Disadvantages of mercury

- It is poisonous.
- It is expensive.

Disadvantages of water

- It does not expand uniformly.
- It evaporates easily.
- It sticks to glass.

Advantages of alcohol

- It expands more than mercury.
- It has a lower freezing point than mercury.
- It is cheap.
- It is not poisonous.

Quick-acting thermometer

This type of thermometer records temperature changes immediately they occur.

Its characteristics are:

- The walls of the bulb are thin so that the heat crosses quickly to the thermometric liquid.
- The thermometric liquid is a good conductor of heat.

Sensitive thermometer

A sensitive thermometer can record very small changes in temperature. Its characteristics are:

- It has a large bulb.
- It has a narrow bore.
- It has a thermometric liquid whose rate of expansion is high.

In such a thermometer, a very small change in temperature should produce a visible (relatively big) expansion.

Other common types of thermometers are gas thermometer and thermoelectric thermometers.

Fixed points on a thermometer

- *Upper fixed point is the temperature of steam from water boiling under normal atmospheric pressure.*
- *Lower fixed point is the temperature of pure melting ice.*

Note

- The boiling point of pure water at atmospheric pressure is 100°C and it is the upper fixed point.
- Dissolved impurities would raise the boiling point of water.
- The boiling point of water increases with atmospheric pressure.
- The freezing point of pure water is 0°C and it is the lower fixed point.
- Dissolved impurities lower the freezing point of water.

The interval between the upper fixed point and the lower fixed point is the fundamental interval. The interval is subdivided into 100 equal intervals. This is the Centigrade (Celsius) scale.

Other scales

The Fahrenheit scale

The formula for converting Celsius scale to Fahrenheit is:

$$degrees\ Fahreheit=\frac{9}{5}(degrees\ Centigrade)+32$$

$$°F=°C\ x\frac{9}{5}+32$$

Absolute Kelvin scale

The formula for converting Centigrade scale to Kelvin scale is

$$Kelvin=degrees\ Centigrade+273$$

$$K=°C+273$$

Note that the degree sign is missing on the Kelvin.

Absolute zero (0 K) is the temperature below which no gas can ever exist. It is the lowest temperature which can be reached in practise.

Clinical thermometer

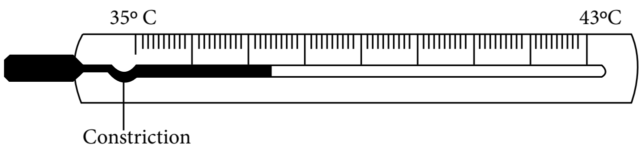


Figure 5.2

The thermometer normally used in health facilities is called a clinical thermometer. Its bore consists of 'kink' or bend which prevents the thermometric liquid from running back to the bulb before the reading is taken. Normal body temperature is about 37°C. The medical worker has to shake the thermometer hard to return the liquid to the bulb before using it to record the temperature of another patient.

Follow-up activity

Temperature changes can cause several things to happen to objects in the environment. Name as many changes caused by heat as you can.

Transmission of heat

Activity 5.3: Comparing the rates of conduction (conductivity) of metals

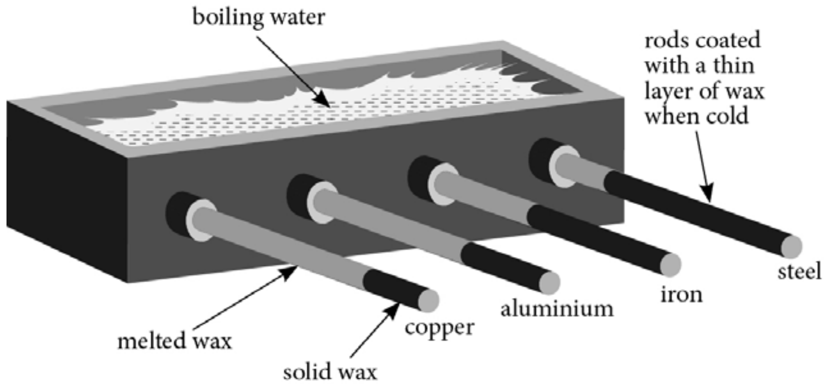


Figure 5.3

What you need

- Bunsen burner
- Matchbox
- Tripod stand,
- 4 cylindrical metal rods of the same length and diameter made of copper, iron, aluminium and brass
- Candle wax

What to do

- Place rods of different metals on the tripod stand spreading out from one end.
- Attach a match stick at each end of the rod using candle wax.
- Heat the metal rods at the opposite end.
- Write down the order in which the rod loses the match sticks.

Activity 5.4: Determining whether water is a good conductor of heat

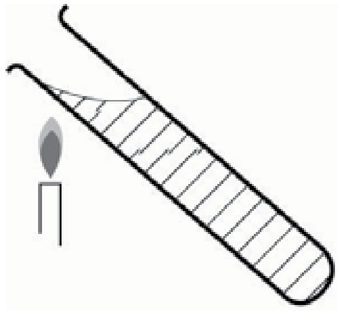


Figure 5.4

What you need

- Bunsen burner
- Matchbox (with match sticks)
- Boiling tube
- Water
- Metal gauze
- Ice

What to do

- Assemble the apparatus as shown in Figure 5.4.
- Heat the water in the test tube near the open end of the test tube and note what happens.
- *What is the use of the metal gauze?*

Observation

Observe what happens to the water at the top and to the ice below in the first 2 minutes and draw your own conclusion.

Questions

1. Explain why when cooking food, the fire is put at the bottom of the sauce pan.
2. What do you think would happen if the element of an electric water heater was positioned half way down inside the heater?

Activity 5.5: Demonstrating how convection currents are formed in air

What you need

- 2 chimneys
- A box of matches
- Model smouldering rag with holder

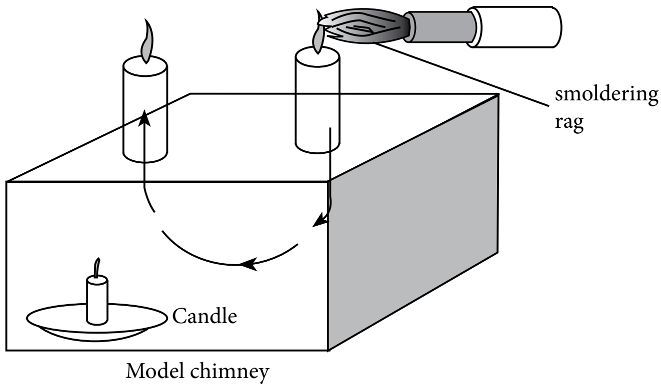


Figure 5.5

What to do

- Place a burning candle beneath one of the chimneys and close to the glass window.
- Bring a smouldering rag or burning piece of paper near the mouth of the other chimney.

Observation

- Observe the movement of the smoke from the smouldering rag /paper.
- What causes it to get into one chimney and get out through the other?

Questions

1. What causes the wind to blow from one direction to the other?
2. Explain the occurrence of land and sea breezes.
3. Explain the use of window and ventilators on buildings.

Activity 5.6: Demonstrating convection currents in liquids

What you need

- Bunsen burner
- Round bottomed flask
- Retort stand
- Water
- A few crystals of potassium permanganate
- A drinking straw

What to do

- Pour water into a round bottomed flask and fix it upright using a retort stand and clamp.
- Carefully drop a few crystals of potassium permanganate through a drinking straw to the bottom of the flask.
- Gently warm the flask at the bottom.

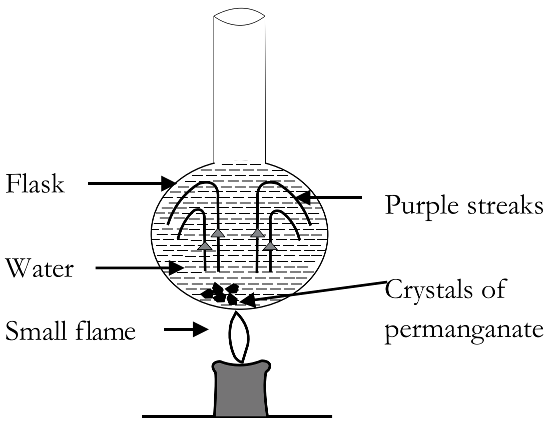


Figure 5.6

Observation

1. Observe what happens as you warm the flask.
2. Explain the coloured patterns in the flask.

Activity 5.7: Determining which of the two, a dull or a shinny body is a better absorber of heat

What you need

- Bunsen burner
- 2 tin lids (1 shinny and 1 dull)
- 2 coins and candle wax

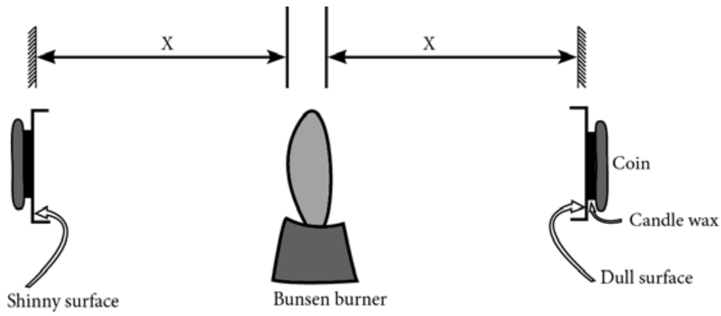


Figure 5.7

What to do

- Place two tin lids (1 shiny and the other dull) vertically at the same distance x, from a burning Bunsen burner. Using candle wax, attach two coins on the lids.
- Assemble the apparatus as in Figure 5.7.

Observation

Which of the coins falls first?

Question

When making a double walled vacuum glass, the inner parts of the glass are silvered. Why is this done?

Activity 5.8: Making a tea warmer

What you need

- Rags or cotton wool

- 2 pieces of cloth (or bark cloth) each 0.5 m x 0.5m
- Thermometer
- Sewing needle
- Thread
- Water
- A teapot

What to do

- Sew the two pieces of cloth together at the edges to make a bag.
- Fill the bag with cotton wool (or rags) and sew up the remaining part.
- Fold the bag into two.
- Sew the two opposite edges of the bag ensuring that a small teapot can fit into the bag.
- Cover a teapot filled with hot water with the bag.

Observation

- Measure the time the tea takes to cool from 90°C to room temperature.
- Do the same for an uncovered tea pot and compare the results.

What is the effect of covering the kettle with an insulating rag?

Activity 5.9: Making a solar water heater

What you need

- A copper tube of about 8 metres in length and diameter 1 cm
- Black paint
- Nails
- A sheet of transparent glass about 0.5 m x 0.5 m
- 20 litre jerry can
- 100 litre water tank with a tap
- Thermometer and strong pieces of wood for supporting the tank

What to do

- Bend the copper tube into rows of 1 metre each to form a grill and paint it black.
- Place the grill in a box measuring 1.0 m long by 0.5 m wide by 0.1 m high.

- Drill two holes in the box for the outlets of the ends of the tube.

- Cover the top of the box with a transparent glass sheet measuring 1.0 m by 0.5 m.
- Assemble the apparatus as in Figure 5.8.

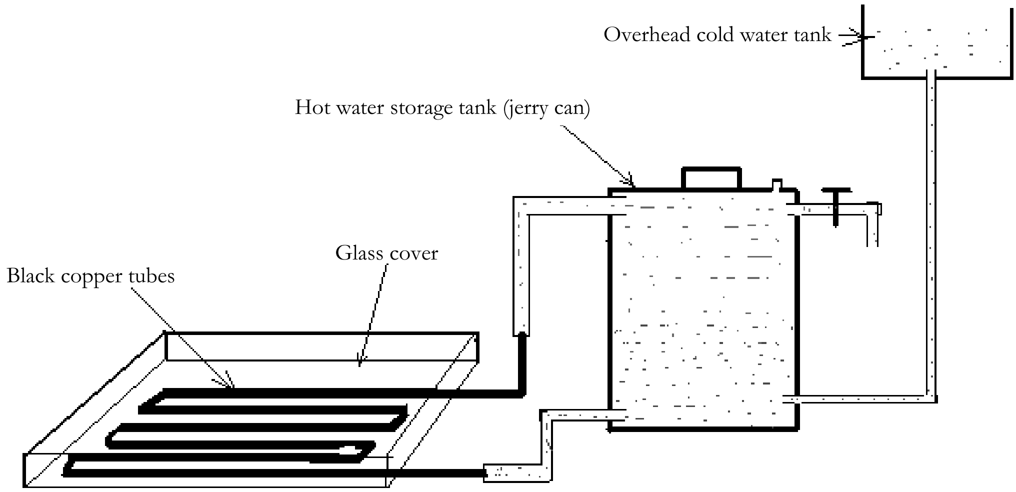


Figure 5.8

Hint

The system should be placed in an open place where sunshine is in plenty.

Observation

Periodically measure the temperature of the water drawn from the hot water tank through the tap.

Activity 5.10: Making a soak pit

What you need

- Charcoal
- Gravel
- Sand
- Hoe
- Water
- Plastic plates

What to do

- Crush some of the charcoal into finer particles.
- Number the plates A to J and fill them in the following way.

Plate	Content of plate	observation
A	Sand only	
B	Gravel only	
C	Coarse charcoal	
D	Fine charcoal	
E	Sand and gravel	
F	Sand and coarse charcoal	
G	Sand, coarse charcoal and gravel	
H	Sand, fine charcoal and gravel	
I	Fine charcoal and gravel	
J	Coarse charcoal and gravel	

Table 5.1

- Fill each plate with water so that its contents are completely covered in water.
- Leave the plate out under the sun for a whole day and note what happens to the water.
- Which plate loses most of its water first?

Questions

a) Which combination of materials would be best suited as a soak pit?
b) Give reasons why your choice is the best.

Follow-up activity

Try out the materials in a real soak pit.

Learning Points

There are three ways through which heat is transferred from one point to another. These ways are conduction, convection and radiation. Heat flows from a region of high temperature to a region of low temperature**.** Below are the three modes of heat transfer:

Conduction

All matter conducts heat although at different rates. Conduction is the transfer of heat by contact. For metals, conduction is higher than in liquids and gases. This is due to the arrangement of particle matter in metals as compared to liquids and gases.

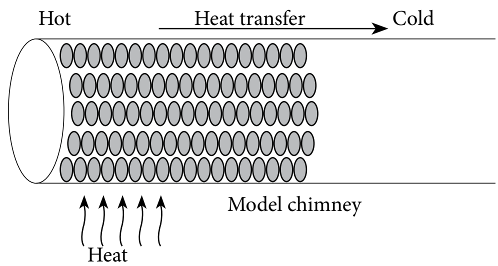


Figure 5.9

When one end of a rod is heated, the molecules there gain energy and vibrate faster with bigger amplitude. The molecules knock their neighbours and force them to vibrate faster and with bigger amplitude. In this way, heat energy is passed on from the hot to the cold end of the rod. In metals, the heat transfer is faster because, in addition, they have free electrons which are moving about randomly in the metal. When a metal is heated, electrons gain energy and quickly transfer it from the hot end to the cold end.

Conduction is, therefore, the transfer of heat energy from the region of higher temperature to the region of lower temperature without movement of the material itself.

Good conductors of heat: metals, graphite

Bad conductors of heat: plastics, cotton wool, air. A vacuum is the worst conductor of heat possible. Why?

Factors which affect the rate of heat transfer by conduction are:

- Cross-section area
- Temperature difference
- Length of conductor
- Nature of material of the conductor

Metallic objects feel colder to the touch than wooden objects to the touch because the metals conduct the heat away faster than wood.

Convection

Convection is the way heat is transferred from one place to another in fluids by the movement of the fluid molecules themselves. The term fluid refers to both liquids and gases.

When a fluid is heated, it expands, becomes less dense and rises to the surface. The hot fluid is replaced by the cold denser fluid which is also heated in turn. In this way, convection current is set up.

Radiation

Radiation this is the method by which heat is transferred from one place to another in form of an electromagnetic radiation (wave). Whereas heat transfer by conduction and convection requires a medium, heat transfer by radiation doesn't. It can be transferred from one place to another without need for any material medium. It can even be transferred through a vacuum.

Follow-up activities

- Vacuum flask

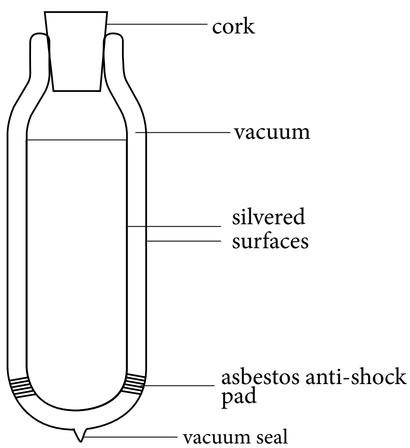


Figure 5.10

Describe how the vacuum flask above is able to maintain the temperature of a liquid stored in it.

- Make a warmer using an ordinary bottle. What are the suitable materials? Explain the special features of the warmer you have made.
- Examine a car radiator and descried how it is used to maintain the temperature of an engine

Specific heat

Activity 5.11: Comparing heat storage by water and a piece of metal of equal mass

What you need

- A piece of metal weighing 0.5 kg tied on a small string
- Thermometer
- Water in a large metallic container (e.g. A cooking pan)
- Measuring cylinder
- 2 small similar containers able to hold more than 3 litres of water
- Beakers
- A stove

What to do

- Place the metal and water in the large container so that the metal is completely submerged.
- Heat the water up to boiling point.
- Fill each of the small containers with 2 litres of cold water each.
- Measure and record the temperature of the water in the two containers. The temperature should be the same.
- Remove the metal solid using the string from the large container, shake off any water and quickly transfer it into one of the small containers with cold water.
- Measure out half a litre of the hot water and quickly pour it into the cold water in the other small container.
- Record the highest temperature reached by the water in each of the two small containers.

Observation

Which of the two stores more heat energy; a 0.5 kg piece of metal or a half litre of water at the same temperature?

Activity 5.12: Comparing the heat capacities of water and cooking oil

What you need

- 50 ml of water
- 50 ml of cooking oil
- Thermometer
- Stop clock
- Glass beaker 200 ml
- Source of heat
- Tripod stand
- Wire gauze
- Stirrer
- Cotton wool

What to do

- Place the wire gauze on the tripod stand above a heat source.
- Pour the water into the beaker.
- Use the thermometer to measure and record its temperature.

Precautions

- Do not heat the glass beaker directly.
- Do not allow any of the liquids to pour in the fire or any part of your body.
- Place the water in the beaker on the wire gauze and start the stop clock.

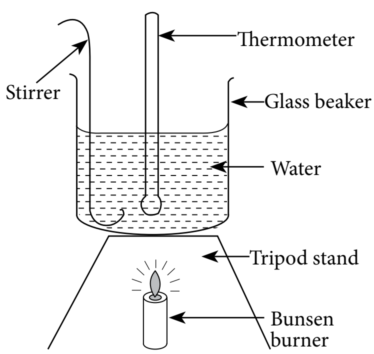


Figure 5.11

Put a surface on top of the liquid

- Stir the water to ensure uniform temperature distribution.
- Measure and record the time it takes for the temperature of water to rise to 80 °C
- Remove the beaker from the tripod stand and record the temperature of the water every after 1 minute for 20 minutes.
- Repeat the procedure described above for cooking oil.

Interpretation

- Explain your observation above.
- On the same axis, plot a graph of temperature against time to obtain the cooking curve for both water and cooking oil.
- Between water and cooking oil, which one took a shorter time for its temperature to rise to 80 °C?
- Which of the two liquids cools faster than the other?

Conclusion

Which of the two liquids has a higher specific heat capacity?

Questions

1. What is the advantage of using water as an engine coolant in vehicles than cooking oil?
2. Mention different activities in which water is used as a coolant.

Activity 5.13: Determining the specific heat capacity of a metal by method of mixtures

What you need

- Water
- Copper calorimeter and stirrer
- Thermometer
- Thread
- Metal (e.g. a bob)
- Cotton wool or a rag
- Beaker
- A weighing balance

What to do

- Weigh the empty calorimeter and stirrer .... M_c kg.
- Weigh the calorimeter with cold water .... M kg.
- Record the temperature of water in the calorimeter .... T_1° C.
- Cover the calorimeter with cotton wool.
- Weigh the metal .... M_m kg.
- Tie the metal on a thread and lower it into water in a beaker or saucepan.
- Heat the water until the temperature has risen to 90°C.
- Record the initial temperature of the metal .... T_2°C.
- Using the thread, remove the metal from the hot water, shake off any water, and transfer it quickly to the water in the calorimeter.
- Stir while observing the temperature.
- Record the final steady temperature of the mixture .... T_3 °C.
- Mention the precautions and sources of error in this experiment.
- Repeat the experiment to measure the specific heat capacities of different objects.

Working

Mass of water in the calorimeter $M_w = M - M_{c.}$
Temperature rise of the water, calorimeter and stirrer = $T_3 - T_{1.}$
Temperature fall of the metal = $T_2 - T_{3.}$

Let
Specific heat capacity of metal be C_m.
Specific heat capacity of water be C_w.
Specific heat capacity of copper be C_c.
Therefore, using the formula $Q = m\ C\ \theta$.
Heat lost by metal = $m_m \times c_m \times (T_2 - T_3)$.
Heat gained by water, stirrer and calorimeter = $m_w \times C_w \times (T_3 - T_1) + m_c \times C_c \times (T_3 - T_1)$.
If no heat was lost to the surroundings,
Heat lost = heat gained
$m_m \times C_m \times (T_2 - T_3) = m_w \times C_w \times (T_3 - T_1) + m_c \times C_c \times (T_3 - T_1)$
Substitute your experimental values in the equation above and calculate the specific heat capacity of the metal.

(Take C_w = 4,200 J kg^{-1} K^{-1} and C_c = 400 J kg^{-1} K^{-1})

Learning Points

Heat capacity

When a body is heated, its temperature rises. Some bodies warm faster than others.

The quantity of heat required to change the temperature of a body by 1°C is known as its heat capacity.

Specific heat capacity, c, *is the quantity of heat required to increase the temperature of 1 kilogram of a body by 1°C.*

Derivation of the formula for quantity of heat lost or gained by a body:

Quantity of heat required to increase the temperature of 1 kilogram of a body by 1°C is C.

Quantity of heat required to increase the temperature of 1 kilogram of a body by 2 °C is C x 2.

Quantity of heat required to increase the temperature of 1 kilogram of a body by θ °C is C x θ.

Quantity of heat required to increase the temperature of 5 kilograms of a body by θ °C is 5 x C x θ.

Quantity of heat, Q, required to increase the temperature of m kilograms of a body by θ °C is m x C x θ.

Therefore, the general formula is

$Q = m \times C \times \theta$ .... (i)

The unit for specific heat capacity, C, is Joules per kilogram per degree centigrade or Joules per kilogram per Kelvin (J kg^{-1} K^{-1}).

Heat capacity, H

Quantity of heat required to increase the temperature of a body by *1°C is heat capacity H.*

Quantity of heat required to increase the temperature of a body by *2* °C is H x 2.

Quantity of heat, *Q*, required to increase the temperature of a body by θ °C is *H x θ*.

Q = H x θ .... (ii)

The unit of H is Joules per degree Centigrade or Joules per Kelvin ($J\ K^{-1}$).

Now, comparing equations (i) and (ii), you can see that H = mc.

Heat capacity = mass x specific heat capacity

Substance	Specific heat capacity, C, ($J\ kg^{-1} K^{-1}$)
Water	4200
Aluminium	900
Iron	460
Copper	400
Zinc	380
Mercury	140
Lead	130

Table 5.1

5.4 Change of state

Activity 5.14: Determining the specific latent heat of evaporation of water

What you need

- Round bottomed flask
- 2 thermometers
- Stove
- Cork
- Cardboard
- Copper calorimeter with stirrer
- Water
- Weighing scale
- Cotton wool or a rag

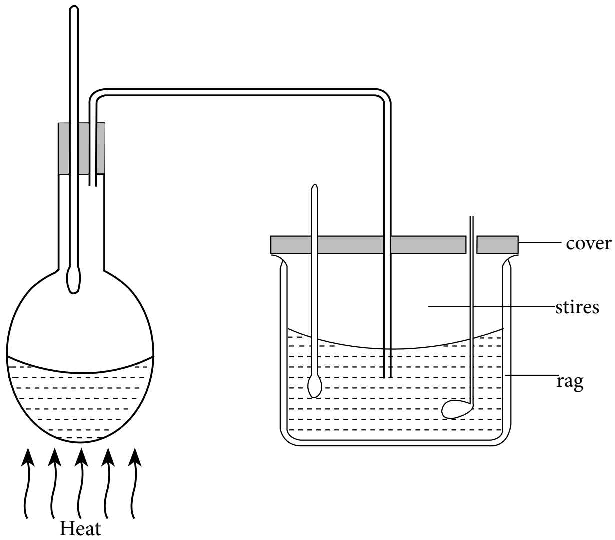


Figure 5.12

What to do

- Weigh the empty calorimeter and stirrer .... M_c kg.
- Weigh the calorimeter with cold water .... M_1 kg.
- Record the temperature of water in the calorimeter .... T_1 °C.
- Set up the apparatus as in **Figure 5.12.**
- Heat the water in the flask until it boils.
- Let the water boil and the steam to issue freely for some time.
- Record the initial temperature of the boiling water .... T_2 °C.
- Bubble the steam into the cold water while stirring.
- When the temperature has risen by over 10 °C, remove the delivery tube from the water in the calorimeter and stop heating the water in the flask.
- Record the final temperature of the water in the calorimeter .... T_3 °C.
- Weigh the calorimeter with the warm water .... m_2 kg.
- State the precautions and sources of error in this experiment.

Working

Mass of calorimeter and stirrer .... m_c .
Mass of cold water in the calorimeter ....$m_w = m_c - m_1$.
Mass of condensed steam ....$m_s = m_2 - m_1$.
Temperature rise of the water in the calorimeter and the calorimeter........... $T_3 - T_1$.
Temperature fall of the hot water .... $T_2 - T_3$.

Let
Specific heat capacity of water be C_w
Specific heat capacity of copper be C_c
Heat lost by steam = $m_s \, x \, l_e + m_s \, x \, C_w \, x \, (T_2 - T_3)$
Heat gained by cold water, calorimeter and stirrer
= $m_w \, x \, C_w \, x \, (T_3 - T_1) + m_c \, x \, C_c \, x \, (T_3 - T_1)$
If no heat was lost to the surroundings
Heat lost = heat gained
Substitute the values you have obtained in the above equation to obtain l_e.
(Assume C_w = 4,200 J $kg^{-1} K^{-1}$ and C_c = 400 J $kg^{-1} K^{-1}$).

Precaution

- Place a cardboard between the source of fire and the calorimeter so that the calorimeter is no heated directly by the heat from the stove.
- Ensure that steam does not get directly in contact with your skin.

Activity 5.15: Determining specific latent heat of fusion of ice

What you need

- Thermometer
- Copper calorimeter with stirrer
- Water
- weighing scale
- Cotton wool or a rag
- Ice blocks
- stove

What to do

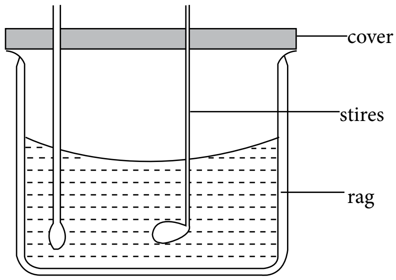


Figure 5.12

- Weigh the empty calorimeter and stirrer .... m_c kg.
- Weigh the calorimeter with hot water .... m_1 kg.
- Record the temperature of the hot water in the calorimeter .... T_1° C.
- Cover the calorimeter with cotton wool.
- Dry a few pieces of ice with the rag, quickly transfer them into the water and stir.
- Record the final temperature of the water in the calorimeter .... T_2° C.
- Weigh the calorimeter with melted ice .... m_2 kg.
- What are the precautions and sources of error in this experiment?
- Mention the assumptions made in the experiment.

Working

Mass of calorimeter and stirrer ....m_c
Mass of hot water in the calorimeter ....$m_w = m_c - m_1$
Mass of melted ice ....$m_i = m_2 - m_1$
Temperature fall of the water in the calorimeter and the calorimeter............$T_2 - T_1$
Temperature rise of the ice .... $T_2 = (T_2 - 0)$
(The temperature of melting ice is taken to be 0° C)

Let

Specific heat capacity of water be C_w

Specific heat capacity of copper be C_c

Heat lost by hot water, calorimeter and stirrer

$= m_w \, x \, C_w \, x \, (T_2 - T_1) + m_c \, x \, C_c \, x \, (T_2 - T_1)$

Heat gained by ice = $m_i \, x \, l_i + m_i \, x \, C_w \, x \, (T_2 - 0)$

If no heat was gained from the surroundings,

Heat lost = heat gained

$m_w \, x \, C_w \, x \, (T_2 - T_1) + m_c \, x \, C_c \, x \, (T_2 - T_1) = m_i \, x \, l_i + m_i \, x \, C_w \, x \, (T_2 - 0)$

Hence substitute the values you have obtained in the above equation to obtain l_i.

(Assume C_w = 4,200 J kg^{-1}K^{-1} and C_c= 400 J kg^{-1}K^{-1})

Activity 5.16: Demonstrating formation of ice by evaporation

What you need

- Menthylated spirit
- Straw
- 100 ml beaker

What to do

- Pour a little water on the bench.
- Place a half-full beaker of menthylated spirit on the bench.
- Using a straw, blow air through the menthylated spirit in the beaker.

Observation

i) What do you see on the sides of the beaker?

ii) Why does ice form under the beaker?

Activity 5.17: Making a cup of hot tea

What you need

- Kettle
- Stove

- Thermometer
- Water
- Cups of different sizes and colours

What to do

- Boil some water in a kettle.
- Pour some hot water into the cup.
- Using a thermometer, record the temperature of the water in the cup.
- Use the thermometer to investigate how the following affect the temperature of the water in the cup:
  - i) Height from which the hot water is poured into the cup.
  - ii) Rate of pouring the hot water into the cup.
  - iii) Rate of movement of wind around the cup.
  - iv) Dampness of the air around the cup.
  - v) Diameter of the cup.
  - vi) Colour of the cup.

Learning Points

Earlier on in this course, you came across the three states of matter, namely, solid, liquid and gases. When a piece of ice at -20°C is heated, its temperature rises to 0°C. Its temperature remains constant at 0°C until all the ice has melted. Note, however, that when more heat is supplied, the temperature of the water rises until when it reaches boiling point. The temperature remains constant when the water is boiling. When the water is boiling, some of it evaporates into vapour.

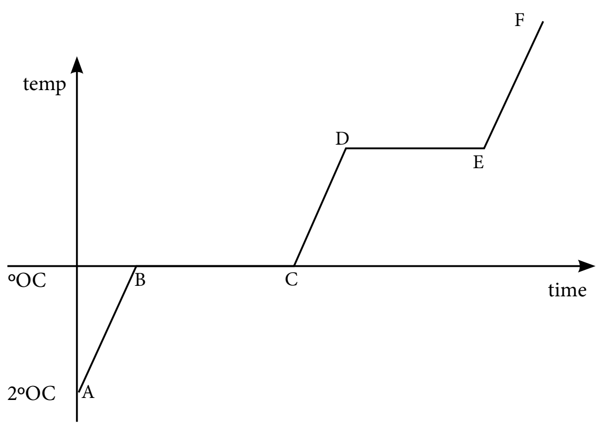


Figure 5.14

Along AB the ice gains heat and its temperature increases.
Along BC change of state from solid to liquid (water) occurs but temperature remains constant.
Along CD water gains heat and it warms. Its temperature rises.
Along DE change of state from liquid to vapour occurs. Temperature remains constant.
Along EF the vapour gains heat.

Evaporation

On the surfaces of liquids, molecules are moving about randomly and exchanging positions with neighbouring molecules. They are prevented from escaping from the surface by the molecular forces. However, some energetic molecules manage to escape (evaporate). They do so by acquiring enough energy to be able to break the molecular bonds. When a boiling liquid is evaporating, its temperature remains constant. All the heat supplied is converted into kinetic energy of the molecules which they use to break the molecular bonds of molecules in the surface of the liquid to cause them to escape (evaporate). The heat required to cause evaporation of a liquid is called the '*latent heat of evaporation*'.

However, both solids and liquids evaporate. Evaporation is strongest at boiling point because the molecular forces are weakest at this temperature.

Specific latent heat of vaporisation is the quantity of heat required to completely vaporise one kilogram of a liquid at its boiling point without change of temperature.

The quantity of heat required to cause evaporation of 1 kilogram of a liquid is the specific latent heat of evaporation, l.
Quantity of heat, Q, required to cause evaporation of m kilograms is ml_e
Therefore, $Q = ml_e$
The SI unit for specific latent heat of evaporation is Joules per kilogram (Jkg^{-1}).
The Specific latent heat of evaporation, l_e, for water is 2,336,000 Jkg^{-1}.

Melting

When a piece of ice whose temperature is below 0°C is heated, its temperature rises to 0°C. The temperature remains constant at 0°C until when all the ice has melted.

All the heat supplied goes into breaking the molecular bonds of molecules in the solid to cause the molecules to be more free to move about. The heat required to loosen the molecules (melting the solid) is called the 'latent heat of fusion'.

> *Specific latent heat of fusion is the quantity of heat required to completely melt one kilogram of a solid at its melting point without change of temperature.*

Quantity of heat required to cause melting of 1kilogram is specific latent heat of fusion, l_f.

Quantity of heat, Q, required to cause melting of m kilograms is $m\, l_f$.

$Q = m\, l_f$

The SI unit of specific latent heat of fusion is Joules per kilogram (Jkg^{-1}).

The specific latent heat of fusion, l_f, of ice is 336,000 Jkg^{-1}.

Cooling by evaporation

The energy necessary for molecules to break loose and escape is the latent heat of evaporation. As the liquid continuously evaporates, it loses molecules of high kinetic energy. With the escape of the more energetic molecules, the overall temperature of the liquid decreases. This explains cooling by evaporation.

Spirit feels cold to the hand because it has a low boiling point and a low specific latent heat of evaporation. As it evaporates, it draws the necessary heat from the body. On the other hand, water has a higher boiling point and a higher specific latent heat of evaporation and therefore does not feel as cold as spirit to the hand.

Factors which affect the rate of evaporation

- *Exposed surface area*. The bigger the area, the higher the rate of evaporation.
- *Humidity*. The more damp the air is, the lower the rate of evaporation.
- *Temperature*. The higher the temperature, the higher the rate of evaporation.

- *Movement of air above the surface*. The faster the air, the higher the rate of evaporation.
- *Boiling point of a liquid*. The lower the boiling point of a liquid, the higher the rate of evaporation.
- *Specific latent heat of evaporation*. The lower the specific latent heat of evaporation, the higher the rate of evaporation.

The refrigerator

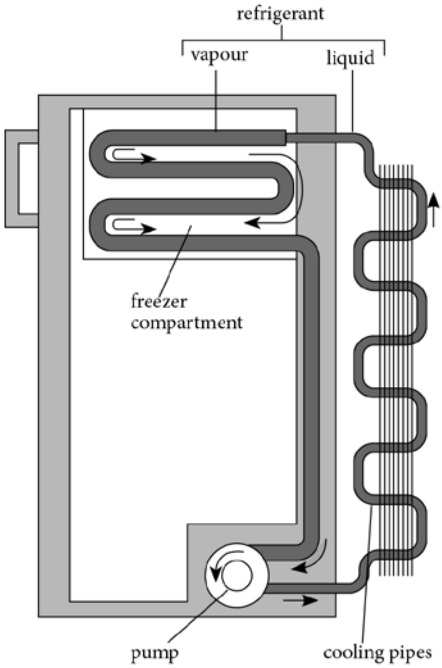


Figure 5.15

How it works

The Freon, which is a very volatile liquid, circulates in the tubes. In the cooling chamber, the Freon evaporates by drawing heat from the contents placed there. Freon vapour is compressed into liquid by a pump thereby giving out the latent heat. This heat is lost to the surroundings through the cooling fins. The fins are desirable because they have a large surface area from which heat can be lost easily to the surroundings.

Therefore, as the Freon circulates in the tubes, it draws the heat from the freezing compartment and loses it to the surroundings through the fins.

The cycle of the process is evaporation compression cooling evaporation and the process continues

Follow-up activity

Assume you are a vendor of sodas. Design a system using evaporation of water that you can use to cool the drinks on a hot day.

Vapours

Activity 5.18: Demonstrating boiling under reduced pressure

What you need

- Round bottomed glass flask with a tightly fitting cork
- Cold water
- Source of heat
- A rag

What to do

- Put a little water in the flask and boil it long enough until all the cold vapour is expelled from the flask.
- Remove the flask from the fire and quickly cork it tightly.
- Cover the flask with a rag soaked in cold water.
- Observe and explain what happens inside the flask.

Follow-up activities

Under the supervision of your teacher, make bone soup from fresh cow bones

Learning Points

In the previous section, you studied about evaporation. At the surface of the liquid, some more energetic molecules are escaping (evaporation) and others are returning into the liquid (condensation).

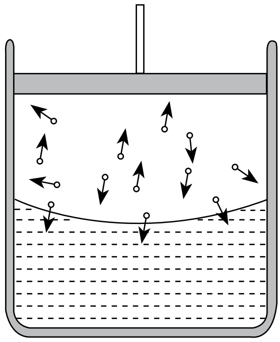


Figure 5.16

In the vapour state, the molecules are moving about randomly, colliding with other molecules and with the walls of the container. At the walls of the container, the molecules exert a pressure called the **vapour pressure.**

When the rate of evaporation is more than the rate of condensation, it means the vapour is unsaturated. The vapour grows at the expense of the liquid.
When the rate of condensation is greater than the rate of evaporation, the liquid grows at the expense of the vapour.
When dynamic equilibrium is reached, the rate of evaporation is equal to the rate of condensation and the vapour is said to be saturated. This occurs at the boiling point of the liquid. At this temperature, the pressure exerted by the saturated vapour is called the saturated vapour pressure (SVP). This happens when SVP is equal to the external pressure above the surface of the liquid.
For a liquid not covered tightly, the external pressure is the atmospheric pressure.

Therefore, for a liquid in an open container

Boiling point of a liquid is a temperature at which the saturation vapour pressure of a liquid is equal to the atmospheric pressure.

The higher the external pressure, the higher the boiling point of the liquid is.

The pressure cooker

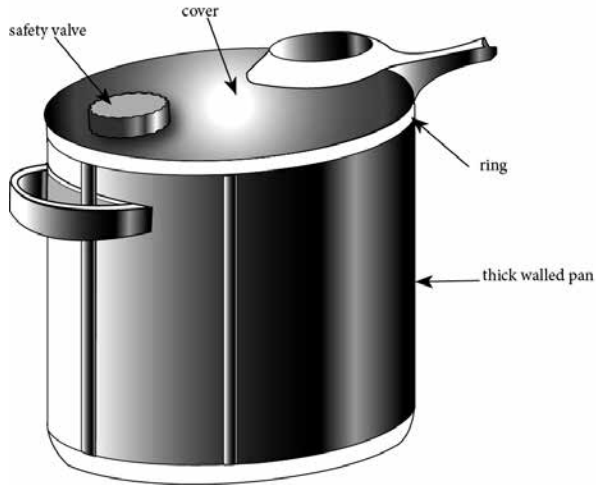


Figure 5.17

Figure 5.17 above shows a pressure cooker. The vapour from the liquid is not allowed out freely. As the liquid is heated, the vapour pressure rises sharply and dynamic equilibrium is restored at a very high pressure. The high SVP raises the boiling point of the liquid. The rubber seal prevents the vapour from escaping. A safety valve is provided to let off some vapour in case the pressure exceeds a safe value. The safety valve should always be free from any food material that might block it. Temperatures in the pressure cooker may rise as high as 125°C.

Expansion of solids and liquids

Activity 5.19: Demonstrating expansion on metals

What you need

- Small metal sphere with a hook
- A circular ring whose diameter is slightly bigger than that of the metal sphere
- Wire of length 100cm

What to do

- Suspend the metal sphere from the hook using the wire.
- Lower the metal sphere to pass through the circular ring.
- Remove the sphere and heat it over a flame.
- Lower the heated metal sphere to pass through the ring.
- Note and record your observation.

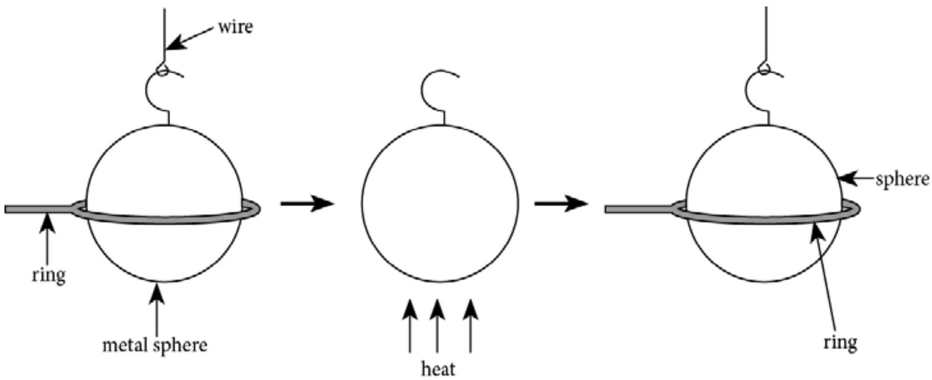


Figure 5.18

Interpretation

a) Does the metal sphere pass through the ring before heating it?
b) Does the metal sphere pass through the ring after heating it?
c) What conclusion can you draw from your observation above?

Activity 5.20: Making a bimetallic strip

What you need

- Strip of copper and iron of same dimension

- Reverts or small nails
- Hammer on a wooden handle

What to do

- Align the two strips parallel to each other.
- Fix them together with a rivet or nail.
- Hammer the rivet so that there is no gap between them.
- Fix a wooden handle to one side.

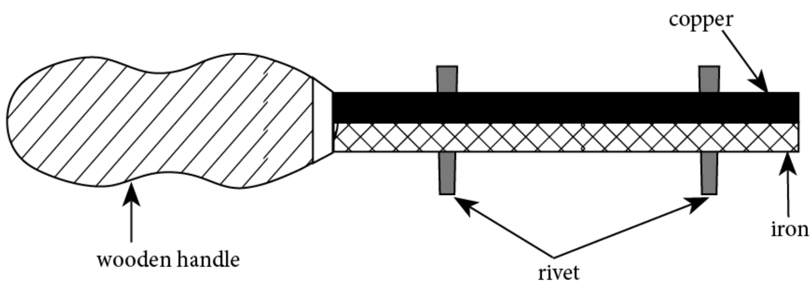


Figure 5.19

Observation

Hold the bimetallic strip by the wooden handle and put the strip into a fire (say burning charcoal stove) for a few minutes.

i) To which side does the strip bend?

ii) Give reasons for the bending to that side.

Precaution

Avoid touching the strip with bare hands when hot but always hold it using a wooden handle.

Activity 5.21: Demonstrating the use of a bimetallic strip in electrical systems

- **What you need**
- Bi-metallic strip
- Connecting wires
- Electric bell
- A metallic contact on the end closest to bimetallic strip

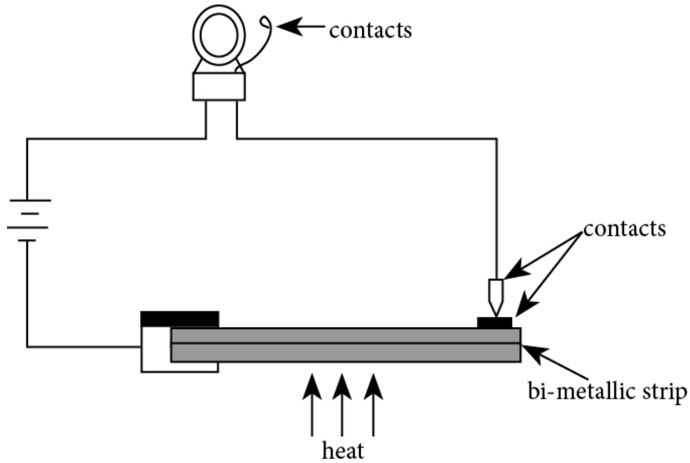


Figure 5.20

What to do

- Assemble the apparatus as in Figure 5.20 making sure a little gap is left between the contact metal and the bimetallic strip.
- Gently heat the bi-metallic strip.
- Replace the electric bell with a torch bulb in its holder. What happens this time?

Observation

What happens to the bi-metallic strip when heated? Explain your observation.

Learning Points

When most solids are heated, their atoms or molecules gain energy and vibrate about their mean positions with bigger amplitude. This means that they occupy a larger space. The metal is said to have expanded.
Note that during expansion, the size of the atoms or molecules themselves does not increase.

Follow-up activity

Identify which use a bi-metallic strip to operate.

Rates of expansion

Some solids and liquids expand more than others. In the following treatment, we consider the expansion of solids.

Linear coefficient of expansion, $\alpha = \dfrac{expansion}{original\ length\ x\ temperature\ rise}$

Another term used for linear coefficient of expansion is expansivity.
The SI unit for linear coefficient of expansion is K^{-1} or $°C^{-1}$.

Metal	Linear coefficient of expansion (K^{-1})
Iron	0.000 012
Brass	0.000 019
Invar	0.000 001
Concrete	0.000 011

Table 5.2

The bimetallic strip

This is a composite strip consisting of two metals e.g. iron and invar, nailed together. Since iron expands more than invar, the strip bends towards the side of invar when heated and towards the side of iron when cooled.

Anomalous (abnormal) expansion of water

Water does not expand the same way like other liquids.

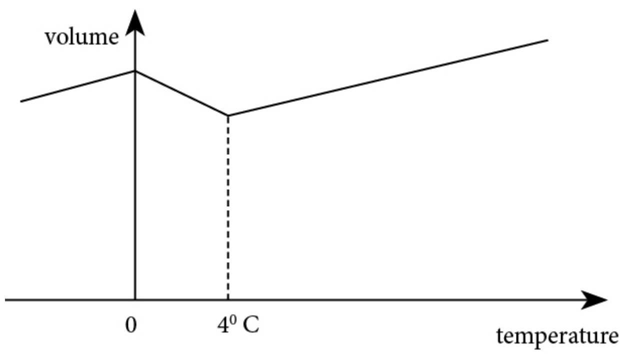


Figure 5.21

The graph above shows the variation of the volume and density of a quantity of water for a range of temperatures. Water has maximum density at 4°C. When it is cooled below 4°C, it expands instead of contracting like other liquids. This explains the air space left above the liquid in a soda bottle.

Biological importance of the abnormal expansion of water

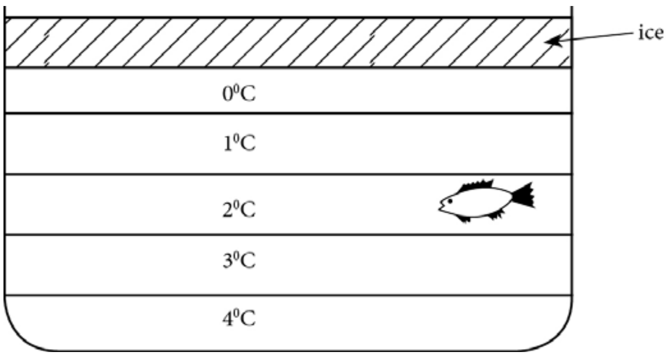


Figure 5.22

Any water which cools to 4°C becomes very dense and sinks to the bottom. The temperature of the water progressively reduces to 0°C at the surface. On the surface, there is a crust of ice.

In regions where lakes freeze, life can exist below the crusts of ice. Fish and other aquatic creatures periodically come to the surface through cracks in the crust for a fresh supply of oxygen.

Follow-up activities

1. Volume of a substance is inversely proportional to its density. Sketch a graph density of water against temperature
2. Devise a system which controls temperature in a baby cot.

Gas laws

Activity 5.22: Working with balloons

What you need

- Balloons of different sizes
- Water in a large cooking pot (constant temperature bath)
- Rag
- Ruler
- Thermometer
- Heater

What to do

a) *Investigating the effect of temperature on volume at constant pressure*

- Blow some air into a balloon and tie its mouth.
- Gently warm the air in the balloon using the warm water.
- Measure the temperature of the water and the diameter of the balloon.
- Repeat the experiment at different temperatures and record your results in a suitable table.
- Plot a graph of diameter against temperature

a) *Investigating the effect of temperature on pressure at constant volume*

- Blow some air into a balloon, tie its mouth and measure its diameter.
- Gently warm the air in the balloon using the warm rag on the balloon.
- Measure the temperature of the water.
- Reduce the diameter of the balloon to its original size by securing its mouth more firmly.
- Find out the resulting effect on the pressure of the air in the hardness of the balloon.

Precaution

Make sure the balloon does not burst in the hot water.

Interpretation

Interpret your results in terms of kinetic theory (explanation using motion of molecules in the gas).

Application

A visiting team from a cold climate country comes with a ball for a game to play with a host team, which also has their own ball. Discuss the advantages and disadvantages of using either ball in the game.

Activity 5.23: Investigating the effect of temperature on pressure of a balloon

What you need

- Balloons of different sizes and colours
- Strings

What to do

- Blow air into the balloons to different sizes and tie their mouths.
- Hang them out in the sun.
- Watch them as the sun becomes hotter.
- Observe the effect of
    - Colour
    - Pressure
    - Temperature

  on how quickly the balloon bursts.

Learning Points

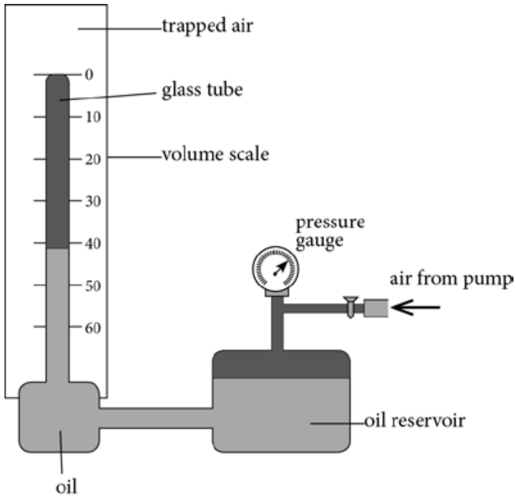


Figure 5.23

In the diagram above, dry air is trapped in a strong tube. The pressure of the air can be increased using a pump each time measuring the volume. Below are typical results:

Pressure (kPa)	Volume (cm^3)
500	100
800	86
1000	50
1200	42
1500	33

Table 5.3

From the table it can be seen that as pressure on the gas increases its volume decreases.

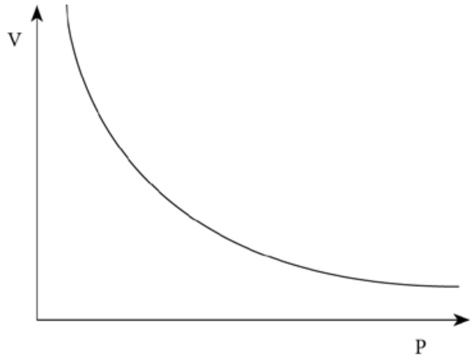


Figure 5.24

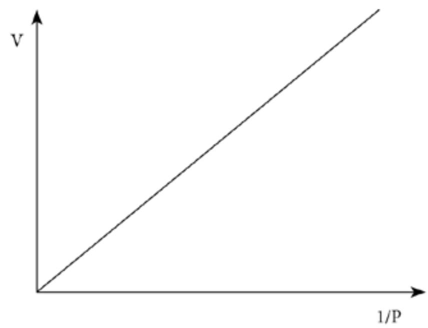


Figure 5.25

A quick glance at the graph shows that as the pressure increases the volume decreases. This means that the volume of the gas is inversely proportional to its

pressure, i.e. *volume* $\alpha \ \frac{1}{pressure}$

or *pressure x volume = constant* (at constant temperature)

P x V = constant

If V_1 is volume at pressure P_1 and V_2 is the volume at pressure P_2 then

$\boldsymbol{P_1V_1 = P_2V_2}$ ***= constant (at constant temperature)***

Boyle's law

The volume of a fixed mass of gas is inversely proportional to its pressure at constant temperature.

Example: A balloon contains 2,000 cm^3 of air at a pressure of 1.2×10^5 Pa. What will its volume be if the pressure is increased to 1.5×10^5 Pa, at constant temperature?

$P_1 = 1.2 \times 10^5$ Pa. $P_2 = 1.5 \times 10^5$ Pa $V_1 = 2000\ cm^3$ $V_2 = ?$

$$P_1V_1 = P_2V_2$$

$$1.2 \times 10^5 \times 2000 = 1.5 \times 10^5 \times V_2$$

$$V_2 = 1600\ cm^3$$

What you need to know

- *An isothermal process is one in which the temperature of the system remains constant.*
- *A gas which obeys Boyles' law is called an* ***ideal gas****.*

Pressure law

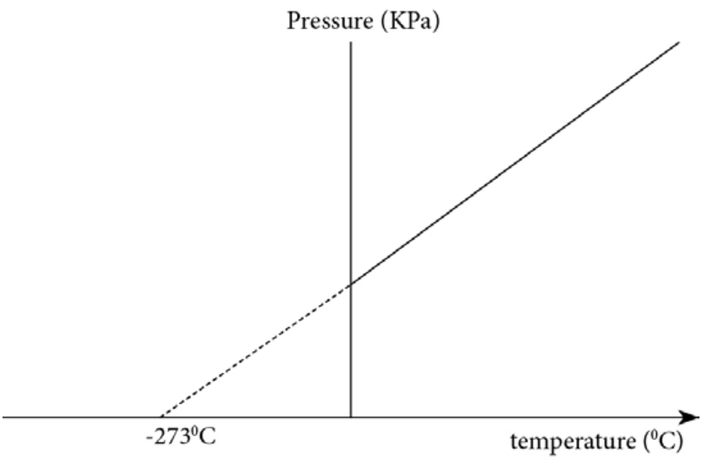


Figure 5.26

In Figure 5.26 above, the temperature of the water is increased by removing some of the water and adding hotter water. The pressure of the gas in kPa is recorded against temperature in °C.

Typical results:

Pressure (kPa)	Temperature (°C)
50.0	10
51.8	20
55.3	40
58.8	60
62.4	80
65.9	100

Table 5.4

From the results, it can be seen that as temperature of the gas is increased (at constant volume), the pressure of the gas also increases.

Absolute temperature

A more suitable temperature scale, called the Kelvin scale, is adopted when dealing with gases.

Temperature in Kelvin (K) = Temperature in Degrees Centigrade (°C) + 273

Note: When recording the temperature on the absolute scale, the symbol ° is not used.

In Table 5.5 below, the temperatures in Degrees Centigrade which were used in the experiment above have been converted to Kelvin.

Temperature (°C)	Temperature (K)
10	283
20	303
40	323
60	343
80	363
100	383

Table 5.5

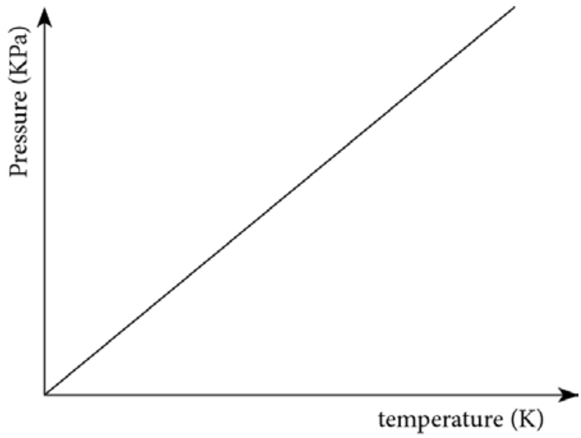


Figure 5.27

A graph of pressure against absolute temperature is a straight line through the origin.

We can, therefore, conclude that t*he pressure of a fixed mass of gas is directly proportional to its absolute temperature at constant volume.*
This is known as the pressure law.
We can write the following:
Pressure α absolute temperature or
pressure = absolute temperature x constant or
P = T x constant or

$$\frac{P}{T} = constant$$

From this statement, we can conclude that if an ideal gas at a pressure P_1 and absolute temperature T_1 is heated at constant volume to an absolute temperature T_2 and its pressure becomes P_2, then,

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} = constant$$ (At constant volume)

The volume – temperature law

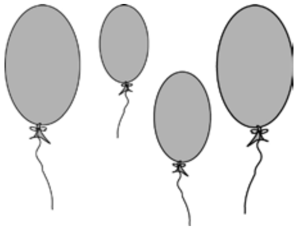


Figure 5.27

When a balloon is heated by direct sunlight, it expands. In this case, the pressure outside the balloon (atmospheric pressure) is constant. Thus we can conclude that at constant pressure, as temperature increases, the volume of a gas also increases.

Graphs

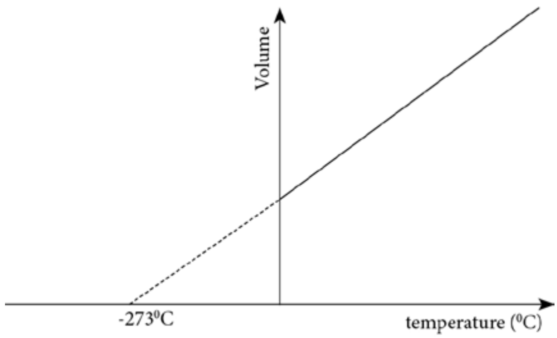


Figure 5.28

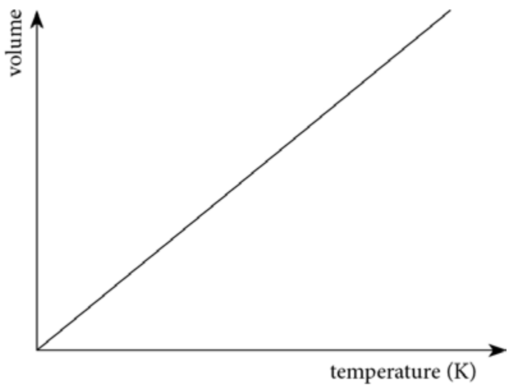


Figure 5.30

A graph of volume against temperature (K) is a straight line through the origin. Therefore, we can conclude that:

The volume of a fixed mass of gas is directly proportional to its absolute temperature, at constant pressure.

The statement above is known as Charles' Law or Volume-Temperature Law.

Mathematically,

Volume α absolute temperature

Or

V = constant x T

$$\frac{V}{T} = constant ,$$

which leads to

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} = constant \text{ (at constant pressure)}$$

The equation of state (The combined gas equation)

Boyles' law, Charles' law and the pressure law may be combined into a single equation called the equation of state.

$$\frac{PV}{T} = cons\tan t$$

Or

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

This equation can only be applied to ideal gases.

Worked example

$1.5 m^3$ of a gas at a temperature of 27°C and a pressure of 1.2×10^5 Pa is heated to a temperature of 87°C and a pressure of 2.0×10^5 Pa. Calculate its new volume.

Solution

$P_1 = 1.2 \times 10^5$ Pa $\quad V_1 = 1.5m^3 \quad T_1 = 27°C = 273 + 27$
$= 300K$

$P_2 = 2.0 \times 10^5$ Pa $\quad V_2 = ? \quad T_2 = 87°C = 273 + 87$
$= 360K$

Applying $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

$$= \frac{1.2 \times 10^5 \times 1.5}{300} = \frac{2.0 \times 10^5 \times V_2}{360}$$

$V_2 = 1.08$ m^3

Learning Points

Kinetic theory of gases

A gas consists of millions of molecules which are moving about randomly. Their speeds depend on temperature of the gas. As they move, they collide with themselves and with the walls of the container. When the molecules collide with the walls of the container, they exert a force on it. This explains why a gas exerts a pressure.

When a gas expands at constant pressure, the molecules rebound with decreased velocities. They, therefore exert a smaller force on the walls of the container which results in reduced pressure. This explains Boyles' law.

If the temperature of a gas is increased while keeping the volume of the gas constant, the speeds of the molecules increase and they rebound off the walls with a bigger force and, therefore, the pressure of the gas increases. Remember, at constant volume, the pressure of a gas increases with temperature.

Using a similar argument, Charles' law can be explained.

Follow-up activities

1. Visit a fuel station or a garage and talk to the attendants about the various aspects that must be considered when pumping a tyre. What would you consider when pumping the tyre of a car?
2. Assume you have been hired to decorate a function with balloons, give reasons why you need to consider the following: colour, weather, beauty, cost, strength, effect of heat on the materials.

Chapter 6: Electrostatics and Electricity

Introduction

Modern homes, factories, schools and offices use electricity. This is a modern form of energy. Electricity can be generated in many ways. In this chapter, you will study how electricity is generated, transported safely and economically used.

Electrostatics

Activity 6.1: Making a charge detector

What you need
- Old cassette tape (or aluminium foil)
- Cork
- Hammer
- New nail
- Rubber band
- Dry empty water bottle

What to do
- Drive a nail through the centre of the cork.
- Tie a piece of cassette tape (2cm long) on the lower end of the nail using a rubber band, leaving one end of the tape free.
- Fix the cork on the bottle.
- You have made an electroscope. Use it to detect and test charges.

Precaution
- The nail should not be rusty.
- Ensure that there is no insulation between the nail and the tape.

Activity 6.2: Charging metals without putting them into contact with charged bodies (charging by induction)

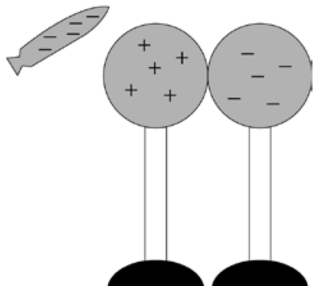


Figure 6.1

What you need
- Two metal spheres standing on insulators
- Ebonite rod
- A hairy animal skin (fur)
- A gold leaf electroscope

What to do
- Bring the two metal spheres into contact.
- Charge the ebonite rod by rubbing it with fur.
- Hold the ebonite rod close to one of the spheres but do not make contact with it.
- Touch one of the spheres and remove your finger from it while still holding the ebonite rod close to one of the spheres.
- Separate the spheres.
- Take away the ebonite rod.
- You can now test the spheres for charge using a gold leaf electroscope.

Explain how the spheres acquired the charges.
You can now charge only one sphere by induction as follows:
- Charge the ebonite rod by rubbing with fur and hold it close to one of the spheres.
- Touch the sphere and remove your finger from it while still holding the

ebonite rod close to it.
- You can now test the sphere for charge.

Activity 6.3: Investigating the distribution of charge on a hollow conductor

What you need
- Cotton thread
- Insulating mat
- Insulating handle
- Fur
- Metal bob with hook
- Metal container
- Gold leaf electroscope
- Connecting wire

What to do
- Place the pail on the insulating material .
- Using a wire, connect the metal container to the cap of the gold leaf electroscope.
- Tie the bob on a thread and charge it by rubbing it with fur.
- Slowly lower the bob into the metal container.
- Observe what happens to the gold leaf as the ball is lowered until it touches the bottom or side of the container.
- Remove the ball from the container after it has touched the bottom and test it for any charge.

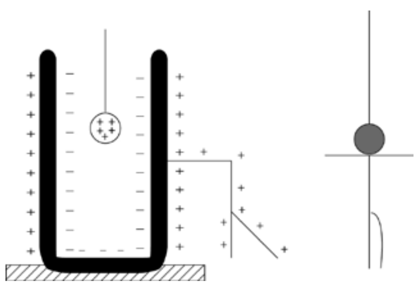


Figure 6.2

A charged metal ball on a thread in a metal container and then transferred to the cap of a goldleaf electroscope

Learning Points

A plastic pen rubbed in dry hair attracts small pieces of paper. The pen is said to be electrified or charged.

Existence of positive and negative charges

Ebonite rods charged by rubbing with fur and tied on insulating threads repel each other. The two are said to possess the same type of charge.
An ebonite rod charged by rubbing with fur attracts a glass rod rubbed with silk. The glass rod and the ebonite rods are said to possess opposite types of charges. One of them, glass, is said to be positively charged and the other, ebonite, is negatively charged.

Law of electrostatics

Like charges repel and unlike charges attract each other. Repulsion between charged objects is the only test we can trust. This is because with a charged body, there are two possibilities: either the other body is oppositely charged or uncharged. Thus attraction between a known charged body and another body is inconclusive.

Metals and insulators

Metals are good conductors of electricity. This is because the atoms of metals have loosely bound outer electrons. Insulators e.g. glass, paper and dry wood are poor conductors of electricity. In insulators, there are no loose electrons.
When charging by rubbing, the frictional force causes the removal of some of the outermost electrons of the surface atoms. The body which loses electrons becomes positively charged and the one which gains electrons becomes negatively charged. The number of positive charges created is equal to the number of negative charges created during the charging by friction.
Both insulators and conductors can be charged by friction, but for metals, this is possible only when they are held in insulating handles.

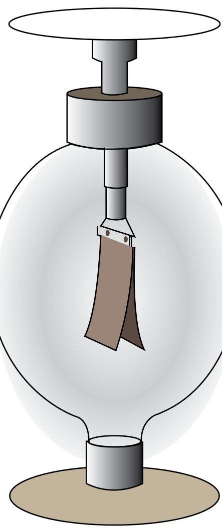
Note: *In metals, only electrons are free to move.*

Answer these questions

1. Why is it difficult to charge metals?
2. Explain why all materials used in electrostatic experiments must be dry.
3. Why is it difficult to charge objects in damp conditions?

The gold leaf electroscope

A gold leaf electroscope is a device used to detect and test charges.



A goldleaf electroscope

Figure 6.3

How the electroscope works

When the cap of the gold leaf electroscope gets in contact with, for example, a negatively charged body, some of the negative charges on the body pass onto the cap and down to the plate and leaf. Since like charges repel each other, the plate repels the leaf and makes it rise (diverge).

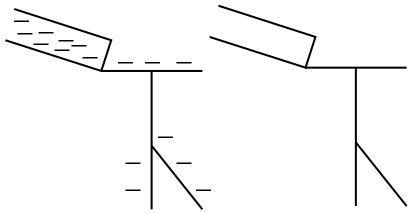


Figure 6.4

A negatively charged touching the cap of a goldleaf electroscope and an un charged body touching the cap of a negatively charged electroscope

Suppose the cap is now touched with a body X with an unknown charge, the following are the possibilities:

Charge on electroscope	Charge on X	Effect on leaf divergence
+	+	Increase
-	-	Increase
+	-	Decrease
-	+	Decrease
+	None	Decrease
-	None	Decrease

Table 6.1

Electrostatic induction

It is possible to charge one body using a charged body when there is no physical contact between the two. This is called electrostatic induction.

Explanation of charging by induction

When, for example, a negatively charged body X is brought close to a metal, it repels the free surface electrons to the side remotest from X. The side closest to X remains with a net positive charge while the side remotest from X acquires a net negative charge. When the metal is touched (earthed) the free electrons at the remote end run to earth. If X is now taken away, the metal remains with a net positive charge.

Explanation of the ice-pail (metal pail) experiment

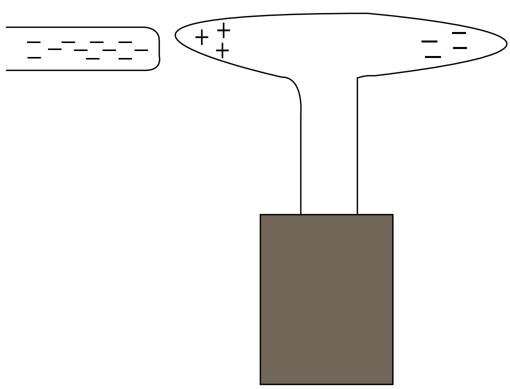
When a charged ball is inside a metal container, it induces a charge equal but opposite to its own on the inner surface of the container and a charge equal and similar to its own on the outer surface. The gold leaf connected to the outside surface rises. When the ball touches the inner surface, the charge on it is neutralised.

Note: Charge cannot reside inside a hollow metal container; either there is no charge at all (when the ball touches the container) or the number of positive charges inside the container is equal to the number of negative charges there. Therefore, the net charge inside a hollow metal container is zero.

Charges in a flame

Inside a flame, the air molecules are moving violently and colliding with each other. The collisions result in ionisation.

i) When a charged body is drawn through the flame, it is found to have lost all its charge.
ii) When a charged body is brought near the flame, it attracts ions of the opposite kind and repels ions of the same kind. This distorts the flame.



A charged body near a flame

Figure 6.5

Charges in the atmosphere

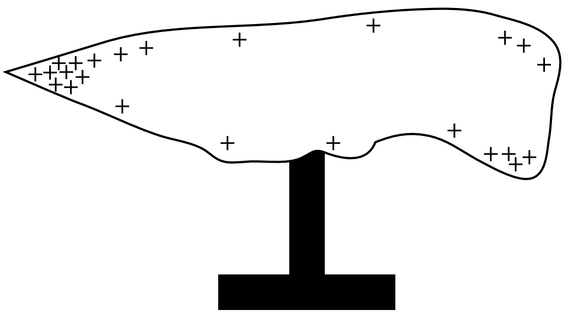
The atmosphere contains ions which are as a result of the following:

- Ionisation by UV radiation from the sun.
- Ionisation by cosmic radiation from outer space.
- Radiation from radioactive substances in the surroundings.

Because of the presences of charges in the atmosphere, a charged body left exposed to the atmosphere will gradually lose its charge due to the presence of opposite charges in the atmosphere.

Charges on a body

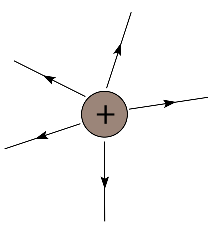
Experiment shows that sharp edges on a body have a higher density of charges than other points on the body.



Concentration of charge on a metal
Figure 6.6

Electric field

This is a region where an electric force is experienced by a charged body. The figures below show the patterns of electric field due to different charge arrangements:



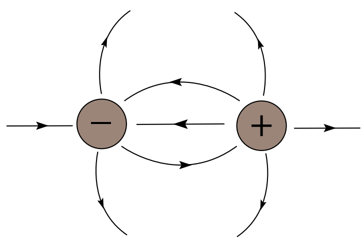


Figure 6.7

i) Due to an isolated point (small) charge
ii) Due to opposite point charges
iii) Between two charged plates
iv) Between a charged plate and a point charge

Potential

A body which is positively charged is said to be at a positive potential and that which is negatively charged is said to be at negative potential. The earth is taken to be at zero potential.

When a wire is connected from a body which is at a positive potential to another one which is at a negative potential, electrons will flow from the object which is at low potential to the object at high potential, i.e. electrons flow from low potential to high potential.

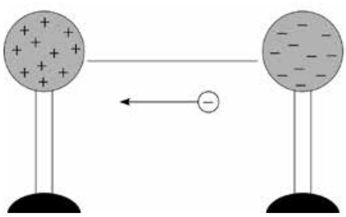


Figure 6.8

Earthing

The term earthing refers to connecting an object to the earth using a conductor, for example, running a connecting wire from an object to a tap on a pipe which runs underground.

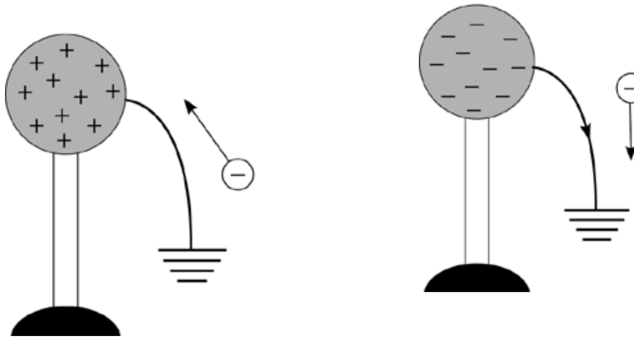
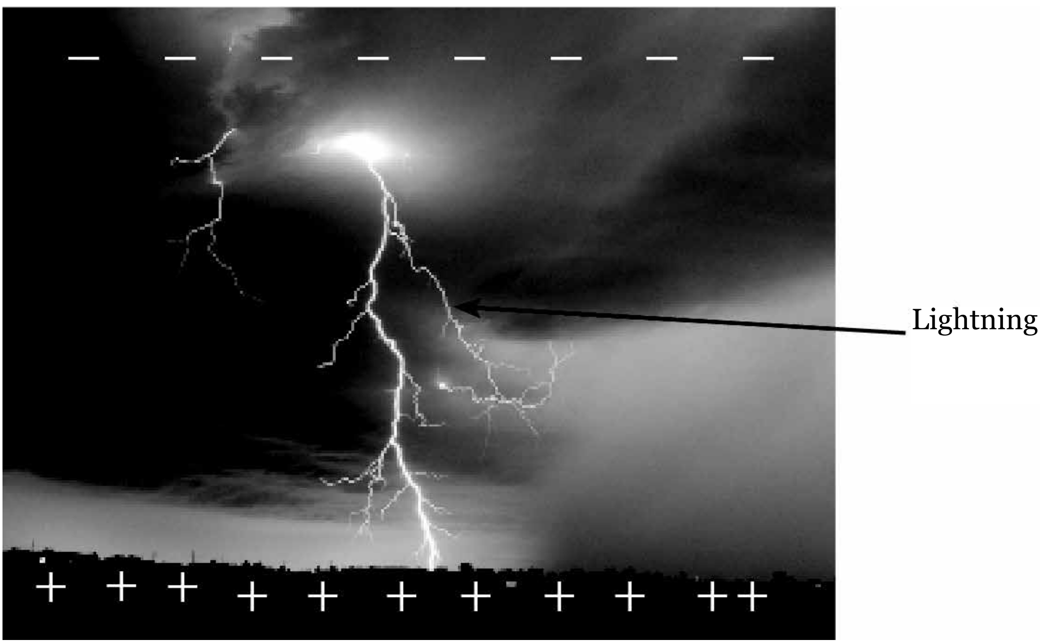


Figure 6.9

Electrons flow from low potential to high potential. The earth has a high affinity to electrons and it can also supply electrons whenever they are needed.

Lightning and thunder

During a storm, clouds may become charged. Consider two clouds charged oppositely near each other as in figure 6.10 below:



Lightning

Figure 6.10

An electric field exists between the clouds. As the storm progresses, charges accumulate in the clouds. At a certain point, the insulation between the two clouds breaks down and a big current flows between them. This big current heat up the air which becomes very hot and in turn gives off a spark of light (lightning). This heat may cause buildings to burn and trees to be uprooted or split because of the sudden heating which results into a sudden expansion of the water in them. The sudden flow of current and heating of the air causes a sudden expansion of the air which causes a loud sound (thunder).
If the charged clouds are close to the ground, people on the ground may be harmed.

Places to avoid during a storm

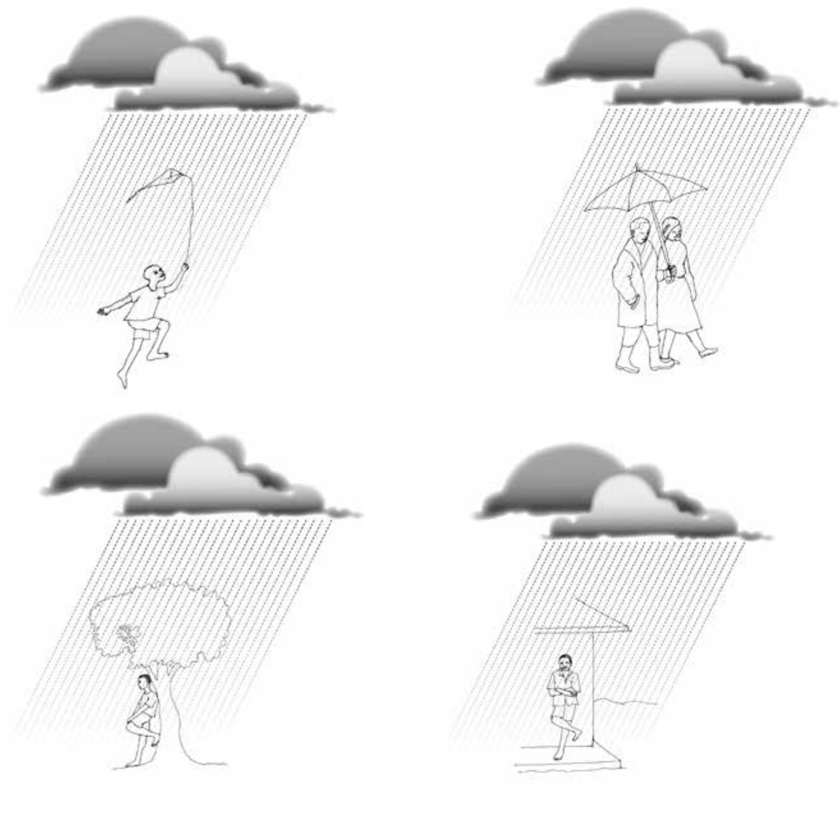


Figure 6.11

Lightning conductor

This is a thick copper wire which runs to the earth from the top of a building. It ends in a sharp point at the top of the building. Sharp points are used to protect buildings from damage which would have been caused by lightning.

How a lightning conductor works

When a cloud passes near the sharp point, it induces in it a high concentration of charges of the opposite kind and the same number of charges of the same kind at the base of the conductor. The latter are neutralised by charges in the earth. The high concentration of charges at the tip of the conductor ionises the air and sends away a stream of charges which neutralise the charges in the clouds. The opposite ions neutralise the charges at the sharp point.

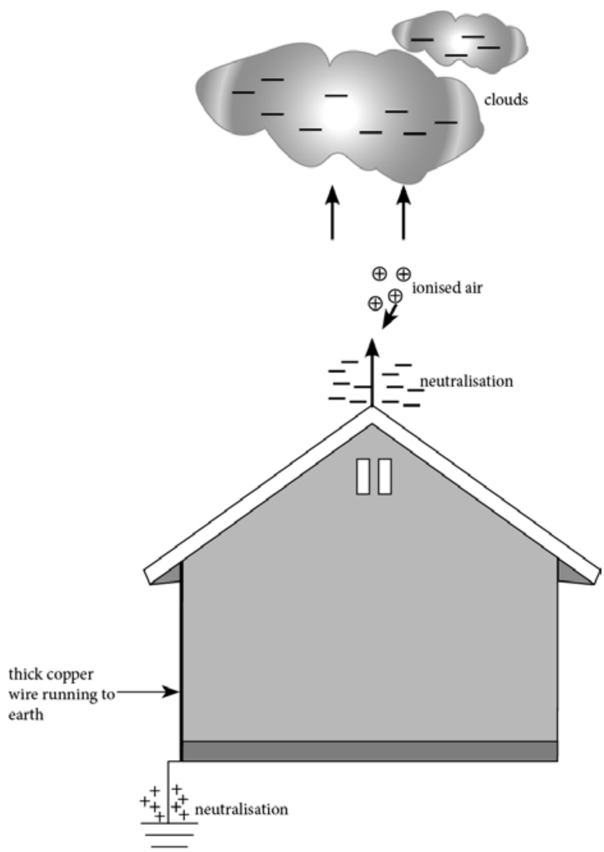


Figure 6.12

Follow-up activity: Studying the installation of a lightning conductor

What you need

A house with a lightning conductor installed

What to do

- Study the shape of the conductor.
- Find out the metal from which it is made.
- Ask a technician how it is installed.
- Find out whether there are any buildings in your compound which require a lightning conductor.

Electric cells

Activity 6.4: Making a simple cell

What you need

- Plastic cup
- Connecting wires
- Ammeter
- Torch bulb and bulb holder
- Dilute sulphuric acid
- Distilled water
- Ripe oranges and lemons
- 1cm x 1cm sheets of copper
- Zinc
- Aluminium or copper
- Iron
- Other available metals

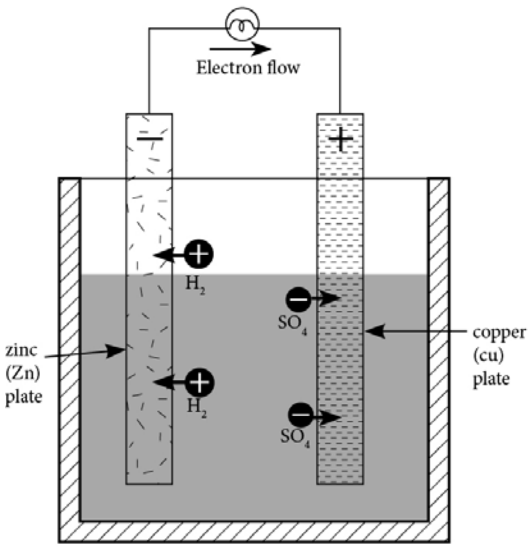


Figure 6.13

What to do

- Assemble the apparatus as in Figure 6.13 above.
- Observe what happens to the ammeter pointer.
- Observe what happens on the plates
- Investigate the effect of:
  - i) Diluting the acid
  - ii) Increasing the temperature of the acid
  - iii) Changing the type of metals making the plates
  - iv) Reducing the distance between the plates
  - v) Increasing the surface area of the plates
- Replace the dilute sulphuric acid with lemon or orange juice and repeat the experiments above.

Activity 6.5: Measuring emf of a cell

What you need

- Voltmeter
- Connecting wires
- Cell holders of different sizes
- Dry cells of different sizes (old and new)

What to do

- Measure and record the emf of different cells.
- Draw the circuit you have used.

Precaution

Cells must never be short circuited. Short circuiting is connecting a conductor of little resistance across the terminals.

Activity 6.6: Combining cells to make a battery

What you need

- Voltmeter
- Ammeter
- connecting wires
- cell holders
- dry cells
- bulb
- bulb holder

What to do

Series connection

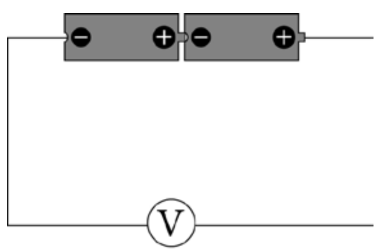


Figure 6.14

Parallel connection

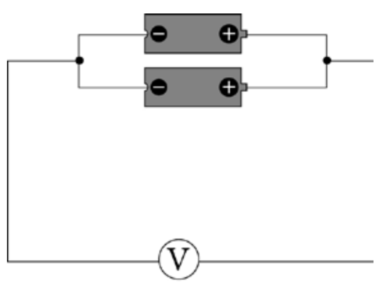


Figure 6.15

- Assemble the apparatus as in the Figures above.
- Measure the emf in each case.
- Now connect each arrangement separately to a bulb. Include an ammeter in the circuit.
- For a given load find the arrangement which delivers:
  (i) a bigger current
  (ii) a bigger emf

Answer these questions

1. Write down the factors which affect the size of emf generated by a simple cell .
2. List the ways of proper handling of cells.

Activity 6.7: Charging a battery

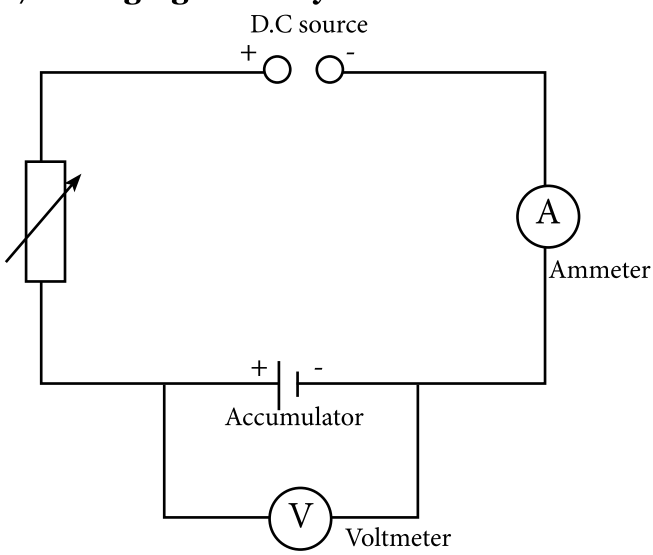


Figure 6.16

What you need

- A car battery
- Connecting wires
- Ammeter
- Voltmeter
- Rheostat

- Charging machine
- Mains electricity

What to do

- Clean the terminals of the battery.
- Assemble the apparatus as in figure 6.16.
- Switch on the charger.
- Vary the rheostat to obtain a suitable charging current (Consult a technician).
- Periodically monitor the voltage across the battery.
- Switch off the mains when the voltage reaches 12 V.

Precaution

- The output emf of the charger must be bigger than that of the battery being charged.
- You should carry out the activity under the supervision of a technician.
- Mention any other precautions you made during the charging process.

Learning Points

A simple cell consists of two plates (called electrodes) made of different metals dipping in dilute sulphuric acid (electrolyte). The electrodes do not come into contact with each other. The acid is contained in a non-conducting container.

How a simple cell works

Zinc and copper behave differently with dilute sulphuric acid**.** Zinc reacts with dilute sulphuric acid. For each atom of zinc that reacts with dilute sulphuric acid, two free electrons are produced. Therefore the Zinc plate becomes negatively charged.

In the acid, the hydrogen ions (which, of course, are positively charged) migrate towards the copper plate and combine with the free electrons which would have moved through a wire connecting the zinc plate to the copper plate.

When hydrogen ions combine with the free electrons, hydrogen gas is produced at the copper plate. The maximum emf generated by such a cell is 1.5 V.

Defects of a simple cell

a) **Polarisation**

When the cell is working, bubbles of hydrogen are observed at the copper plate. These bubbles make it difficult for more hydrogen ions to reach the copper plate. This effectively reduces the emf generated by the cell.

The bubbles of hydrogen can be removed by adding a depolariser to the acid (a chemical which reacts with the hydrogen gas without acting with the essential chemicals). Less effective methods include putting the cell in direct sunshine or using a brush to scratch the bubbles off the copper plate.

b) **Local action**

When the cell is working, a few bubbles of hydrogen gas are seen at the Zinc plate. These are due to the presence of some impurities in the Zinc plate. The presence of impurities creates tiny local cells in the plate.

Local action is minimised by brushing the plate, and dipping it in concentrated sulphuric acid and then in mercury. This action creates a layer of Zinc amalgamate which is impervious to dilute sulphuric acid.

The dry cell

Figure 6.17 below is of dry cell. This type of cell is commonly used in radio sets and flashlights. Dry cells are sold in many sizes according to their intended use.

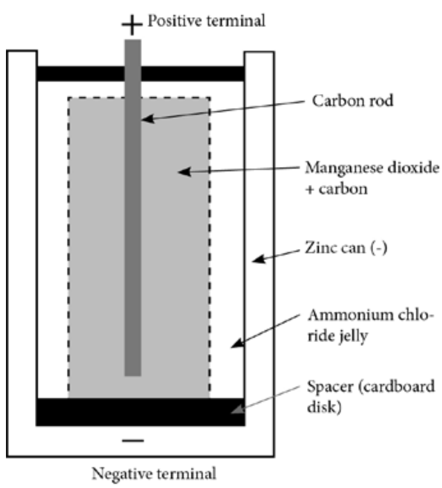


Figure 6.17

Answer these questions

1. Compare the structure of a dry cell with that of the simple cell.
2. What are the advantages and disadvantages of a dry cell compared to the simple cell?

Alkaline cells

In alkaline cells, the electrolyte is an alkali. These cells have the advantage of lasting longer than dry cells but they are more expensive.

Primary cells

When a dry cell is used for a long time its emf drops. This is because most of the chemicals in the cell would have reacted. This chemical reaction is not easily reversible. The best we can do is to discard the cell and replace it with a new one. This type of cell is called a primary cell. An example of a primary is a dry cell.

The Lead-Acid Accumulator

This is a battery which can be recharged and used over again. It is a secondary cell. The chemical reactions in the battery are reversible. The electrolyte is dilute sulphuric acid. The electrodes are large plates placed close to each other. The active chemicals are packed in the plates. The large area of the plates ensures a large area over which chemical reactions can take place. The small distance between the plates reduces the internal resistance of the battery. This arrangement makes the battery deliver a large current.

Charging a battery

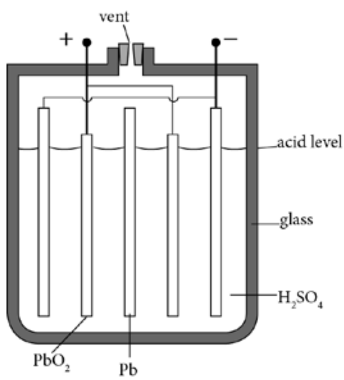


Figure 6.18

Things to note when charging a battery

- The emf of the charging battery must be greater than that of the battery being charged.
- The positive terminal of the charging battery must be connected to the positive terminal of the battery being charged and vice versa.
- The charging current must be controlled using a rheostat and measured using an ammeter.
- The caps of the battery chambers must be left open during the charging process.
- Avoid overcharging. Use the voltmeter to measure p.d. across the battery.
- Charging should be done in an open place and with no fire in the vicinity.
- The acid level should be made up using only special distilled water.

Care of accumulators

We have already seen how an accumulator can be charged. In order to ensure long life of the accumulator, you should visit a local mechanic and find out the various precautions they take when charging an accumulator and the best way of handling batteries.

Electromotive force

Electromotive force is the rate at which energy is drawn from a source that produces a flow of electricity in a circuit. It is expressed in volts.

The emf of a new dry cell (size D) used in most radio sets is 1.5 V. Emf is measured using a voltmeter connected across the terminals of the cell when it is not connected on anything else.

Electromotive force is the p.d. across the terminals of a cell when it is not delivering current to any external load.

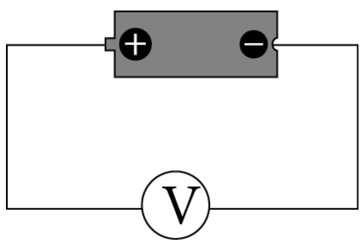


Figure 6.19

A battery is a combination of cells. Sometimes it is called a battery of cells.

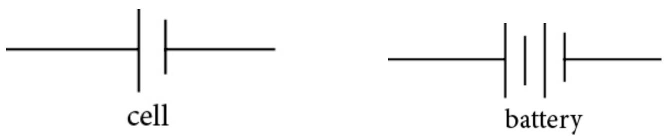


Figure 6.20

A cell drives current through a circuit to which it is connected in the direction shown on the diagram below.

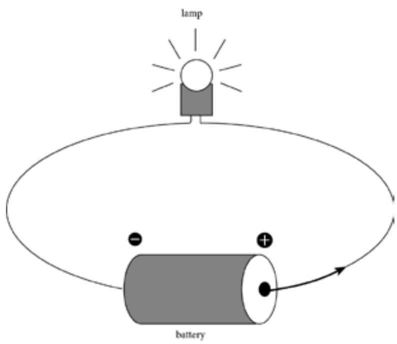


Figure 6.21

Follow-up activity

Dismantle an old car battery and an old dry cell and observe the arrangement of the parts inside it. You may ask a local mechanic to give you some more information on the operation of the battery and its proper handling.

Electric circuits, electric current and resistance

Activity 6.8: Investigating the relationship between current and potential difference across a conductor

What you need

- Two dry cells (size D)
- Connecting wires
- Rheostat

- Cell holder
- Voltmeter
- Torch bulb
- Bulb holder
- Metal wire e.g. constantan or tungsten (SWG 28)

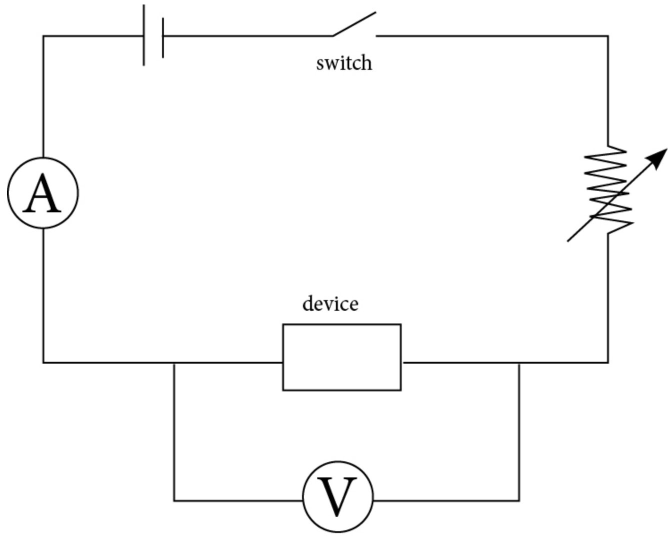


Figure 6.22

What to do

- Assemble the circuit as in Figure 6.22 and close the switch. Read the current through the conductor or device (a bulb in this case) and the p.d. across it.
- Change the current through the conductor using a rheostat and read both the current and p.d. Tabulate the results in a table.
- Plot a graph of current against p.d.
- Repeat the experiment using other conductors, e.g. different types of wires.
- What can you say about the behaviour of these conductors?

Activity 6.9: Connecting simple circuits and locating circuit faults

What you need

- Cells
- Bulb holders
- Connecting
- Voltmeters

- Ammeters
- Bulbs
- Connecting wires
- Multimeter

What to do

Your teacher will give you a circuit to practise with.

- Connect the circuit given to you by your teacher.
- Check the circuit for any faults.
- Measure the current flowing in each of the loops and the p.d. across the various components in the circuit.
- Find out where short circuits could easily occur and suggest ways of avoiding them.

Precaution

Ensure that the wires are well insulated to avoid electric shocks and short circuits.

Activity 6.10: Wiring of a circuit for providing electricity to run systems at an outdoor wedding function

What you need

- Connecting wires
- Torch bulbs
- Bulb holders
- Switches
- Cells
- Cell holders

What to do

Assuming you have been asked to provide electricity service at an outdoor wedding function, draw a circuit suitable for the purpose. Include the position of the switch.

Learning Points

When charge flows in a conductor, we say there is current flowing in the conductor. Current is the rate of flow of charge. In a metal wire, current is due to movement of free electrons while in electrolytes it is due to movement of both positive and negative charges. In ionised air current, it is due to the movement of both positive and negative charges.

In a circuit (electric path), current flowing is measured using an ammeter.

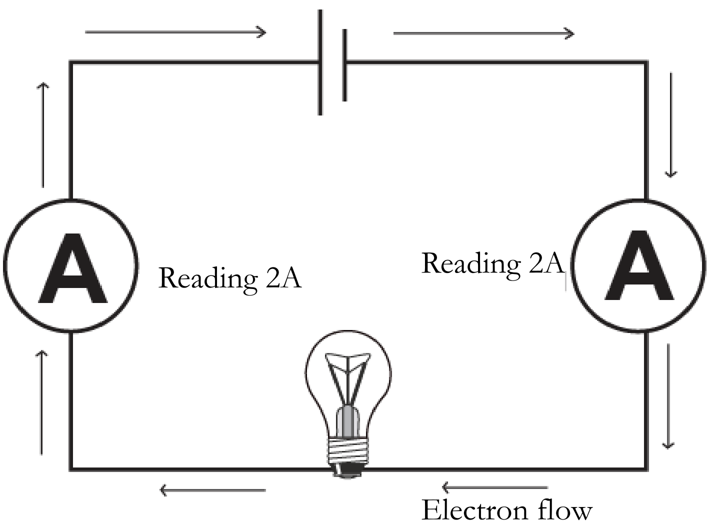
Current is the rate of flow of charge.

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

Charge is measured in coulombs (C).

The unit for current is the Ampere (A). One Ampere is equal to one Coulomb per Second ($1A = 1Cs^{-1}$).

A coulomb is the quantity of charge which passes a point in a circuit when a current of one ampere is flowing.



Measuring current
Figure 6.23

Electrical resistance

When electrons move through a conductor, they encounter obstacles along the way which make their movement difficult. Resistance is the opposition to the flow of current in a conductor.

Good conductors of electricity allow easy movement of current through them. They include metals and graphite. Water is also a good conductor of electricity.

Conduction in metals can be explained by the presence of many free electrons. When a p.d. is applied across the ends of the metal, the free electrons (which are very mobile) are quickly triggered to move towards the positive end of the metal.

Electrical insulators do not allow electricity to flow through them easily. Good insulators include dry wood, some plastics and air. A vacuum is a very good insulator. Both insulators and conductors have several applications in electricity. Can you try to find out some from your local electrician?

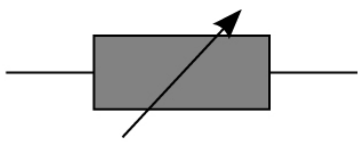
Resistance is the ratio of the p.d. across a conductor to the current through the conductor.

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

The unit for resistance is the ohm (Ω).

Symbols for resistors

You will find the following symbols used in many books on electricity.



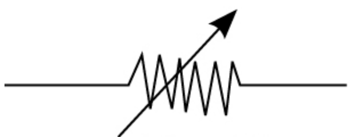


Figure 6.24

Mechanism of conduction of current through a metal

When a metal conductor is connected across the terminals of a cell, a current is made to flow in the circuit. The electromotive force or emf of a cell drives the free electrons through the metal. Chemical energy stored in the chemicals of the battery is transformed into electrical energy. As the electrons move through a conductor they collide with the atoms and give up some of their kinetic energy to them. The atoms vibrate faster and with bigger amplitude. The energy lost by the electrons is transformed into internal energy (heat) of the metal. Thus the conductor becomes warm. The electrons are again accelerated on and make further collisions.

At higher temperature the vibrations of atoms in a metal are more vigorous and with a bigger amplitude. This kind of vibration can cause more difficulty to electrons moving through the metal. Therefore, resistance of metals increases with temperature.

In a metallic conductor current electricity is due to movement of free electrons. In a circuit current moves from the positive terminal to the negative terminal.

Factors affecting resistance

a) Length of conductor: the longer the conductor the bigger the resistance.
b) Cross-section area: the thicker the conductor the smaller the resistance
c) The nature of the material. Some materials are good conductors and others poor conductors.

From Activity 6.8, a graph of current through a tungsten wire against p.d. across it is a straight line through the origin. From the results of this experiment, a scientist called Ohm concluded as follows:

The p.d. across a conductor is directly proportional to current through the conductor under constant physical conditions.

This is known as Ohm's Law.

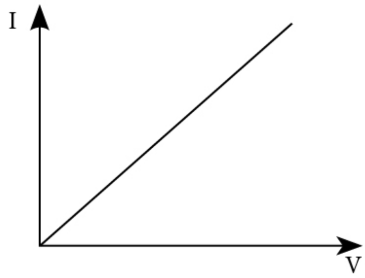


Figure 6.25

Therefore, p.d. is directly proportional to current.

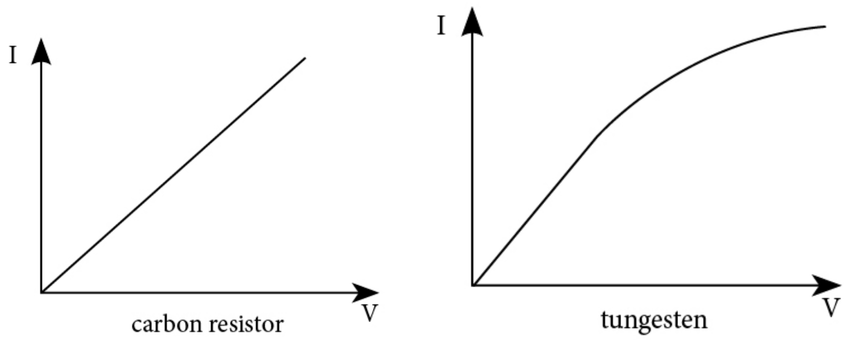
p.d(V) is directly proportional to current(I)

or $V = I \times constant$

The constant is the resistance, R, of the conductor.

Generally, **V = IR**

Since the graph is a straight line, the resistance of the conductor is constant over a wide range of values of p.d. and current as long as its temperature remains constant. However, at higher values of p.d. and current, the conductor warms up and the I-V graph ceases to be a straight line.



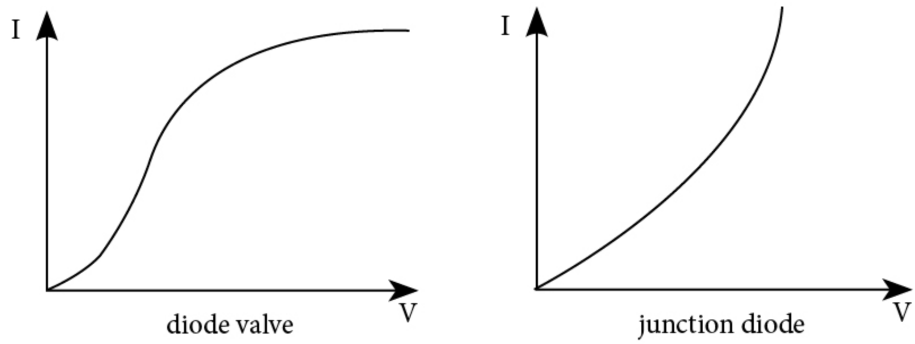


Figure 6.26

Passage of electricity through liquids (electrolytes)

Conducting solutions are called electrolytes. These are mainly solutions in water of acids, bases and salts. The plates or wires which dip into the electrolyte are called electrodes. Current enters the electrolyte via the anode (positive plate) and leaves via the cathode (negative plate).

The chemical changes which occur when a current passes through an electrolyte are called electrolysis. At the anode, metals lose electrons and go into solution, while at the cathode, the positive ions in the solution gain electrons and become neutral atoms. Thus atoms of metals are deposited at the cathode.

Note: Unlike in metals, a flow of current through an electrolyte involves movement of both positive and negative ions (charges).

Applications of electrolysis

- Electroplating: A metal used as the electrode at the cathode will be covered with a layer of metal atoms which have been thrown out of the electrolyte. This is used to beautify the metal or to protect it against corrosion by chemicals in the environment.
- Purification of impure ores and extraction of metals: An impure metal ore is used as the anode. Pure metal atoms dissolve into the electrolyte and are deposited at the cathode.

Electrical energy

Activity 6.11: Wiring a model house

What you need

- Cardboard paper
- Nails
- Pieces of wood
- Hammer
- Connecting wires of different thicknesses
- Connectors
- Wire clips
- Tester
- Multimeter

What to do

- In your group construct a two bedroom model house (2m by 2m) using cardboard, wood and nails.
- Draw the wiring circuit of the house.
- Show it to your teacher for comment.
- Use the services of an electrician to wire the model house.
- Ask him/her why certain wires are more suitable for specific purposes.
- Check the continuity and earthing of the circuit.

Activity 6.12: Inspecting the wiring of a house

What you need

- Multimeter
- Tester

What to do

Inspect the electricity circuit of your house under the supervision of a qualified electrician.

Precaution

- Avoid touching bare wires.
- Turn off the main switch before inspecting the circuit.

Activity 6.13: Energy use in the homestead

What you need

- Electric iron or kettle
- Energy saver bulbs
- Filament bulbs
- Electricity bill
- A building with mains electricity
- Access to the meter tester
- 3-pin plugs
- Fuses
- Filament bulbs
- Other different domestic electrical appliances

What to do

- Unscrew a 3-pin plug, study the wiring and name the three pins.
- Study the markings on the electrical appliances, e.g. power rating and voltage.
- Connect each one in turn to the mains supply.
- Note the speed at which the dial in the meter moves or the speed at which the readings change (Note: For some appliances you may need to wait a little longer in order to notice any change).
- Which of the appliances consumes most power and which one consumes the least power?
- Some appliances have fuses while others do not. Find out which ones have and which ones do not have. Find out why.
- Study the electricity bill to learn how the cost of electricity is calculated.

Follow-up activities

1. Survey the wiring of a house and note the various safety features.
2. Fix a socket on a piece of wood and connect the wire to its terminals.

3. Calculate the appropriate fuse rating for the different appliances.
4. Home A uses five energy saving bulbs each rated 8W while home B uses five filament bulbs each rated 100W. If both homes use all the bulbs for 10 hours a day. Calculate the saving made by home A as compared to home B in the month of December.

N.B. Use the rates on the energy bill.

Learning Points

In our earlier work, we saw that the work done to transfer Q coulombs of charge across a potential difference of V volts, the work done is QV Joules.

i.e. $W = Q V$

But $Q = I t$

Combining the two equations above, we get $W = V I t$

Since $V = I R$

$W = I^2 R t$

or $W = \frac{V^2}{R} t$

Electrical power

Power is the rate of doing work or $Power = \frac{work}{time}$.

Therefore, $P = \frac{W}{t}$ and $W = Pt$

Below is a summary of the equations for power:

$P = VI$

$P = \frac{V^2}{R}$

$P = I^2 R$

Domestic electricity supply

The basic unit used for calculating energy used is the kilowatt-hour (kWh).
Energy used (in kWh) = power (in kW) x time (in hours).
Cost of using electricity = number of units consumed x unit cost
Example 1: Calculate the numbers of units energy used when five electrical bulbs each rated 100W are switched on 8 hours a day for a week.

Solution: number of units = $5x\frac{100}{1000}x\ 8\ x\ 7$ = 28

Example 2**:** What is the cost of using a 1500 W heater for 30 minutes if power costs Ushs 500 per unit?
Solution: Cost = no. of kilowatts x no. of hours x unit cost

$$= \frac{1500}{1000}x\frac{30}{60}x500$$

= Ushs 375

High energy consuming filament lamps are currently being replaced by energy savers which consume low power although they are more expensive to buy. Some energy savers' power rating is as low as 8W compared to a 100W filament bulb. Long fluorescent tubes are also low power consumers but they are also more expensive to buy and are also being replaced by energy savers.
Appliances which normally radiate heat during their operation, such as ovens, are high consumers of energy.

Domestic electricity installation
Mains electricity from the pole enters the house through a cable containing two thick wires. One of the wires is red (live) and the other is blue (neutral). The neutral wire is at zero potential because it is earthed at the local substation and the live wire is at a high potential. It is important that these wires are properly insulated to avoid causing danger to anyone touching the cable. They should also be properly insulated from each other to prevent short circuits occurring where they touch each other. A short circuit results into sparks which may cause a fire

breakout.

The cable enters a meter box where the energy consumed is measured and recorded. From the main switch, electricity goes to the **main switch** which controls all electrical circuits in the house. It is important that the main switch is placed in an accessible position for easy reach in case of danger. Modern houses are fitted with circuit breakers which automatically switch off the electricity when it surges (when the current flowing goes above a safe limit).

Fuses

A fuse is a short length of a thin wire which melts (blows) when the current exceeds a safe value. Old age can also be the cause of the melting of the fuse wire. Fuses come in the following ratings: 3, 5, 10 and 13A. Using improvised pieces of metals as fuse wires might be fatal to the electrical equipment because they might fail to blow when current exceeds a safe value. Before a fuse is replaced, the fault in the circuit which caused it to blow must be found and rectified first as shown in figure below.

A fuse
Figure 6.27

Note

- Fuses and switches must always be positioned on the live wire. If they were on the neutral wire, appliances would remain live even after isolating them.
- Switches must not be positioned in bathrooms where they are likely to be handled using wet hands.

The 3-pin plug

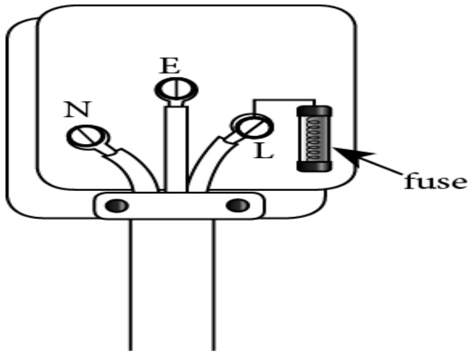


Figure 6.28

Plugs provide a convenient way of connecting electrical appliances to the mains.

Modern wiring colour code

Brown	live
light blue	neutral
green or green yellow	earth

Table 6.4

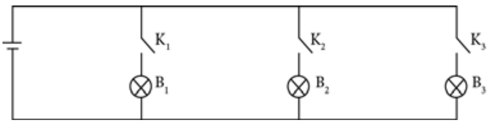
Old wiring colour code

red	live
black	neutral
green	earth

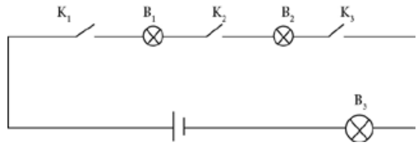
Table 6.5

Most appliances are normally fitted with a third wire called the **earth wire**. It runs to the earth. This wire is meant to protect the user of the appliance in case, for example, a live wire within the appliance becomes loose and touches the metal casing. If this happens, a large current flows to earth making the fuse blow. Some equipment, e.g. radios, do not need the earth wire because their casings are made of plastic which are themselves insulators (This is known as double insulation).

Series and parallel connections



parallel connection



series connection

Figure 6.29

Disadvantages of a series connection

- If one of the appliances is switched off, the others automatically go off.
- They divide the p.d. from the source between themselves and are therefore likely to be dim.

Advantages of a parallel connection

- Each appliance gets the full p.d.
- Each appliance acts independently. If one is switched off, the other is not affected.
- The p.d. across each appliance is the same.

Chapter 7: Magnetism

Introduction

In your childhood, you probably played with magnets. They can be used to attract metals, generate electricity and they can be used to show geographical direction. In this chapter, you will be able to try out the various applications of magnetism.

Magnets

Activity 7.1: Magnetisation of a nail

What you need

- Insulated connecting wire
- Cells and cell holder
- Switch
- Nail
- Permanent magnet
- Rheostat
- Knitting needle
- Small pieces of iron

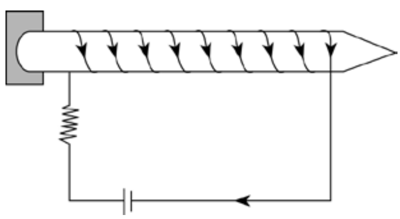


Figure 7.1

- Assemble the circuit as in Figure 7.1.
- Place the nail in the East-West direction.

- Switch on for about 3 minutes and then switch off.
- Use your magnet to attract a knitting needle or small pieces of iron.
- You have now made a magnet.

Activity 7.2: Showing magnetic field lines

Method 1

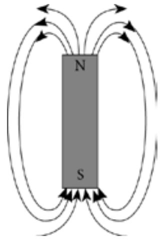


Figure 7.2

What you need

- Piece of paper
- Magnet
- Iron powder (normally called iron filings)

What to do

- Place a magnet on a piece of paper in a lying position.
- Gently sprinkle the iron filings around the magnet and gently tap the paper.

Observation

Describe and draw what you observe.

Method 2

What you need

- Plotting compass
- piece of paper
- pencil
- bar magnet

What to do

- Place a magnet on the piece of paper lying on a table in a horizontal position.
- Place a compass near one of the poles.
- Using a pencil, make a mark on the paper at the tip of the compass needle.
- Push the compass until the tail of the pointer is at the mark you made.
- Repeat the procedure above until the line reaches the other pole.
- Draw a line through the points.
- Draw other lines following the same procedure.

Activity 7.3: Making magnetic toys

a) **A metal finder**

What you need

- A strong magnet
- Piece of wood
- Pieces of materials: metals, non-metals, magnetic and non magnetic

What to do

- Dig a hole in the piece of wood.
- Seal the magnet inside the hole in such a way that it is not visible.
- Devise a game of searching using the hidden magnet in which the winner will be the one who discovers the most magnetic metals.

b) **Making a clever floating toy**

What you need

- A permanent magnet
- A piece of cork
- Razor blade
- A needle

What to do

- Stroke the needle with the magnet repeatedly until the needle is magnetised.
- Curve a toy out of a piece of cork.

- Push the needle into the cork in such a way that the toy always faces in North-South direction.
- Spin the floating cork gently. When it stops, the needle will point in the North-South direction.

You have made a compass in the form of a toy.

Hint

Experiments using magnets should not be carried out near magnetic materials such as iron bars or near wires carrying electrical current, since it will affect the magnetic fields under consideration.

Learning Points

Some ores seem to attract small pieces of iron. They are said to be magnetic. Magnetic materials include:

- *Ferromagnetic materials - these are strongly magnetic.*
- *Paramagnetic materials - these are weakly magnetic.*
- *Diamagnetic materials - these are not magnetic.*

The attractive forces seem to be concentrated at certain points, called poles, on the ore. When a magnetic rod is suspended freely at its centre of gravity, it settles down pointing in the North-South direction. The pole which points North is the North seeking pole or simply the North Pole and vice versa. An attractive force exists between unlike poles while a repulsive force exists between like poles.

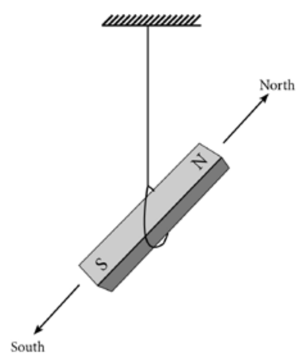


Figure 7.3

Law of magnets

Like poles repel each other and unlike poles attract each other.

Magnetisation (making magnets)

a) Stroking

(i) Single stroke

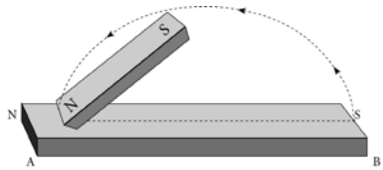


Figure 7.4

The magnetising magnet should be lifted high above at the end of the stroke to avoid disturbing the magnetism already created. Note that the pole created at the end of the stroke is opposite to the pole of the permanent magnetising magnet.

(ii) Double stroke (using two permanent magnets)

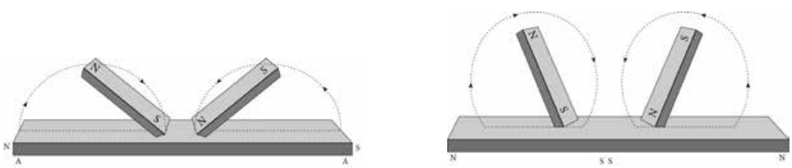


Figure 7.5

b) Electrical method

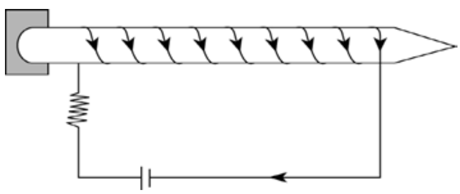


Figure 7.6

Polarity

The pole at the end will be South if on looking at this end directly, the current is flowing clockwise and North if it is flowing anticlockwise.

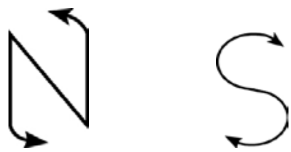


Figure 7.7

Answer these questions

1. Why is it necessary to use d.c. only?
2. Give a reason why the steel bar had to be placed in the East-West direction.
3. Explain why the connecting wire used must be insulated.

Demagnetisation

The following actions will cause loss of magnetism:

- Heating
- Dropping
- Hitting
- Placing inside a coil through which an alternating current is flowing
- Bad storage
- Causing the magnet to vibrate

Try some of them out.

Magnetic field and magnetic field lines

A magnetic field line or line of force is a line such that a tangent to it at any point is in the direction of a magnetic force experienced at the point.

Magnetic field lines always run from the North to the South Pole.

Magnetic field

A magnetic field is a region where a magnetic force is experienced.

The diagrams below show patterns of magnetic field

a) around a single magnet
b) between two opposite poles
c) between two similar poles

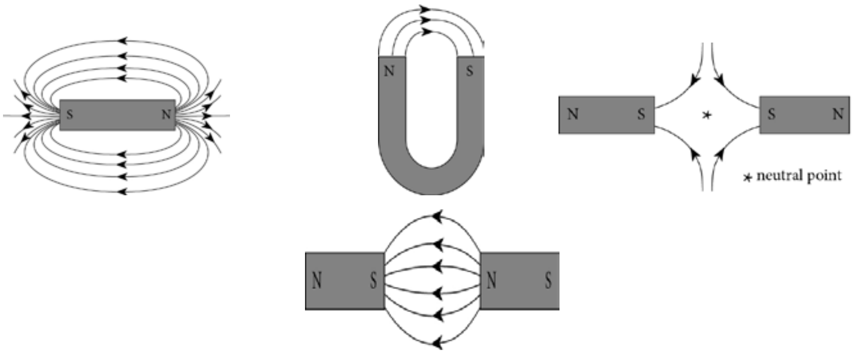


Figure 7.8

Properties of steel and iron

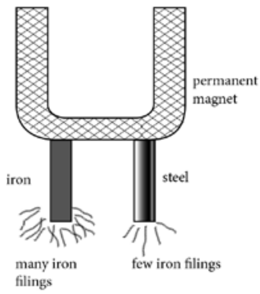
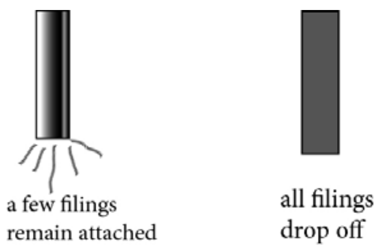


Figure 7.9

In Figure 7.9 above, both iron and steel can be magnetised but iron is more easily magnetised than steel (compare the number of iron filings on each) when they are removed from the permanent magnet



Steel iron

Figure 7.10

When they were removed from the permanent magnet the steel remained with some filings while iron lost all. Steel is easy to demagnetise.

Steel is said to be magnetically hard while iron is magnetically soft (soft iron). When a soft iron bar or ring is placed inside a magnetic field, it provides an easier path for the magnetic field lines.

Magnetic induction

When a magnetic material is placed near a magnet, magnetism is induced in it. This means it is caused to become a magnet. It is then attracted by the permanent magnet. In this way, a chain, for example, of iron nails may be made to hang on a permanent magnet.

Figure 7.11

The earth as a magnet

The earth behaves like a magnet with North and South poles. Magnetic field lines of the earth run from the South Pole to the North Pole.

Angle of declination

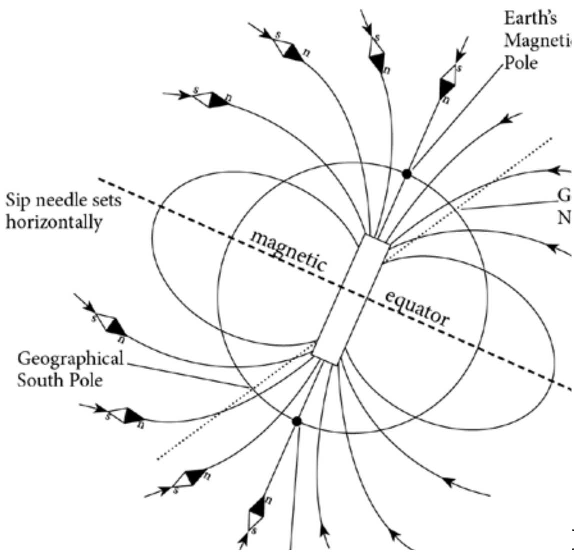


Figure 7.12

Angle of inclination

Consider an unmagnetised steel needle balanced at its centre of gravity. It balances horizontally. If it is now magnetised and pivoted at the same point, it dips a little at some angle from the horizontal.

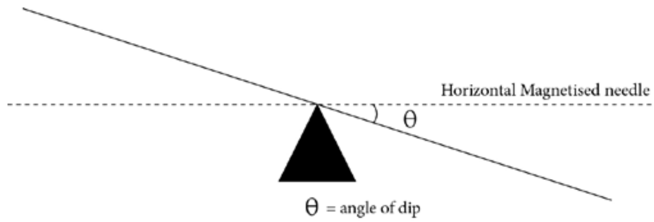


Figure 7.13

The needle is now pointing in the direction of the resultant magnetic field at the place where you are doing the experiment.
Angle of inclination (dip) is the angle between the horizontal and the direction of the resultant earth's magnetic field at a location. At the magnetic equator, the angle of dip is 0° and at the poles it is 90°, i.e. it increases as one approaches the magnetic poles from the magnetic equator.

Interaction of magnetic fields

Consider a permanent magnet placed in the earth's magnetic field:

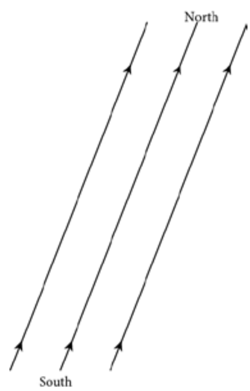
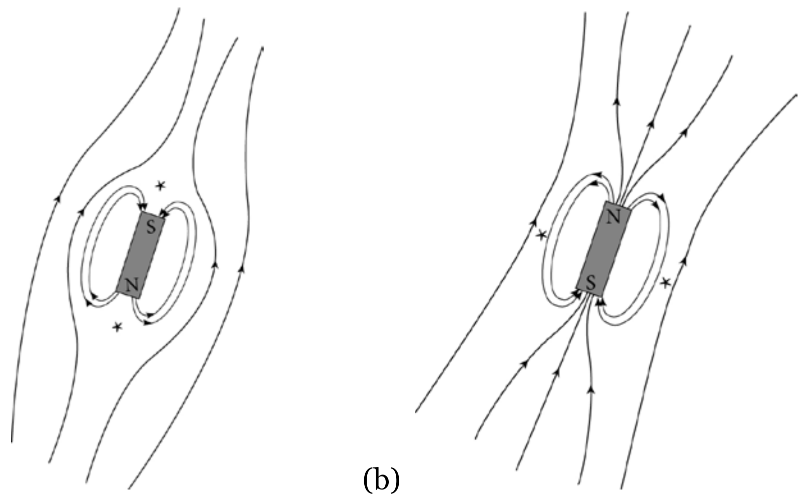


Figure 7.14: Magnetic field patterns on the Earth

Appearance of the magnetic field when the magnet is placed in the earth's magnetic field:



(a) (b)

Figure 7.15

a) When the north pole of the magnet is pointing towards the Earth's North Pole.
b) When the south pole of the magnet is pointing towards the Earth's South Pole.

Neutral point

You can notice that there are points in the magnetic field where there are no magnetic field lines. These points are called neutral points.

A neutral point is a point in a magnetic field where the net magnetic field is zero.

Breaking a magnet; theories of magnetism

When a magnet is broken into several pieces, each of them is itself a magnet. This means that if we continued breaking the magnet to the smallest piece, even that one will be a magnet. The smallest 'piece' is the atom or a molecule. It is called a **dipole**.

In diamagnetic materials, the dipoles are randomly arranged. Nothing can be done to organise them to face the same direction. A diamagnetic material cannot be magnetised. In paramagnetic materials, the dipoles can be partially arranged.

This type of material can be weakly magnetised.
In ferromagnetic materials, the dipoles are arranged in groups or 'domains'. Dipoles in a given domain point in a preferred direction.

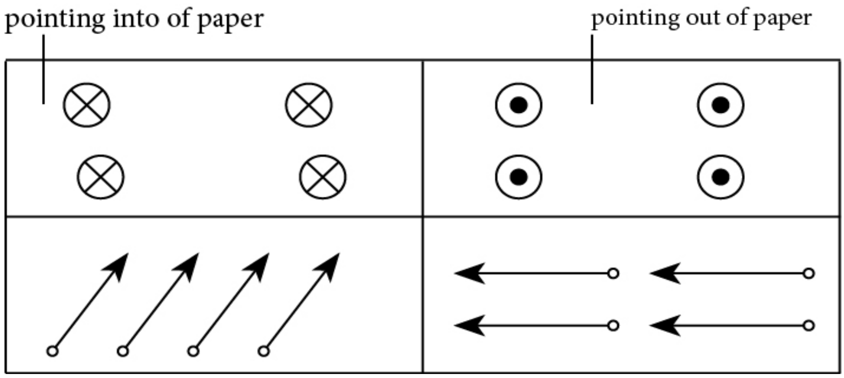


Figure 7.16

When this material is magnetised, the dipoles can be made to point in the same direction. Magnetic saturation is when all the dipoles are pointing in the same direction.

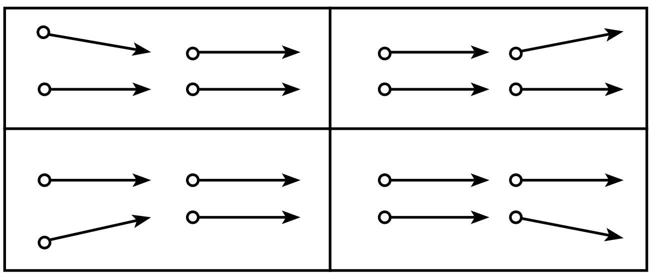


Figure 7.17

Keeping magnets

In order to store magnets properly, they should be kept in pairs with the South Pole of one magnet lying close in contact with the North Pole of the other. This sets up a chain of dipole which is stable and difficult to break.

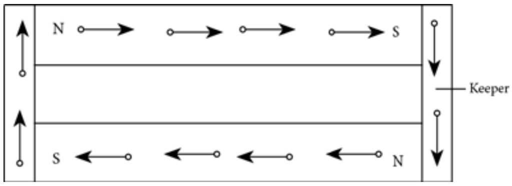


Figure 7.18

Magnetic effect of an electric current

Activity 7.4: Investigating magnetic field patterns around a current carrying wire

What you need

- Iron fillings
- Wire (single strand)
- Manila paper (15cm x15cm)
- Dry cell and rheostat

What to do

- Using a pin, put a hole through the middle of a manila paper and assemble the circuit as in Figure 7.19 below.
- Pass the wire through the hole and hold it in the vertical position with the manila in the horizontal position.
- Pour iron fillings onto the manila near the wire and spread them around it.
- Gradually increase the current and note what happens to the iron filings.

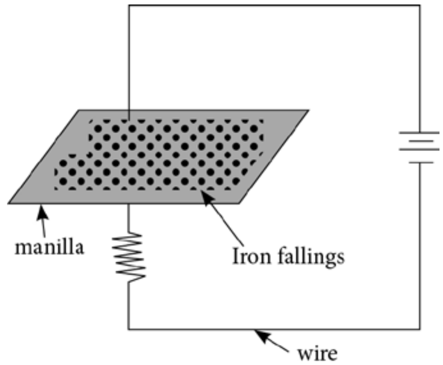


Figure 7.19

Observation

Describe and draw the patterns formed by the iron fillings. What could have caused what you have observed?

- Put another hole in the card board and pass the same wire through to form an n turn. Spread the iron fillings around both parts of the wire and connect the ends to a cell.

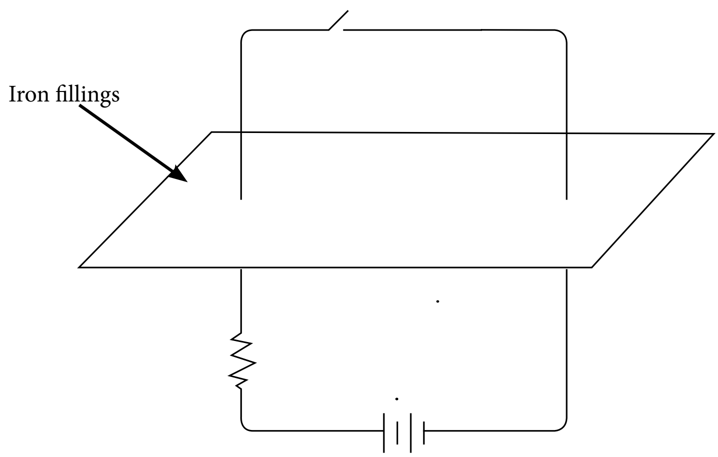


Figure 7.20

Draw the pattern you have observed.

Activity 7.5: Assembling an electric bell

What you need

- An electric bell
- Multimeter

- Tester
- Diagrams showing the structural arrangement of their parts

What to do

- Carefully dismantle an electric bell.
- Look at the way the different parts are connected to or separated from each other.
- Note the safety features.
- Make notes as you undo the parts.
- When you have finished separating the parts, try putting them together. Use the notes you made to help you avoid making errors.
- Test the electric bell when you have finally reassembled it.

Activity 7.6: Assembling a loudspeaker

What you need

- An old loudspeaker
- Multimeter
- Tester

What to do

- Carefully dismantle the loudspeaker.
- Look at the way the different parts are connected to or separated from each other.
- Make notes as you undo the parts.
- Draw the structural arrangement of the parts of the loudspeaker.
- When you have finished separating the parts, try putting them together. Use the notes you made to help you avoid making errors.
- Test continuity using the Multimeter.
- Test the loudspeaker when you have finally reassembled it.

Learning Points

Oerested's experiment

Oerested placed a compass needle on top of a wire (conductor) carrying current and noticed that the pointer deflected. When he placed it below the wire, the needle deflected in the opposite direction. When he reversed the direction of the current, the directions of deflection of the pointer also reversed.
He concluded that there is a magnetic field around a conductor carrying current and that the direction of the magnetic field depends on the direction of current.

Direction of magnetic field

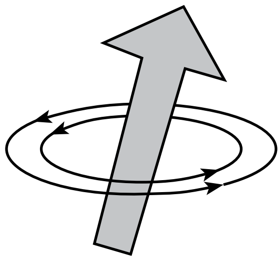


Figure 7.21

Fleming's Right Hand Grip (Corkscrew Rule)

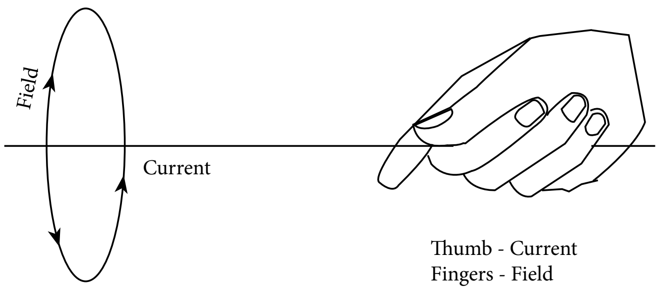


Figure 7.22

Thumb = Direction of current
Rest of fingers = Direction of magnetic field

Corkscrew Rule

When the screw is turned clockwise (direction of magnetic field) the cork moves inwards (direction of current).

a) **Magnetic field inside a narrow circular coil**

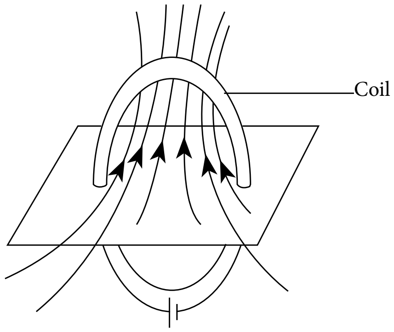


Figure 7.23

Notice that in the centre of the coil, the lines are parallel. This means that at the centre of the coil, the magnetic field is uniform.

b) **Magnetic field inside a straight coil (solenoid)**

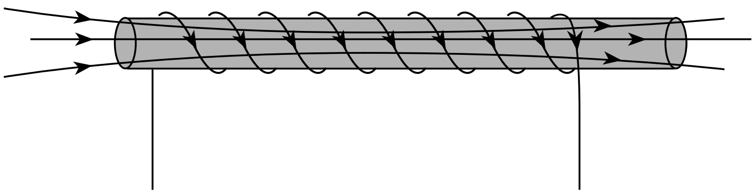


Figure 7.24

The magnetic field is uniform inside the coil.
Notice that at one side of the coil the lines are entering. A steel rod placed in the coil becomes magnetised. This end of the steel rod becomes the South Pole of the magnet. The end of the coil where the lines are coming out is the North Pole.

The electromagnet

You have seen above that a magnetic material placed inside the coil becomes magnetised by a direct current flowing through the coil. If the current flowing is a.c., the material would continuously be magnetised and demagnetised when the current constantly changes direction.
Now if a soft iron rod is placed inside the coil when a direct current is flowing, the soft iron becomes magnetised and when the current is switched off, the rod loses the acquired magnetism. This is called an electromagnet.

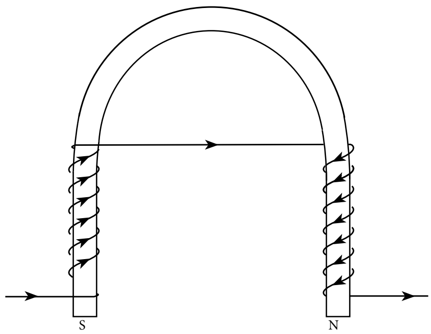


Figure 7.25

Applications

a) Lifting

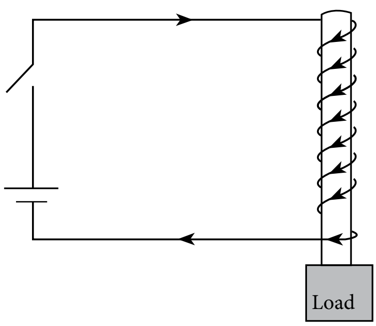


Figure 7.26

b) The electric bell

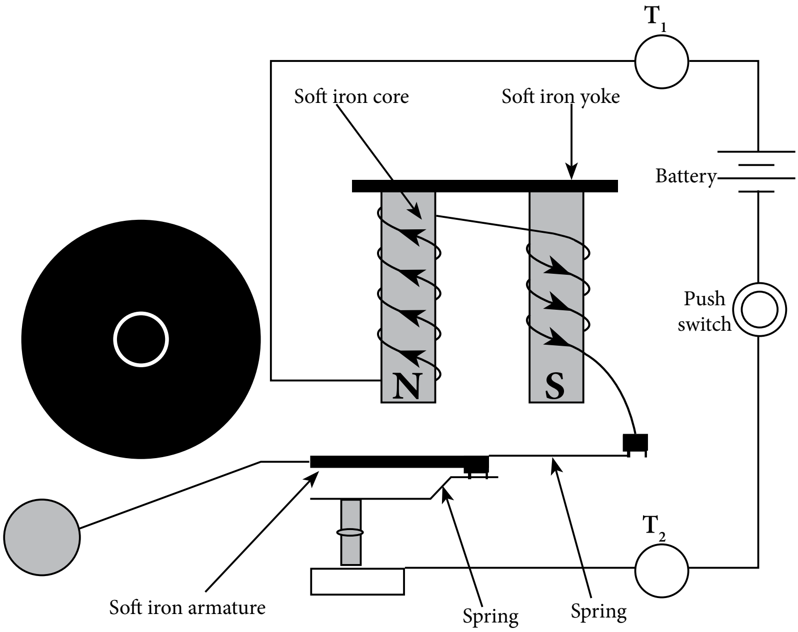


Figure 7.27

Figure 7.27 above shows an electric bell. Describe how it works.

The principle of the d.c. motor

Activity 7.7: Assembling a d.c. motor

What you need

- An old d.c. Motor
- Multimeter
- Tester

What to do

- Carefully dismantle the motor.
- Look out for the way the different parts are connected to or separated from each other in the motor.
- Make notes as you undo the parts.
- When you have finished separating the parts, try putting them together. Use the notes you made to help you avoid making errors.
- Test continuity using the Multimeter.

- Test the motor when you have finally reassembled it.

Learning Points

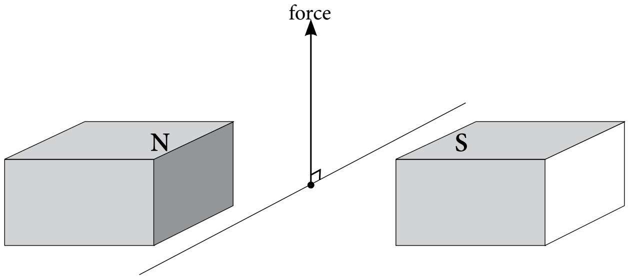


Figure 7.28

When a conductor carrying current is placed in a magnetic field, it experiences a force. A stronger force would be obtained by doing one of the following:

- Using a stronger magnet.
- Increasing the size of current.
- Increasing the length of the conductor in the magnetic field.
- Making the angle between the direction of the magnetic field and the conductor 90°.

Origin of the force on a current carrying conductor placed in a magnetic field

In the earlier work, we saw that when two magnets are brought near each other, they either attract or repel each other. The force between these magnets is due to the interaction between their respective magnetic fields.

A magnetic field exists around a conductor carrying current. The magnetic field due to the current interacts with the magnetic field due to the permanent magnet. This interaction results in a force being produced on the conductor.

We can determine the direction of the force produced using Fleming's left hand rule.

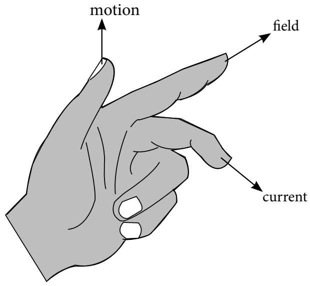


Figure 7.29

Hold the thumb, first finger and middle finger of your left hand at right angles to each other as shown in Figure 7.29 above.

- First finger = direction of magnetic field of the permanent magnet (north to south)
- Thumb = direction of force
- Middle finger = direction of current

*Remember: We use the **L**eft hand for **D**irection of **F**orce produced (**LDF)***

The principle of the d.c. motor

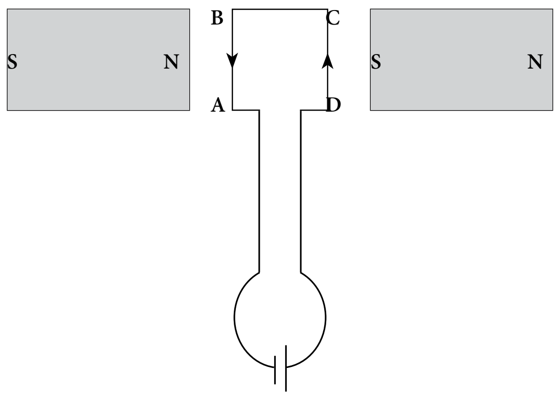


Figure 7.30

In section AB of the frame, current is following from B to A and the magnetic field due to the permanent magnet is pointing from North to South (left to right). The resulting force on AB is pointing out of paper.

Similarly, in section CD of the frame, current is flowing from C to D. The resulting force on CD is pointing into the paper.

The two equal and opposite forces (couple) cause the frame to rotate anticlockwise until when the new plane of the frame is parallel to its original plane (rotation through 180°).

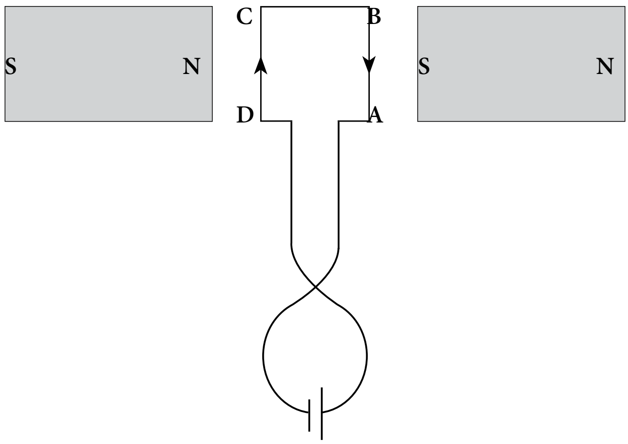


Figure 7.31

The frame rotates on the axis of rotation. You can notice that after a rotation of 180°, current will flow in the frame from A to B and from D to C. This leads to a reversal of the direction of rotation of the frame. Thus the frame keeps on changing the direction after every 180°.
Secondly, the wires (leads) connecting the frame to the battery will tend to twist around each other.

A simple d.c. Motor

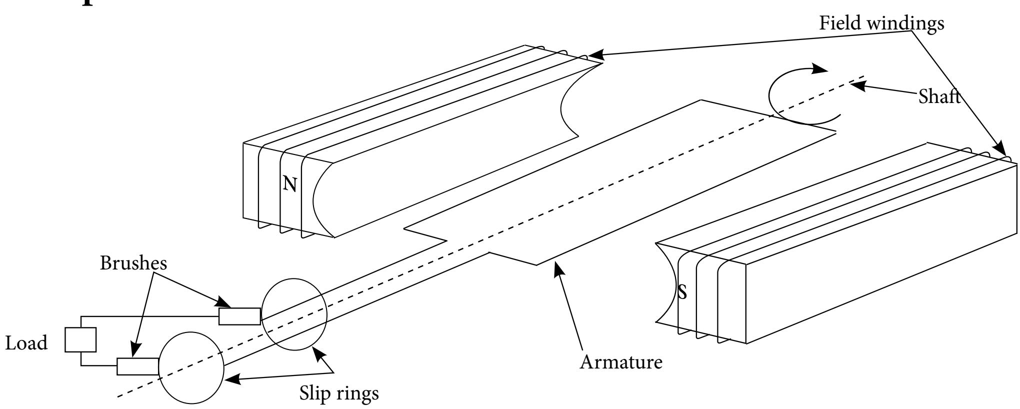


Figure 7.32

In a simple d.c. motor, the coil is fixed on and rotates with a pair of half copper rings (called a commutator). The half rings are separated by an insulator. As the coil rotates, the half-rings (another name for them is split-rings) rub against carbon brushes. This ensures that the rotation is only in one direction and the leads do not twist around each other. The turning effect can be increased by

- Using a stronger magnet.
- Increasing the current through the coil.
- Increasing the cross-section area of the coil.
- Increasing the number of turns of the coil.

The moving-coil loud speaker

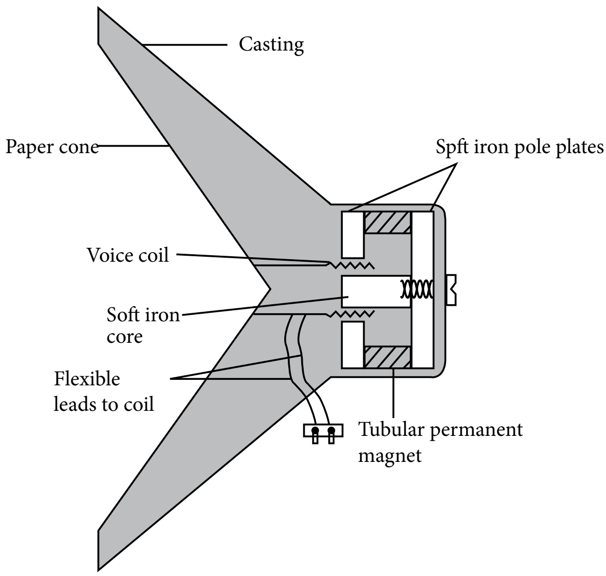


Figure 7.33

In figure 7.33, the soft iron core is magnetised by the permanent magnet. When an alternating current from the amplifier flows through the coil, it experiences a varying force. Therefore, the coil moves outwards and inwards as the current flows through it. This causes the cone to which it is attached to vibrate. A vibrating cone produces sound.

Moving-coil instruments (ammeters, voltmeters and galvanometers)

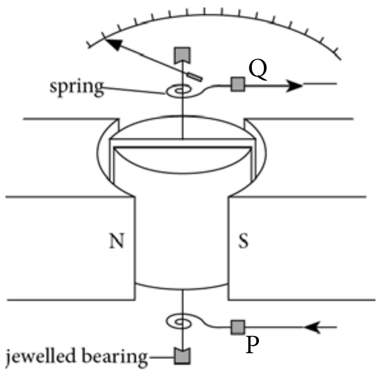


Figure 7.34

Current enters the instrument at P and leaves it at Q. The magnetic field due to the permanent magnet interacts with the magnetic field due to the current flowing in the coil. The interaction produces two equal and opposite forces on the coil (couple). The couple causes the coil to rotate on its axis. The pointer attached to the coil moves on the scale. The angle of rotation of the pointer depends on the amount of current flowing. A fine spring attached to the coil is stretched as the coil rotates and pulls it back when the current is switched off.

Electromagnetic induction

Activity 7.8: Magnetism from electricity (Faraday's experiment)

In the early nineteenth century, Faraday carried out the following experiments in a bid to find out the relationship between electricity and magnetism.

What you need

- Centre-zero galvanometer
- Insulated connecting wires
- Soft iron rod
- Cells and cell holder
- Magnets of different strength

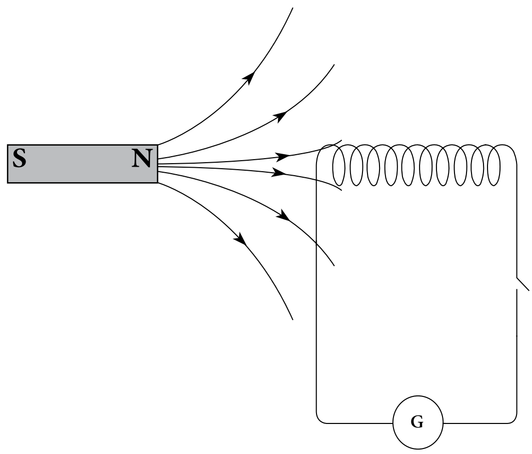


Figure 7.35

What to do

- Carry out the actions listed in the table below and observe what happens to the needle of the galvanometer.

	Action	Observation
1	Place the magnet near the coil	
2	Move the magnet slowly towards the coil	
3	Move the magnet quickly towards the coil	
4	Move the magnet away from the coil	
5	Move a stronger magnet towards the coil	
6	Effect of increasing the number of turns of the coil	
7	Effect of increasing the cross-section area of coil	
8	Effect of winding the coil on a soft iron rod	
9	Move the coil away from the magnet	

Table 7.1

Answer the following questions

1. When is a current made to flow in a coil?
2. How can the current in the coil be increased?

Activity 7.9: Making a simple transformer

What you need

- Soft iron metal plates
- Metal cutter
- Connecting wires
- Glue galvanometer
- Ammeter
- Voltmeter
- Old radio transformer
- Screw driver

What to do

- Dismantle an old transformer and study how the parts are arranged.
- Now make your own transformer by doing the following:
  - Cut windows (6cm by 6cm) at the centre of the soft iron plates.
  - Using sticky glue, fix insulating paper between the plates.
  - Wire the transformer by making the number of turns in the primary circuit to be more than those in the secondary circuit:
  - Test to see whether it works
  - Fix the transformer on a bicycle dynamo. Turn the wheel of the bicycle and measure the input and output voltages

Answer these questions

- What is the relationship between the input and output voltages and the number of turns in the primary and secondary?
- What should be done to prevent the transformer from warming up?

Precaution

- The wires used for winding the coil must be insulated.
- Beware of electric shocks.

Learning Points

Discussion of Faraday's experimental results

a) When a coil is moved relative to the magnet, a current flows in the coil. This current is called **induced current**. As we saw earlier, what drives the current in the coil is the electromotive force. This type of electromotive force is called **induced emf**.
b) When a magnet is placed near a coil, its magnetic field links with the coil.
c) When the magnet is moved towards or away from the coil, the number of magnetic field lines or **flux** linking with the coil **changes**. This is when an emf is induced in the coil.
d) An increase in the number of turns of the coil or increase in its cross-section area or placed soft iron inside enables it to trap more flux. This would result in a bigger induced emf.
e) The size of induced emf also increases with the speed (rate) of change of flux linking with the coil.
f) When the direction of change of flux is reversed, the direction of the induced emf also reverses.

From the discussion above, we can generalise as follows: *Electromagnetic induction occurs when the flux linking with a coil changes.*
Factors which affect the magnitude of induced emf can be obtained from the table above.
Note
1. The same results would be obtained if the coil was moved instead of the magnet.
2. No induced current would be obtained if the coil and the magnet were moving together in the same direction at the same speed.

Faraday's law:
Induced emf in a coil is directly proportional to the rate of change of flux linking with the coil.

Lenz's law:
Induced emf is always in such a direction as to oppose the change producing it.

Fleming's law of electromagnetic induction

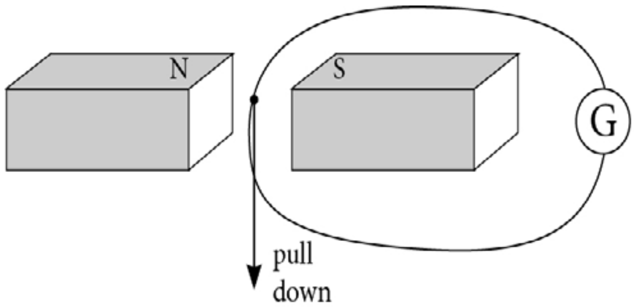


Figure 7.36

Hold the thumb, first finger and middle finger of your right hand at right angles to each other as in diagram.

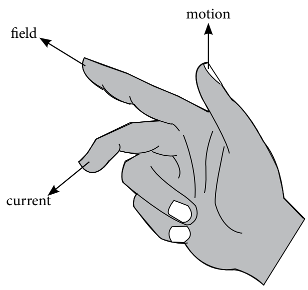


Figure 7.37

- Index = Direction of magnetic field of the permanent magnet (north to south).
- Thumb = Direction of motion.
- Middle finger = Direction of induced current.

(Remember: We use the **R**ight hand for **D**irection of **C**urrent produced or **RDC**)

We can now investigate current induced in a wire placed in a magnetic field. When a wire is placed in a magnetic field, some magnetic flux links with it.
If the wire is suddenly withdrawn out of the magnetic field, a current is induced in it. In this case, when withdrawing the wire, it cuts across the magnetic field

lines and the flux linking with it changes. This action results in a current being induced in the coil. Note that if the coil is moved in a direction to the magnetic field lines, no current is induced in the wire.

Ways of increasing induced current

The size of the induced current can be increased by:

- Moving the wire faster
- Winding the wire into a coil of many turns
- Using a stronger magnet

Eddy currents

Consider a large piece of metal placed in a magnetic field. When the magnetic field is varied or the metal is moved inside the field, the flux linking with the metal changes. Currents are induced in the metal to produce an opposing effect (Lenz's law). Work must be done to overcome the opposing effect of the Eddy currents. The work done to overcome them is converted into heat in the metal. Eddy currents may at times be useful and sometimes they are a nuisance.

Applications of Eddy currents are many. Below are a few examples. They are used to:

- damp the pointer of a moving coil instrument.
- detect hidden metals e.g. mines and weapons.
- determine the speed of a vehicle in speedometers.

The disadvantage of Eddy currents is that the heat generated to overcome them may ruin electrical equipment.
The size of the Eddy currents and their effect can be minimised by cutting the metal into layers inserting an insulator between them. This is called lamination.

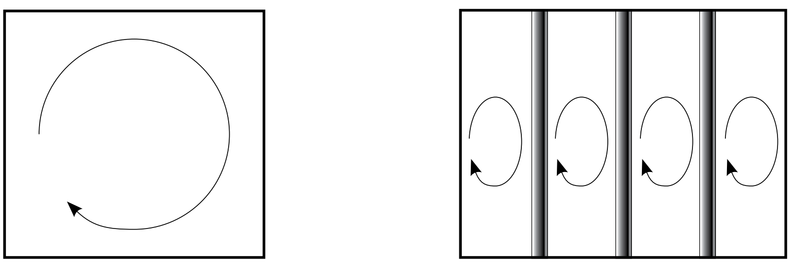


Figure 7.38

A.C. generators

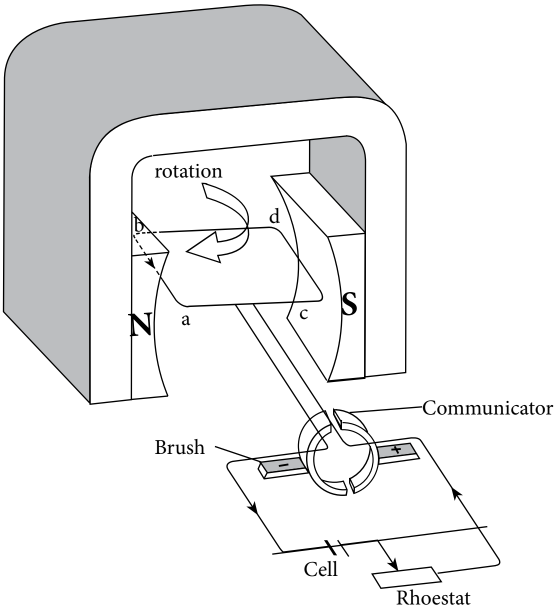


Figure 7.39

An insulated coil on a shaft (axle) is rotated by some external agent for example wind, moving water or a wheel of bicycle. The coil is fixed to and moves with a pair of copper rings called slip rings. These rings rub against carbon brushes as the coil rotates.

As we saw earlier, the use of slip rings ensures that the leads (connecting wires) do not twist as the coil rotates. When the coil is rotating, it cuts across the magnetic field lines and a current is induced in it. The induced current is carried away by the brushes to the load (output).

When the coil is perpendicular to the magnetic field lines, it is moving parallel to the flux and therefore not cutting the lines. In this position, the current induced in the coil is zero. As the angle between the coil and flux increases, the induced current also increases. Maximum current will be obtained when the coil is parallel to the magnetic field lines. Beyond 90°, the current decreases and reaches zero again when the coil is perpendicular to the lines.

When the coil is rotated beyond 180°, the induced current changes its direction in the coil and in the load. The current will again be zero when the coil is parallel to the magnetic field lines and reduce to zero after turning through 360°. This type of current which constantly changes direction is called alternating current (a.c.). The maximum current is called the peak value. A rotation of 360° completes a full cycle. The time taken to complete one cycle is called the period (measured in seconds) and the number of cycles made in one second is called the frequency (measured in Hertz). The frequency of mains electricity is kept steady at 50Hz.

The maximum output current may be increased by:

- Rotating the coil faster.
- Increasing the number of turns of the coil.
- Increasing the cross-section area of the coil.
- Using a stronger magnet.
- Winding the coil on a soft iron core .

Self-induction

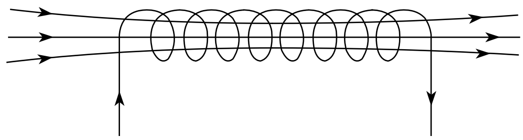


Figure 7.40

When a current flows in a coil, it sets up a magnetic field within the coil and when it is switched off, the magnetic field collapses (changes). A current is induced in the coil to oppose the change. A spark may be seen at the switch.

Mutual induction

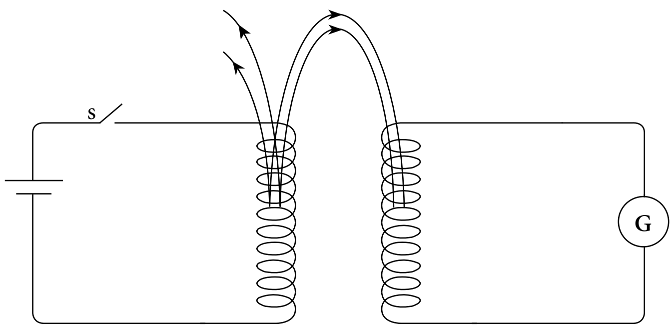


Figure 7.41

When current is switched on in coil P, a magnetic field is set up which links with coil Q.

If the current in coil P is switched off, the magnetic field in coil Q collapses (changes). Thus a current is induced in coil Q to oppose the change. The same thing happens when the current in P is switched on in coil P but this time the current induced in Q is in the opposite direction. If it is switched on and off continuously, the direction of induced current in B also continuously changes as a result of changing current in A. Thus the current in Q is alternating current. Note that if the switch is kept closed, there will be no current induced in coil Q. Inclusion of a soft iron rod inside the coils increases the maximum current obtained.

The transformer

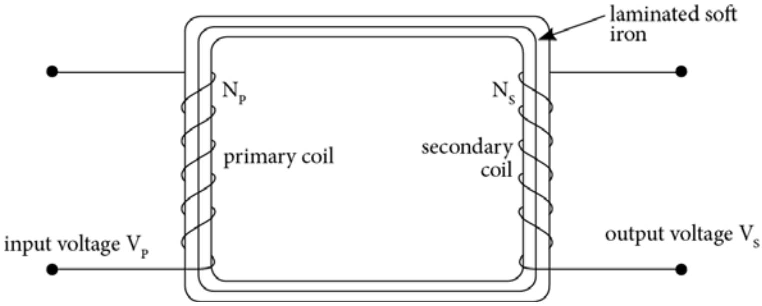


Figure 7.42

A transformer consists of two coils on a laminated soft iron core. An alternating current in the primary (input) produces an alternating current in the secondary (output) coil. It can be shown that::

$$\frac{output\ voltage}{input\ voltage} = \frac{number\ of\ turns\ in\ secondary}{number\ of\ turns\ in\ primary}$$

$$\frac{V_s}{V_p} = \frac{n_s}{n_p}$$

$$\frac{n_s}{n_p}$$

is called the turns ratio. For a step-up transformer, n_s is greater than n_p. Similarly, for a step-down transformer, n_s is less than n_p..

Energy losses in transformers and how they are minimised

- **Ohmic losses**: The wires making the coils of the transformer have a resistance. Heat energy is dissipated in the coils when current flows through them due to their resistance. This loss of energy is minimised by using copper wires which have a very small resistance to wind the coils.
- **Eddy current losses**: These are minimised by using a laminated soft iron core.
- **Loss of flux**: Some of the flux from the primary coil may not link with the secondary coil. These losses are minimised by proper design of the transformer.
- **Hysteresis losses**: When a piece of metal is taken through a magnetisation-demagnetisation cycle, some magnetism remains in it at the end of the cycle. If the cycle has to be repeated, work must be done against this residual magnetism leading to energy loss. This is minimised by winding the coils on a soft iron core which is easy to magnetise and easy to demagnetise.

Even with the best designed transformer, there will still be some energy losses. Most transformers become warm after prolonged use. They are cooled by circulating cold water or air around the coil.

Comparing Alternating Current with Direct Current

Advantages of a.c. over d.c.

Alternating current:

- Is easy to generate
- Is easy to transmit around the country
- Can be stepped up and down

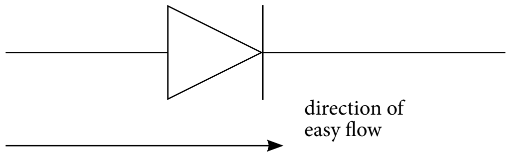
Disadvantages of a.c. over d.c.

Alternating current:

- cannot be used to charge a battery
- cannot be used in electrolysis

Changing from a.c. to d.c (rectification)

Sometimes we may need to connect equipment which use d.c. on an a.c. circuit. This can only be done by using a device known as a diode. A diode allows current to flow through it in only one direction.



A diode
Figure 7.43

The process of changing a.c. to d.c. is known as rectification.

Follow up activities

- Discuss how to improve the design of a transformer to reduce energy losses.
- Wind a small transformer suitable for use on a small radio.

Chapter 8: Atomic and Nuclear Physics

Introduction

In this chapter, you will study about the smallest particles of matter which can take place in a chemical reaction. When matter interacts with energy, very interesting and useful results are obtained. You will find a number of applications of the effects of matter interacting with energy.

X-Rays

Activity 8.1: Visiting a local hospital

What to do

This activity should be carried out as a class with the guidance of your teacher. You will visit a local hospital to study about the various applications of X-rays.

At the hospital, ask the technician:

- To show you how the X-ray machine works.
- The necessary preparations and precautions taken before a patient is x-rayed.
- To teach you how to interpret an x-ray picture.
- To tell you about the use of x-rays and their side effects.
- To tell you the diseases which can be treated using x-rays.

Learning Points

While studying the electromagnetic spectrum, we came across x-rays. These are electromagnetic waves of very short wavelength of the order 10^{-10}m (or very high frequency). X-rays were discovered by a German physicist in 1895.

Production of x-rays

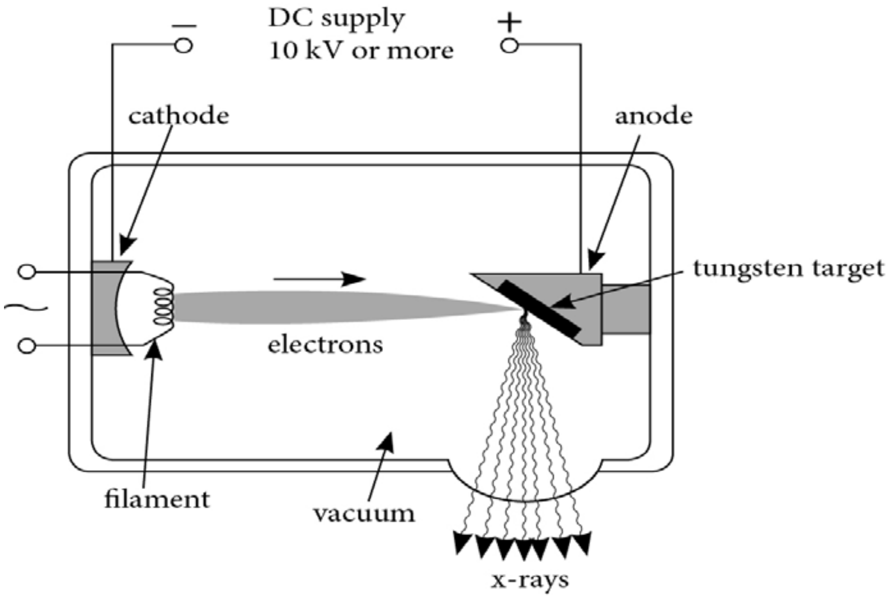


Figure 8.1

The p.d. between the cathode and anode accelerates the electrons through the vacuum. X-rays are emitted when fast moving electrons strike a hard target. Very short wavelength X-rays (known as hard x-rays) which are very energetic and penetrative are produced using high potential differences. Less energetic and less penetrating x-rays (soft x-rays) are produced using lower voltages. The intensity of the x-rays increases with the p.d. between the cathode and anode.
A small fraction of the energy of the incident electrons is turned into x-rays and the rest is transformed into heat. The heat is absorbed by the copper block and is radiated away by cooling fins. A target with a high melting point at the anode is suitable. Tungsten is particularly suitable for this purpose.

Properties of x-rays

- Short x-rays are very energetic and extremely penetrative and only high density metals like lead can reduce their energy. Long x-rays are less penetrative but can pass through flesh although they cannot penetrate the bones.

- They are diffracted by crystals.
- They travel at the speed of light.

Uses of x-rays

These can be classified into medical and industrial uses:

Medical

- Location of fractures in bones.
- Treatment of cancer.
- Location of foreign objects in the body.

Industrial

- Revealing cracks in metal castings.
- Detecting alterations on works of art.
- Determining crystal structures.

Hazards of x-rays

Uncontrolled exposure to x-rays damages living cells of the body. Operators of x-ray equipment and patients must be properly protected.

Atomic and nuclear structure

Activity 8.2: Making ornaments

What you need

- Beads of different colours with holes and of different sizes
- Flexible wires which can go through the holes in the beads
- Pliers
- Glue
- Vanish
- Brushes
- Pieces of wood
- Saw
- Jack plane

What to do

- Draw the atomic structure of an element, indicating the nucleus with protons and neutrons and the electrons in the orbits.
- Wire the beads to get out the atomic structure of an atom.
- If you so wish, you can glue your model onto a piece of timber.
- Give the protons, neutrons and electrons different colours.
- Blend the colours well to produce a beautiful ornament.

Follow-up activity

Price your ornament and make a marketing strategy for it.

Learning Points

The Bohr atom

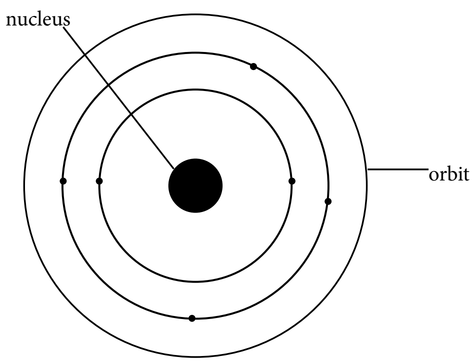


Figure 8.2

Niels Bohr visualised the atom as consisting of a tiny massive nucleus surrounded by electrons orbiting around it in their orbits. At ordinary temperatures, the radii of the orbits are constant. When an atom gains energy, it jumps to a higher energy level, we say the atom has been excited.

The atom stays in the 'excited' state for a short time and soon falls back to some lower energy level by giving out (radiating) energy in form of an electromagnetic wave. Energy is absorbed or radiated in full packets known as photons or quanta.

Terminology used

a) **Nuclide** is an atomic species. It is a family of atoms with the same chemical properties. It is represented by a symbol, e.g. **H** for hydrogen, **He** for Helium, **Na** for sodium and **U** for Uranium. The nucleus of the atom consists of protons which are positively charged and neutrons which are neutral. A general name for protons and neutrons in the nucleus is nucleons.

b) The number of protons in the nucleus is known as the **atomic number**, abbreviation **Z**. In a neutral atom, the number of protons is equal to the number of electrons.

c) The number of neutrons in the nucleus is abbreviated **N**.

d) The sum of the number of neutrons and protons in the nucleus is called the **mass number**, abbreviated, **A**.

Thus, A = Z + N

The symbol for a nuclide, X, is $^{A}_{Z}X$, for example:

$^{4}_{2}He$ represents a Helium nuclide with 2 protons and 2 neutrons in the nucleus.

Similarly, $^{24}_{11}Na$ represents a sodium nuclide with 11 protons and 13 neutrons.

Isotopes *are nuclides with the same number of protons but with different number of neutrons.*

Examples of isotopes include $^{7}_{3}Li$ and $^{6}_{3}Li$ which are isotopes of Lithium. The former has 4 protons and the latter has 3 protons in the nucleus. Both have identical chemical properties.

Radioactivity

Activity 8.3: Reading about hazards of radioactivity

What you need

- Articles about nuclear accidents for example the Fukoshima nuclear accident in Japan.

What to do

- In groups read articles on nuclear accidents.
- Discuss the hazards caused by the accidents.
- What are the social and economic costs of the accidents?

Activity 8.4: To simulate a decay experiment

What you need

- Water
- Burette
- Stand and clamp
- Stop clock

What to do

- Clamp the burette vertically and fill it with water up to the 50 cm mark.
- Open the tap so that the water runs out slowly and simultaneously start the clock.
- Read the volume of water remaining in the burette after 30, 60, 90, 120, 180, 210, 240, 270 and 300 seconds.
- Plot a graph of volume remaining in the burette against time.

Learning Points

Some heavy nuclei are unstable. They decay (or disintegrate) naturally by emitting radiation. The radiation emitted may consist of alpha particle, beta particles or gamma rays. In addition, the decay is accompanied by emission of energy.

An Alpha particle, α, is a Helium nuclide, ${}_{2}^{4}He$, with 2 protons and 2 neutrons. A beta particle, β, is an electron, ${}_{-1}^{0}\beta$ or ${}_{-1}^{0}e$. Gamma rays, γ, are just electromagnetic radiation of very short wavelength.

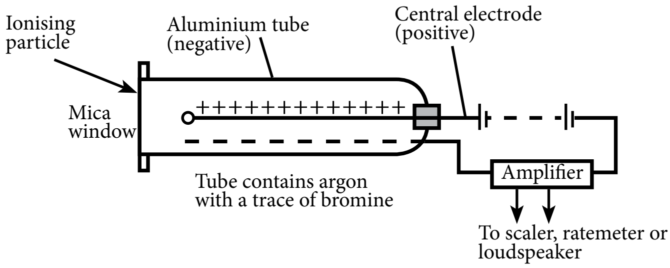
Properties of radiation

The table below summarises the properties of radiation emitted during radioactive decay.

	Property	**Alpha (α)**	**Beta (β)**	**Gamma (γ)**
a)	Range in air	low	high	very high
b)	Penetration power	low	high	Very high
c)	Ionisation power	Very high	high	Low
d)	Deflection in electric field	Deflected towards the negative plate (a direction which suggests they are positively charged).	Deflected towards a positive plate (a direction which suggests they are negatively charged).	Not deflected
e)	Deflection in a magnetic field	Deflected in a direction which suggests they are positively charged.	Deflected in a direction which suggests they are negatively charged.	Not deflected
f)	Mass	heavy	light	No mass
g)	Charge	Positive (charge +2)	Negative (charge -1)	Uncharged (charge 0)
h)	Nature	Helium Nuclide, ${}_{2}^{4}He$ (2 protons and 2 neutrons in the nucleus)	Electron, ${}_{-1}^{0}e$	Electromagnetic radiation of short wavelength

Table 8.1

Detection of radiation



Geiger-Muller (GM) tube

Figure 8.3

When an ionizing particle enters the tube it ionizes the air in it. The positive ions move towards the cathode (negative biased) and the negative ions move towards the anode (positively biased). Thus an instantaneous current (pulse) flows through the space between the cathode and anode. This current is very small. It is amplified and either fed into

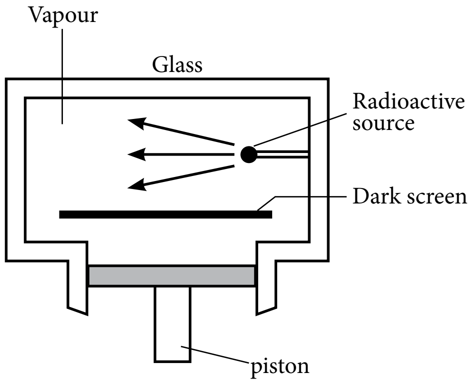
(i) A loudspeaker so that when a pulse passes it is audible.

(ii) A ratemeter which detects the number of pulses which pass in a second.

(iii) A scaler which .which detects the total number of pulses

Cloud chamber

When an ionizing particle passes through a region where there is a supersaturated vapour (a vapour which is about to condense), droplets of liquid will form around it. When it moves through the liquid it leaves a trail to show its path. The tail is clearly visible when illuminated by a bright light. Photographs of the paths may give a clue to the type of radiation which has passed through the chamber. Paths due to alpha particles are straight, short and thick, whereas paths of beta particles are long, thin and a bit curved. Tracks due to gamma rays are disorderly.



Cloud chamber
Figure 8.4

Background radiation

The atmosphere around us contains a small quantity of radiation called background radiation. This radiation is due to the following:

- Objects in the atmosphere contain radioactive elements which decay and the resulting radiation enters the atmosphere.
- **Cosmic radiation.** This is radiation from outer space. It has a high ionising effect.
- **Ultraviolet radiation (UV)** from the sun also ionises the air in the atmosphere.

Note: The radiation detected by the devices includes the background radiation.

Alpha decay

$${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

where X is the parent nuclide, Y is the daughter, and He is the alpha particle. Note that the daughter is two steps behind the parent nuclide in the periodic table.

Example,

$${}^{226}_{88}Ra \rightarrow {}^{222}_{84}Rn + {}^{4}_{2}He.$$

Note:

- Mass number on the left is equal to total mass number on the right.
- Atomic number on the left is equal to total atomic number on the right.

Beta decay

$${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e$$

where X is the parent nuclide, Y is the daughter, and ${}^{0}_{-1}$e is the beta particle. Note that the daughter is one step ahead of the parent nuclide in the periodic table.

Example,

$${}^{24}_{11}Na \rightarrow {}^{24}_{12}Mg + {}^{0}_{-1}e$$

Gamma radiation

Gamma decay is just the release of excess energy by exited atoms. It normally follows alpha and beta decay. Gamma decay creates no change in the mass and atomic numbers.

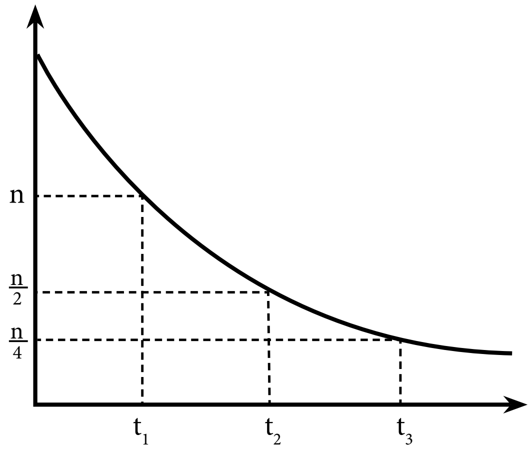
Note that during all types of radiation energy is emitted. Radioactivity is a valuable source of energy.

Half-life ($t_{\frac{1}{2}}$)

Radioactivity is a random natural process. It cannot be slowed nor speeded up by any physical or chemical process. For example heating a radioactive substance has no effect on the rate of activity. We cannot tell which atom in a group of atoms will disintegrate next but we can tell the number of atoms that will disintegrate in a given time.

Half-life is the time taken for one half of the number of atoms in a given sample to decay.

Count rate (or rate of decay) is directly proportional to the number of un-decayed radioactive atoms present. The graph below shows how the number of atoms present in a given sample varies with time. This is called a decay curve.



Decay curve

Figure 8.5

Time	Number of atoms remaining
0	N
$t_{\frac{1}{2}}$	$\frac{N}{2}$
$2t_{\frac{1}{2}}$	$\frac{N}{4}$
$3t_{\frac{1}{2}}$	$\frac{N}{8}$
$4t_{\frac{1}{2}}$	$\frac{N}{16}$
$5t_{\frac{1}{2}}$	$\frac{N}{32}$

Decay table **Table 8.2**

Half-life of different elements varies from a very small fraction of a second to millions of years.

Applications of radioactivity

- Tracers
  - Detecting leaks in hidden pipes. A small sample of a low-activity radioisotope is introduced into the liquid in the pipe. At the point of leakage the count rate will be abnormally high.
  - If a small amount of fertilizer is added to the soil, its uptake through the roots, stem and leaves can be tracked.
  - If a patient is injected with a low-activity radioisotope, its uptake by certain body organs can be monitored.
- Detecting cracks in metal castings.
- Detecting wear of metal plates e.g. break pads.
- Sterlising medical equipment.
- A concentrated beam of gamma rays is used to kill cancerous cells in the body.
- Controlling thickness of metal plates and paper in industry during their manufacture.
- Carbon dating.

  Plants take in carbon-14 which is radioactive as they grow. When a plant dies, it stops taking in the carbon. If the activity of the carbon in the dead plant is compared to the activity of the carbon in the live plant, the age of the dead fig can be calculated, using the half-life.

  The same procedure can be used to determine the age of dead fossils
- Finding the ages of rocks. When rocks were formed some radioisotopes were trapped in them. By comparing the number of the radioisotopes (parent nuclides) remaining in a rock sample with the daughter nuclides the age of the rock can be determined.
- Used in agriculture to produce drought resistant crops.
- Production of nuclear energy.

Absorption of radiation

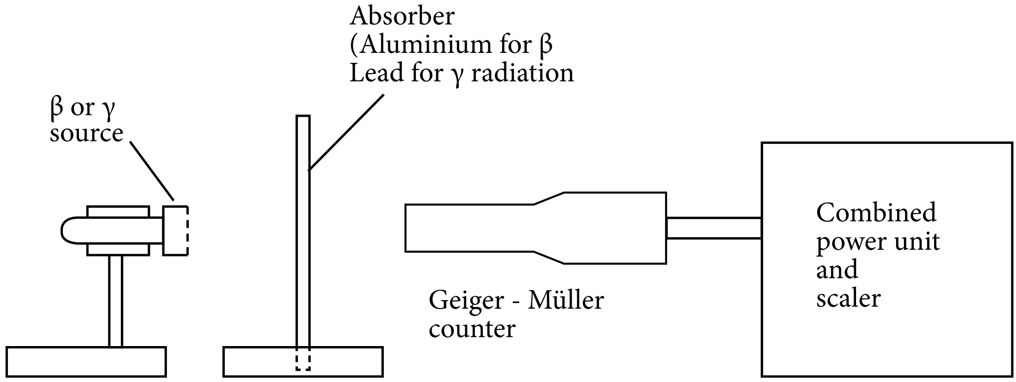


Figure 8.6

By increasing the number of metal plates we can investigate the penetration of radiation using a detector placed at the same distance from the last plate.

As we saw earlier in Table 8.1, different types of radiation have different penetration powers. Alpha particles are relatively big. As they move through a material they make many collisions with the atoms of the material. This would limit their progress through the material. Alpha particles can easily be stopped by a sheet of writing paper. Beta particles are more penetrative and can only be stopped by a thin sheet of Aluminium a few millimetres thick. Gamma rays are the most penetrative. They can be stopped by at least 10cm of Lead metal or concrete.

Hazards of radiation

Strong doses of radiation are harmful to humans. Alpha particles are the most harmful because of their high ionizing effect. Exposure to strong doses of alpha radiation can cause skin burns and leukemia (shortage of red blood cells). Gamma rays which are extremely penetrative can cause damage to the organs deep inside the body. Radiation can also affect the chromosomes and cause genetic alteration.

Safety precautions

- Radioisotopes must be handled with tongs.
- Storage of radioactive substances must be in properly protected and shielded containers (using lead or concrete or some other suitable materials).
- Food should be contaminated with radioisotopes.

Nuclear energy

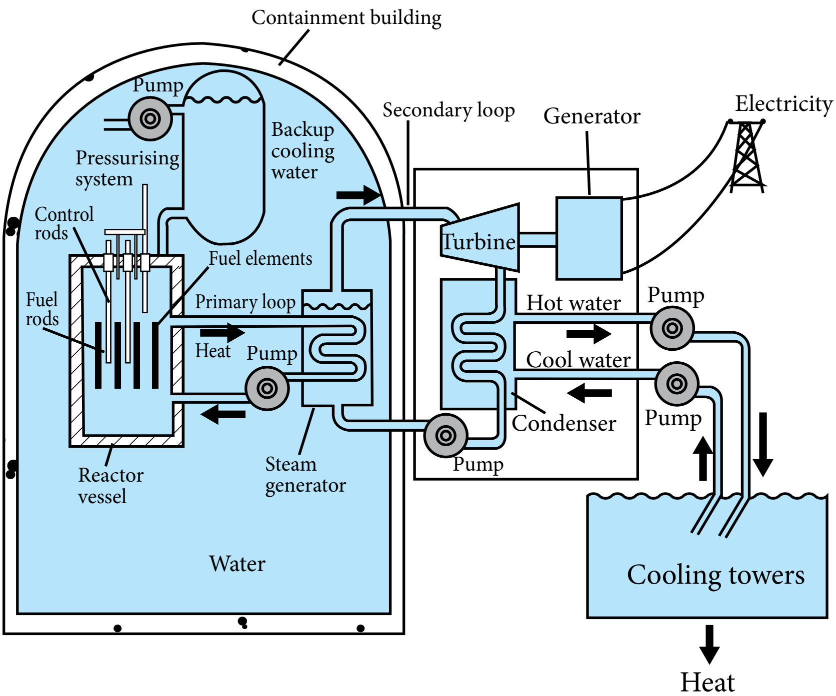


Figure 8.7

Nuclear fission

When an atom of natural Uranium absorbs a neutron it becomes unstable and split up into two nearly equal fragments. This reaction is called nuclear fission. This reaction releases two or more neutrons and plenty of energy. Neutrons are very good initiators of nuclear fission because they are uncharged and do not suffer any repulsion while approaching the nuclide.

Nuclear fission is the splitting up of a heavy unstable nuclide into two nearly equal fragments and some neutrons.

$$ {}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{144}_{56}Ba + {}^{90}_{36}Kr + 2\,{}^{1}_{0}n $$

In the above reaction two neutrons are produced. Gamma rays are also produced by this reaction. These two free neutrons trigger more fission reactions. This will turn out to be a chain reaction when a large number of neutrons are produced. A lot of energy too is produced.

Nuclear fusion

At very high temperature, some light nuclei join up to form a heavy nuclide. This reaction is followed by release of vast amounts of energy.

$$ {}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}H + {}^{1}_{0}n $$

Nuclear fusion is the joining up of two light nuclei to form a heavy nuclide.

Nuclear fusion occurs in the sun's atmosphere where temperature is very high.

Artificial isotopes

When a stable nuclide is bombarded with an energetic particle it becomes unstable and decays giving off other particles.
Example,

$$ {}^{24}_{12}Mg + {}^{1}_{0}n \rightarrow {}^{24}_{11}Na + {}^{1}_{1}H $$

Stable   unstable

The unstable sodium isotope then decays as follows:

$$ {}^{24}_{11}Na \rightarrow {}^{24}_{12}Mg + {}^{0}_{-1}e $$

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