Secondary

Physics

Students' Book One

Fourth Edition

Approved by the Ministry of Education

KENYA LITERATURE BUREAU

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PHYSICS

Student's Book One

(Fourth Edition)

KENYA LITERATURE BUREAU
NAIROBI

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ISBN 978-9966-10-142-6

First published 1988
Second Edition 1995
Third Edition 2004
Reprinted 2006, 2007, 2008 (twice), 2010, 2011
Fourth Edition 2013

KLB 10821 10m 2013

Published and printed by Kenya Literature Bureau

Contents

Prologue

This book is primarily meant to cover exhaustively the Form One Physics syllabus as per the new 8-4-4 curriculum. It is by design also a versatile companion for those students taking related courses in technical colleges and other institutions.

The book has been made more elaborate and the in-depth theoretical coverage boosted with numerous experiments to enhance a better understanding of concepts under study.

Any student making full use of the title and by extension the KLB Secondary Physics series, will certainly acquire scientific knowledge and skills useful in answering the challenges of daily life.

I am grateful to the panel of writers and everybody who took part in the preparation and production of this edition.

THE MANAGING DIRECTOR
Kenya Literature Bureau

Acknowledgements

The Managing Director, Kenya Literature Bureau, would like to thank the following writers who participated in the revision of this book:

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Erastus Muni

Hesborne Omolo

Grace Mwangasha

Chapter 1

Introduction to Physics

Physics as a Science

One of the subjects offered in primary school is Science. At secondary school level and beyond, this subject is split into three main areas namely, Biology, Chemistry and Physics.

The three, however, are interrelated since they are all human attempts to explore the universe and its contents by establishing facts through observation and experiment.

The primary school science syllabus covers topics such as Matter and its Properties, Energy in its various forms, e.g., heat, light, sound and their corresponding sources, Machines and the way they make work easier, Balancing and Weighing of various Shapes of objects, Electricity and Magnetism. All these topics form the basic foundation for Physics at secondary school level.

Meaning of Physics

Physics is defined as the study of matter and its relation to energy. The subject is applied in explaining phenomena like eclipse, lightning, rainbow, mirage and many other wonders of nature. Physics explains the how and why behind the:

- falling of bodies towards the ground.
- daily occurrence of tides in the sea.
- rising up of a liquid through a drinking straw.
- cracking sound produced when removing a nylon cloth from the body, and many more.
- rapid technological developments in communication, transport, medicine, among other disciplines.

Boeing 787, tablet, smart phone, I-pad and plasma TV.

Through the study of Physics, the various forms of energy available can be harnessed for a more easily manageable and fulfilling life. Thus, a waterfall or a hot spring is seen as a source of electrical energy. On the other hand, radio waves and microwaves as a means of energy propagation, have been put into use in the working of radio, television, satellites, computers and the telephone.

As a subject, the study of Physics involves measurement of quantities and collection of data. Through experimentation and observations, hypotheses are drawn, tested and consequently laws and principles established.

Branches of Physics

Physics as a study may be divided into the following key areas:

Mechanics

This involves the study of motion of bodies under the influence of forces. In mechanics, the characteristics of linear, circular and oscillatory motion are explained. The equilibria of forces of bodies and fluids at rest and when in motion are also explored.

Electricity and Magnetism

This deals with the relationship between electric currents and magnetic fields and their extensive applications in the working of the electric motor, magnetic relay and telephone receiver, among others.

Thermodynamics

This is the study of transformation of heat to and from other forms of energy. A major reference is made to gas behaviour in which thermal exchanges and the accompanying changes of pressure and volume are explained in line with the Kinetic Theory of Matter.

Geometrical Optics

Under this title, the behaviour of light as it traverses various media is studied. Optical instruments such as telescopes, microscopes, periscopes and laws governing their working form a major part of this branch of physics.

Waves

In this area, the propagation of energy through space is discussed. In addition, effects such as reflection, refraction and diffraction of light and sound are explained using the wave theory.

Atomic Physics

This involves the study of the behaviour of particles constituting the nucleus and the accompanying energy changes. It is within this area that radioactivity, nuclear fission and fusion are dealt with.

Relationship between Physics, other Subjects and Technology

Physics and Religion

Systems in the universe reveal great orderliness which can be traced back to the creator. The study of Physics comes up with findings that are in total agreement with this orderliness. The earth faithfully maintains its rotation so that the sun will always rise from the East and never from the West. Among the many wonders of creation in Physics is the anomalous expansion of water and its implications on aquatic life.

Physics and History

Carbon dating, an application of radioactivity, serves as a crucial tool to historians in establishing fossil ages and hence past patterns of life. Early explorers like Vasco da Gama made use of the magnetic properties of lodestone to determine direction.

Physics and Geography

Establishment of weather patterns relies on the accurate use of instruments like the thermometer, wind-vane and hygrometer. Heat transfer by convection explains the formation of convectional rainfall and pressure variations that determine wind patterns. All these are concepts in Physics.

Physics and Home Science

Physics knowledge has been applied in the design and manufacture of domestic equipment. Examples are pressure cookers, microwave ovens, refrigerators and the energy saving *jiko* and light bulb.

Physics and Biology

Knowledge of lenses has helped in the making of the microscope which has assisted in the study of the cell, the basic unit of life. Similarly, the knowledge of levers helps to explain locomotion in Biology.

Physics and Chemistry

Physics has helped in explaining forces within atoms and therefore, atomic structure. It is this structure of the atom that then determines the reactivity of the atom as explained in Chemistry.

Physics and Mathematics

Physics relates strongly to Mathematics. Many concepts in Physics are expressed mathematically. In manipulations involving extreme quantities like the mass of the earth or the charge on an electron, a good grasp of mathematical skills is essential.

Physics and Technology

In the field of medicine, X-rays, body scanners and lasers are applications of Physics used in diagnosis and treatment of diseases. Even in the continuing research necessitated by the challenge posed by such diseases as Ebola and HIV/AIDS, the development of high precision equipment employing the principles of Physics remains necessary.

Information technology has reduced the world to a global village through the use of satellites and microwave dishes which relay information over extremely long distances in fractions of a second.

The wide range of applications of Physics is used in industrial development for the improvement of material well-being of the human race.

In the entertainment industry, Physics has contributed to the refinement of sound and colour mixing techniques to create special effects in stage presentations.

The defence industry has also become highly technological. Wars can now be fought using laser-guided bombs of extremely high precision.

However, if technology is not used responsibly, it can lead to social and environmental problems. Notable cases are the Chernobyl nuclear disaster in Ukraine of 1986 and the Hiroshima and Nagasaki atomic bomb attacks during the Second World War.

Career Opportunities in Physics

There is a wide range of opportunities involving Physics. The following is a list of courses offered at university level that require sound knowledge of Physics:

1. Bachelor of Arts (Buiding Economics).
2. Bachelor of Science (Construction management).
3. Bachelor of Architecture.
4. Bachelor of Medicine.
5. Bachelor of Dental Surgery.
6. Bachelor of Pharmacy.
7. Bachelor of Science (Nursing).
8. Bachelor of Science (Environmental Health).
9. Bachelor of Science (Bio-medical Science Technology).
10. Bachelor of Education (Home Science and Technology).
11. Bachelor of

Science (Agricultural Education).

12. Bachelor of Science (Agricultural and Home Economics).
13. Bachelor of Science (Animal Production).
14. Bachelor of Science (Dairy and Food Technology).
15. Bachelor of Science (Fisheries).
16. Bachelor of Science (Food Technology).
17. Bachelor of Science (Food Science and Technology).
18. Bachelor of Science (Horticulture).
19. Bachelor of Science (Natural Resources).
20. Bachelor of Science (Range Management).
21. Bachelor of Science (Tourism).
22. Bachelor of Science (Wildlife and Management).
23. Bachelor of Science (Wood Science Technology).
24. Bachelor of Veterinary Medicine.
25. Bachelor of Science (Hotel and Institution Management).
26. Bachelor of Science (Environmental Studies).
27. Bachelor of Science (Textiles Design and Merchandising).
28. Bachelor of Science (Applied Aquatic Science).
29. Bachelor of Science (Food Nutrition and Dietetics).
30. Bachelor of Education (Agriculture and Home Economics).
31. Bachelor of Science (Agricultural Engineering).
32. Bachelor of Science (Civil Engineering).
33. Bachelor of Science (Electrical Engineering).
34. Bachelor of Science (Surveying).
35. Bachelor of Science (Electrical and Electronic Engineering).
36. Bachelor of Science (Electrical and Communication Engineering).
37. Bachelor of Technology (Electrical and Communication Engineering).
38. Bachelor of Technology (Production Engineering).
39. Bachelor of Technology (Chemical and Process Engineering).
40. Bachelor of Technology (Civil and Structural Engineering).
41. Bachelor of Technology (Textile Engineering).
42. Bachelor of Science (Water and Environmental Engineering).
43. Bachelor of Science (Manufacturing and Engineering Technology).

44. Bachelor of Science (Instrumentation and Control Engineering).
45. Bachelor of Science (Computer Science).
46. Bachelor of Education (Technology).
47 Bachelor of Science (Computer Electronics, Science and Technology).
48. Bachelor of Home Economics (Food, Nutrition and Dietetics).

The above courses are also offered at diploma and certificate levels.

Basic Laboratory Rules

The laboratory is a facility designed and equipped for conducting scientific research, experiments and measurements.

An average laboratory has electrical energy supply, water and gas piping systems, workbenches and cabinets for storage of equipment and chemicals. Some of the chemicals and equipment are particularly dangerous. An individual working in a typical laboratory will be exposed to a number of dangers including poisons, flammable materials, explosive materials, extreme temperature, moving machinery and high voltage electricity. The following precautions must, therefore, be taken when working in the laboratory:

(i) Proper dressing must be put on. Shirts and blouses must be tucked in and long hair tied up. Closed shoes must be worn. This is to avoid loose clothing or body parts such as hair getting accidentally tangled up in moving machinery. In addition, safety glasses or face shields must be worn when working with hazardous or poisonous materials. Shorts and sandals must never be worn in the laboratory, and lab coats, if in use should always be buttoned.

(ii) The locations of electricity switches, fire-fighting equipment, First Aid kit, gas supply and water supply systems must be noted. These will be extremely useful in case of any emergency within the laboratory. Access to all these facilities must remain unobstructed, this includes emergency showers and eye washes, where these are available in the laboratory.

(iii) While working in the laboratory, windows and doors should be kept open. This is to prevent inhalation of dangerous materials or gases and also to allow for easy escape/evacuation in case of an emergency. Similarly, corridors or pathways within the laboratory should not be used as working or storage areas.

(iv) Any instructions given must be followed carefully. Never attempt anything while in doubt. In case of any doubt or queries, consult your teacher or the laboratory assistant. Additionally, if any equipment fails to function, this should be reported immediately to the teacher or the laboratory technician. Never try to fix a problem on your own as this could cause a serious accident or damage to the equipment

(v) Never taste, eat or drink anything in the laboratory. Food should also never be stored in the laboratory. This is to avoid the risk of consuming dangerous or poisonous materials or substances. Related to this, never pipette anything by mouth (a bulb should be used instead). Smelling of gases is also highly discouraged.

(vi) Ensure that all electrical switches, gas and water taps are turned off when not in use. This is to avoid wastage in addition to averting the risk of fire or other hazards.

(vii) When handling electrical apparatus, hands must be dry. Do not splash water where electrical sockets are located. Water to some extent is an electrical conductor and when in contact with exposed power cables, can cause severe electric shock.

(viii) Never plug foreign objects into electrical sockets. Apart from damaging the socket, this can also cause an electric shock.

(ix) Keep floors and working surfaces dry. Any spillage should be wiped off immediately. Liquid on the floor surface can cause skidding, resulting in serious injuries. Some corrosive liquids will damage the floor or working surfaces.

(x) All apparatus must be cleaned and returned to the correct location of storage after use. This facilitates easy re-use of the apparatus, apart from ensuring good order in the laboratory.

(xi) Laboratory equipment should not be taken out of the lab. This is to minimise the risk of damage to the equipment, or even loss.

(xii) Any waste after an experiment must be disposed of appropriately. This is because waste from certain experiments can be quite hazardous to the body and to the environment.

(xiii) Hands must be washed before leaving the laboratory.

Experiments should never be left unattended. Similarly, the bunsen burner should be adjusted to give a luminous flame, or turned off, when not in use. Never should an open flame be left unattended. This is to minimise the risk of fire or other serious accidents.

Volatile and flammable compounds should only be used in the fume cupboard. The same applies to procedures that should result in hazardous fumes or any inhalable material.

One should never look directly down into the liquid being heated in a test-tube. The tube should also not be pointed towards anyone nearby.

Corrosive chemicals should be kept separately. This is to prevent damage to other laboratory appliances especially the metallic type.

First Aid Measures

Accidents or emergencies are prone to occur any time and it is, therefore, the user's responsibility to be conversant with the safety and fire alarm posters strategically positioned within the laboratory premises. These must be followed strictly during an emergency. The locations of vital emergency equipment such as fire extinguisher must be known and easily accessible to all, and users must be continually reminded of building evacuation procedures.

In case of injuries in the laboratory, the teacher in charge or the laboratory technician must be immediately informed and necessary action taken without delay. Common laboratory injuries include burns, cuts and bruises (sometimes resulting in bleeding), poisoning and foreign matter in the eyes. These cases should be handled in the following way. (Those offering first aid should ensure they are in the first place safe from the danger).

Cuts

These may result from poor handling of glass apparatus or cutting tools like razors and scalpels.

In case the cut results in bleeding, pressure or direct compression should be applied directly to the wound and proper dressing applied as medical assistance is sought.

Burns

Burns may result from naked flames or even splashes of concentrated acids and bases.

Burns should generally be treated by flushing cold water over the affected area. Acid burns could alternatively be treated with sodium hydrogen carbonate (baking soda), and base burns with boric acid or vinegar.

Poisoning

This may result from inhaling poisonous fumes or swallowing of poisonous chemicals or materials. In case this happens, the poisoning agent should be noted while urgent medical assistance is sought. For a poison ingested through the mouth, the recommended antidote should be given to the victim, and vomiting should not be induced unless recommended by a medical practitioner.

If the poison is in form of a gas, the first step should be to remove the victim from the area and take him/her to an area with fresher air. If the poison is corrosive to the skin, the victim's clothing should be removed from the affected area, and cold water run over the area for at least 30 minutes. If the poison gets to the eye, the same should be flushed with clean water for at least 15 minutes, and the patient advised not to rub the eyes.

Electric Shock

This may result from touching exposed wires or using faulty electrical appliances.

Without getting in contact with the victim, the first thing to do is to cut off the current causing the shock by:

(i) Turning off the current at the main switch, or,

(ii) Using a non-conducting object, such as wooden rod, to move the victim away from the conductor.

In the meantime, urgently seek medical assistance. If the victim has a pulse but is not breathing, offer mouth to mouth resuscitation as you await assistance.

If for some reason a laboratory user faints or loses consciousness, he/she should be promptly and gently moved to an area with fresh air and placed in a recovery position (with the head slightly lower than the rest of the body). If necessary, mouth to mouth resuscitation should be offered.

Chapter 2

Measurement (I)

Up to 1960, scientists were using different units of measurement depending on the immediate environment. Some of the common units were the inch (2.54 cm), the mile (1.61 km), acre (0.41 Ha), pint (0.57 litres), gallon (4.55 litres), pound (0.45 kg) and tonne (1 000 kg). Others used grams, centimetres and seconds. There was need to harmonise the units of measurement. The metric system is a decimalised system expressing quantities in larger or smaller multiples of the unit, e.g, milligramme/grammes/kilogrammes or millimetre/centimetre/metre.

Consenquently, scientists agreed on one international system of units to be used, the Systeme Internationale d'Unites (International System of Units), shortened to SI units, in all languages. This system has **seven basic physical quantities** and units as shown in table 2.1.

Table 2.1: The seven basic physical quantities and units

Basic physical quantity	SI unit	Symbol of units
Length	Metre	m
Mass	Kilogram	kg
Time	Second	s
Electric current	Ampere	A
Thermodynamic temperature	Kelvin	K
Luminous intensity	Candela	Cd
Amount of substance	Mole	mol

These quantities cannot be obtained from any other physical quantities. On the other hand, there are quantities obtained by multiplication or division of basic physical quantities. These are called **derived quantitie**s, for example, area, volume and density. This chapter will deal with the measurements of length, mass, time and their derived physical quantities.

Length

Length is a measure of distance between two points. Breadth, width, height, radius, depth and diameter are all lengths.

The SI unit of length is the metre (m). One metre is the distance between two marks on a standard platinum-iridium bar kept at a constant temperature of 0^oC. The bar is kept at Sevres, near Paris, France.

Table 2.2 shows the multiples and sub-multiples of the metre.

Table 2.2: Multiples and sub-multiples of the metre

Unit	Symbol	Equivalence in metres
Kilometre	km	1 000
Hectometre	Hm	100
Dekametre	Dm	10
Decimetre	dm	0.1
Centimetre	cm	0.01
Millimetre	mm	0.001
Micrometre	m	0.000001

Measurement of Length

Length can be determined by estimation or accurately by using a measuring instrument. There are various instruments for measuring length. The choice of the instrument is determined by the level of the accuracy desired and the size of the object to be measured.

Some instruments used to measure length are meter rule and tape-measure.

Metre Rules

For day-to-day work in Physics, metre rules and half-metre rules are used. They are graduated in centimetres and millimetres.

The following procedure should always be followed when using a metre rule:

(i) Place the metre rule in contact with the object.

(ii) Place the end of the object against the zero mark on the scale.

(iii) Position your eye perpendicularly above the scale, as shown in figure 2.1 (a).

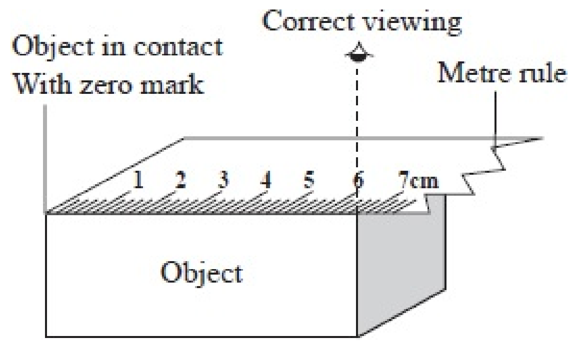


Fig. 2.1: (a) Accurate use of a meter rule

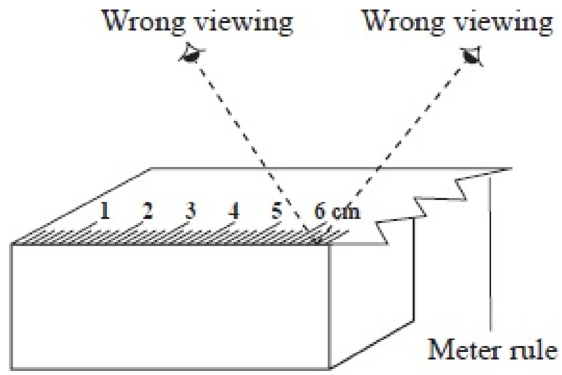


Fig. 2.1: (b) Inaccurate positioning of the eye

Figure 2.2 shows other ways of inaccurate use of the metre rule. In figure 2.2 (a), arrangement will not give a fair result because, the rule is not in contact with the object. While in (b) the object is not aligned to the zero mark on the scale.

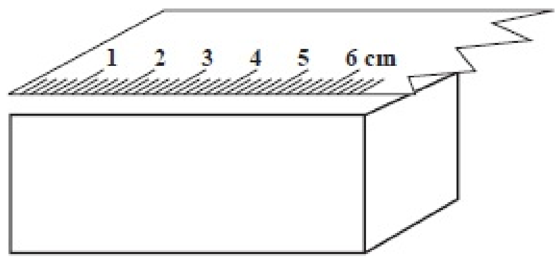
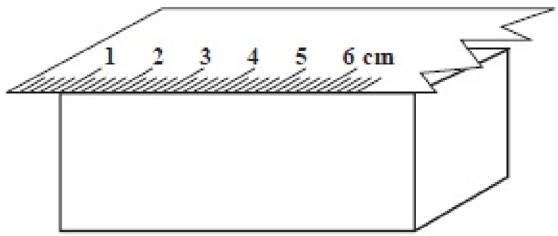


Fig. 2.2: (a) Rule not in contact



(b) Rule not aligned

Figure 2.2 shows the inaccurate use of the rule. The arrangement will not give an accurate result because:

(i) the rule is not in contact with the object.

(ii) the object is not aligned with the zero mark on the scale.

(iii) the position of the eye is not perpendicular to the scale.

Note that when the eye is not perpendicular to the scale, there is an error due to parallax.

Reading a metre rule

Consider the reading shown by the arrow in figure 2.3 (rule not to scale).

The reading is more than 1.6 cm but less than 1.7 cm. The second decimal place is approximated. It is 1.67 cm. It could even be 1.66 cm.

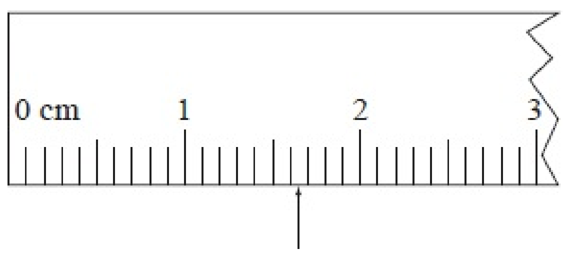


Fig: 2.3: The reading on a metre rule

The second decimal place cannot be accurately determined. However, it is important to note that the readings from a metre rule may be written up to the second decimal place of a centimetre.

A reading like 3.675 cm cannot be taken by a metre rule. However, if the readings 5.6 cm and 6 cm are taken with a metre rule, then they should be written as 5.60 cm and 6.00 cm respectively.

Example 1

What are the readings indicated by arrows P_1, P_2 and P_3 on the metre rule in figure 2.4? (Diagram not to scale)

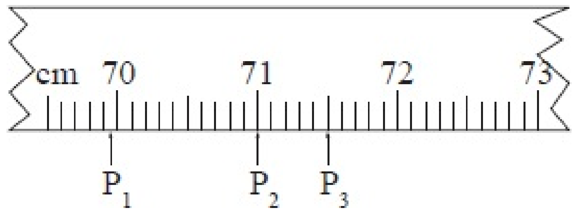


Fig 2.4

Solution

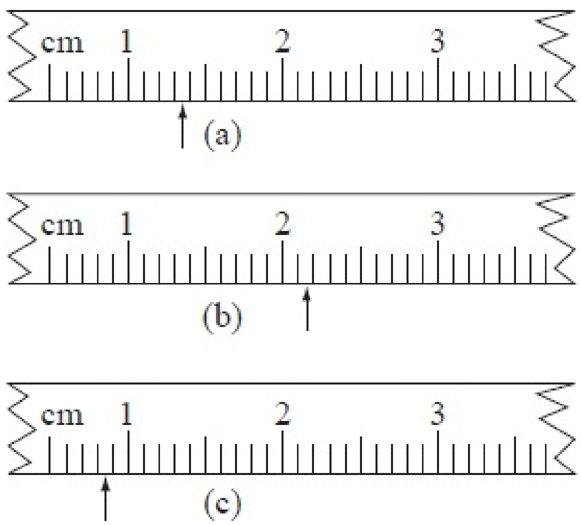
P_1 = 69.50 cm

P_2 = 71.00 cm

P_3 = 71.50 cm

Exercise 2.1

1. What are the readings indicated by the arrows in the figures (a) to (c) below? (Diagrams not to scale)



Care should be taken to avoid damage to the ends of metre rules as most of them do not have the short ungraduated portion at the ends to cater for wear.

Tape-Measure

There are several types of tape-measures, for example, tailor's, carpenter's and surveyor's types. The choice of a tape-measure is determined by the nature of the distance to be measured. For example, to measure the length and breadth of a plot of land, or the distance covered by a discus or javelin throw, a surveyor's tape-measure would be the most convenient.

Always ensure that the tape-measure is taut when measuring.

Measurement of Curved Length

Curved lengths such as roads and railway lines on a map or dimensions of some containers can be measured using a thread. The thread is placed along the required lengths and the length is then found by placing the thread on a millimetre scale. For curved surfaces such as a cylinder, a thread is closely wrapped around the surface a number of times.

Experiment 2.1: To measure the circumference of a cylinder using a thread

Apparatus

A cylinder, a thread, a metre rule.

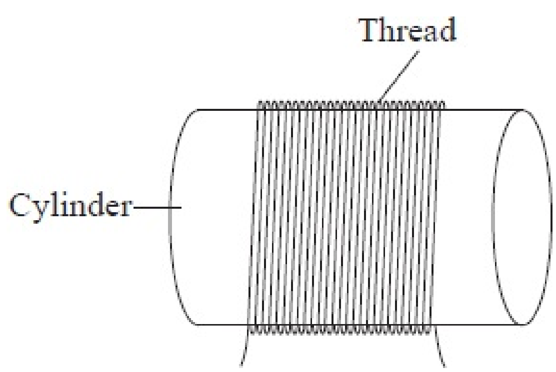


Fig. 2.5: Estimating the circumference of a cylinder

Procedure

- Closely wrap a thin thread 10 times around a cylinder, as shown in figure 2.5.
- Mark with ink the beginning and end of the turns.
- Remove the thread.
- Measure the length between the ink marks and call it a_1.

Repeat three times recording the readings as a_2 and a_3 to ensure accuracy of your measurement. Find the average length a:

$$a = \frac{a_1 + a_2 + a_3}{3}$$

Divide the average length by 10 to find the length of one turn. This gives the circumference of the cylinder. Thus;

Circumference of the cylinder = $\frac{a}{10}$

Note:

The diameter of the cylinder is obtained by using the formula;

Circumference = πD (where D is the diameter)

$$\text{Diameter} = \frac{\text{circumference}}{\pi}$$

But D = 2r, where r is the radius.

$$\text{Hence, } r = \frac{\text{circumference}}{2\pi}$$

Other instruments for measuring length, like the micrometer screw gauge and the vernier callipers will be dealt with at a later stage.

Estimation of Length

One may wish to know which of the several objects is the largest. This could be established by comparing the sizes of the objects directly. At times, it is better to compare them with that of a chosen basic length called a *standard length*.

The following activities will make the estimation of sizes of various objects such as the height of a tree, flagpost or the length of a rope possible by comparing with standard lengths.

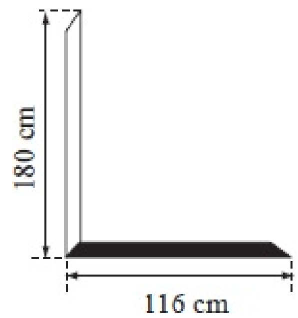
Experiment 2.2: To estimate the height of a tree

Apparatus

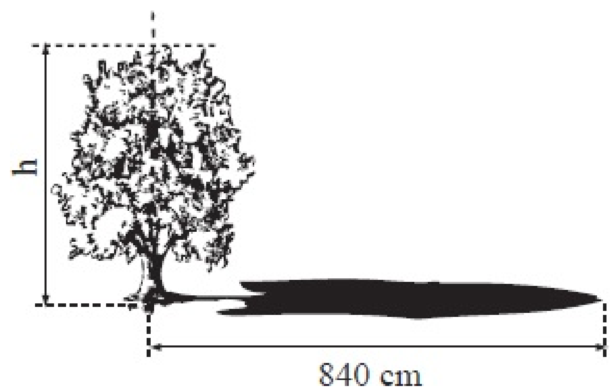
A rod about 2 m long, a tape-measure.

Procedure

- Hold the rod upright and measure its length using the tape-measure.
- Measure the length of its shadow, see figure 2.6 (a).
- Measure the length of the shadow of a tree in the school compound as in figure 2.6 (b).



(a) A rod and its shadow



(b) A tree and its shadow

Fig. 2.6: Estimation of height using shadow

Results

The height of the tree is estimated from the relation:

$$\frac{\text{height of tree}}{\text{height of rod}} = \frac{\text{length of the shadow of the tree}}{\text{length of the shadow of the rod}}$$

Consider a certain experiment in which the following measurements were recorded:

Height of the rod = 180 cm

Length of the shadow of the rod = 116 cm

Length of the shadow of the tree = 840 cm

Height of the tree would be given by;

Height of tree =

$$\frac{\text{height of rod} \times \text{length of the shadow of tree}}{\text{length of the shadow of the rod}}$$

$$= \frac{180 \times 840}{116}$$

$$= 1\ 303.4 \text{ cm}$$

$$= 1\ 300 \text{ cm}$$

Therefore, the height of the tree is approximately 13 m.

Experiment 2.3: To compare the lengths of ropes

Apparatus

Three pieces of rope and a metre rule.

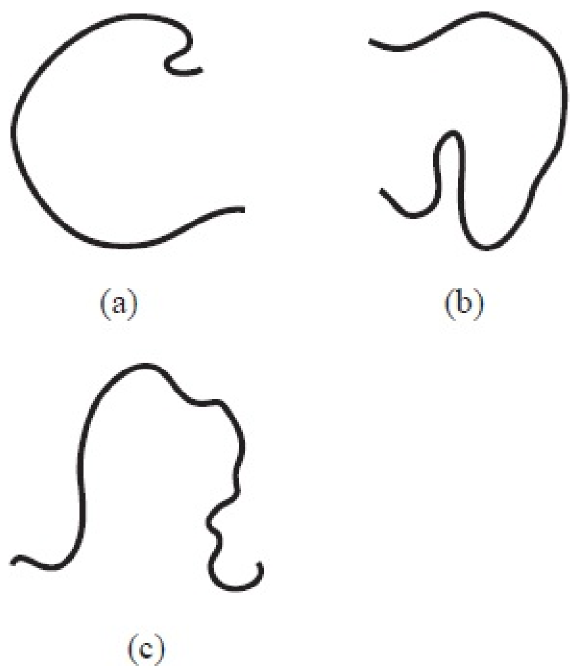


Fig. 2.7: Comparing lengths

Figure 2.7 (a), (b) and (c) shows three pieces of rope. Look at them closely. Which of the ropes appears longest?

One way of finding out which rope is longest is to stretch them out from the same point and adjacent to one another. Try this and state which of the ropes is the longest. Which one is shortest?

Example 2

Atieno found that the width of her desk was approximately 10 palm-lengths. If her palm was 15.0 cm long, what was the width of her desk in centimetres?

Solution

1 palm-length is 15.0 cm long.

Therefore, 10 palm-lengths

$= (15.0 \times 10)$ cm

$= 150.0$ cm

Hence, width of her desk was approximately 150.0 cm.

Exercise 2.2

1. Charo found that the perimeter of his farming plot was approximately 200 strides. His stride was 0.9 m long. What was the perimeter of the plot?
2. Use the method in Experiment 2.2 to estimate the height of a flag post and a goal post in your school.
3. Estimate the width of your desk, classroom door and the classroom by counting how many of your palm-lengths or foot-lengths and strides there are in each length.
4. Suggest a method you can use to estimate the width of a page of your book. (text-book or notebook).
5. Devise a method that should be used to estimate the thickness of a razor blade.
6. How would you measure the length of the curve of an athletics field?

Area

Area is the quantity that expresses the extent of a given surface on a plane. It is a derived quantity of length. The SI unit of area is the square metre, written as m^2. It can also be measured in multiples and sub-multiples of m^2, for example, cm^2 and km^2.

The following examples show the conversion of units of area.

Example 3

Express each of the following in cm^2:

(a) 7.5 m^2

(b) 4.2 m^2

(c) 0.09 m^2

(d) 0.0000007 km^2

Solution

(a) 1 m = 100 cm

$1 \text{ m}^2 = 1 \text{ m} \times 1\text{m}$

$= 100 \text{ cm} \times 100 \text{ cm}$

$= 10\,000 \text{ cm}^2$

$7.5 \times 10\,000 \text{ cm}^2 = 75\,000 \text{ cm}^2$

(b) $4.2 \text{ m}^2 = 4.2 \times 100 \times 100 \text{ cm}^2$

$= 42\,000 \text{ cm}^2$

(c) $0.09 \text{ m}^2 = 0.09 \times 100 \times 100 \text{ cm}^2$

$= 900 \text{ cm}^2$

(d) $0.0000007 \text{ km}^2 = 0.0000007 \times 1\,000 \times 1\,000 \times 100 \times 100 \text{ cm}^2$

$= 7\,000 \text{ cm}^2$

Example 4

Express the following areas in m^2:

(a) 9 000 cm^2

(b) 0.05 cm^2

Solution

(a) $1\text{m}^2 = 10\,000 \text{ cm}^2$

$$\therefore 9\,000 \text{ cm}^2 = \frac{9\,000}{10\,000} \text{ m}^2$$

$$= 0.9 \text{ m}^2$$

(b) $$0.05 \text{ cm}^2 = \frac{0.05}{10\,000}$$

$$= 0.000005 \text{ m}^2$$

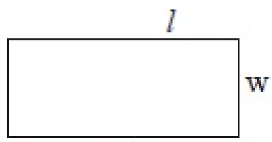
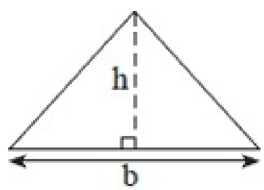
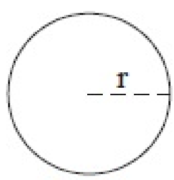
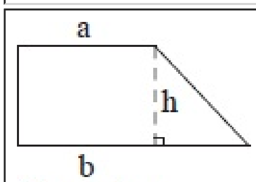
Measurement of Area

Area of regularly-shaped objects

The area of regularly-shaped surfaces such as rectangles, triangles and circles can be obtained by applying appropriate formulae.

Table 2.3 shows some regular shapes and their corresponding formulae for area.

Table 2.3: Shapes and their areas

Shape	**Area**
 Rectangle	$A = \text{length} \times \text{width}$ $= l \times w$ $= l\,w$
 Triangle	$A = \frac{1}{2}(\text{base} \times \text{height})$ $= \frac{1}{2} b \times h$ $= \frac{1}{2} bh$
 Circle	$A = \pi r^2$
 Trapezium	$A = \frac{1}{2}(a + b)\,h$

Area of irregularly-shaped surfaces

An estimate of the area of an irregular shape can be made by dividing it up into squares, each of area 1 cm^2.

Figure 2.8 shows an irregular shape drawn on a squared paper. By counting the number of small squares, the area can be estimated.

Example 5

Estimate the area of the irregular surface shown in figure 2.8 by counting the small squares.

Solution

The number of complete squares = 39

Number of incomplete squares = 30

These are equal to $\frac{30}{2}$ = 15 complete squares

Therefore, the number of complete squares = 39 + 15 = 54

Hence, the estimated area of the surface

$= 54 \times 1\ cm^2$

$= 54\ cm^2$

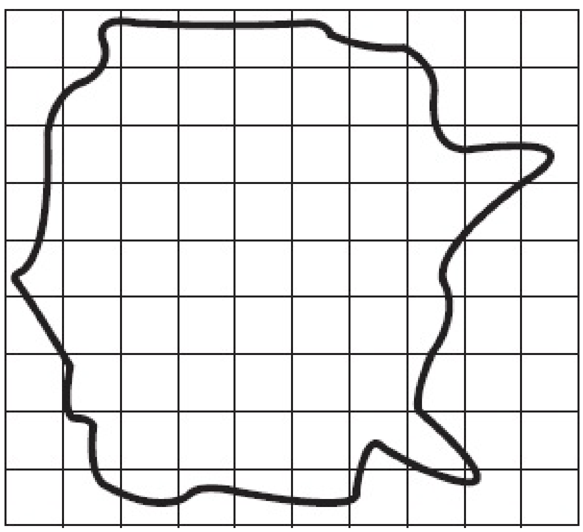
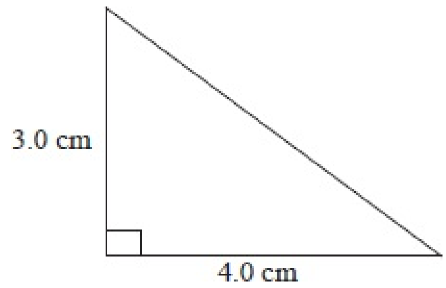


Fig. 2.8: Estimating area of irregular shapes

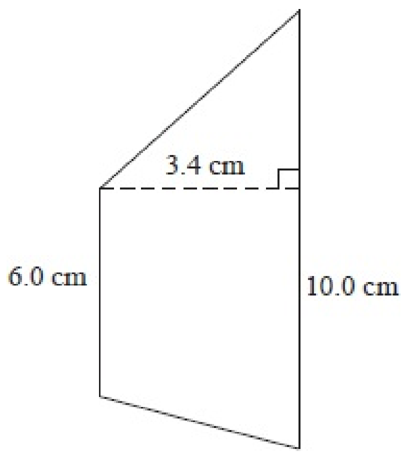
Exercise 2.3

1. Determine the area of each of the following:
   (a) The floor of your classroom.
   (b) The walls of your classroom.
   (c) The top of your desk.
2. (a) Calculate the area of a circle of radius 7.0 cm.
   (b) Calculate:

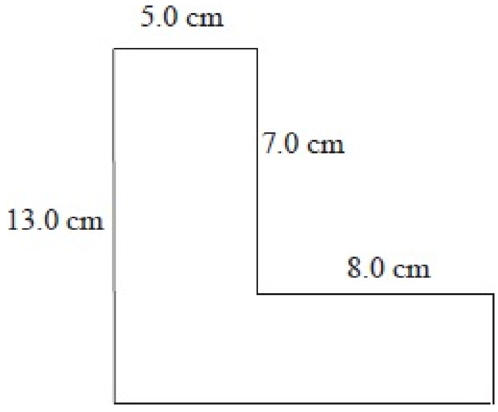
(i) the area of the triangle shown in the figure below:



(ii) the area of the trapezium below:



(iii) the area of the figure below:



3. Trace an outline of your palm and foot on a graph paper and estimate the area of each shape obtained.
4. Trace the shape of a leaf on a graph paper and estimate its area.
5. The diameter of the bore of capillary tube is 1.0 mm. Calculate the cross-section area of the bore in cm^2.

(Take $\pi = 3.142$)

6. A sheet of paper measures 25 cm by 15 cm. Calculate its area in mm^2.

Volume

Volume is the amount of space occupied by matter.

The SI unit of volume is cubic metre (m^3). However, sub-multiples of m^3, for example, cm^3 and mm^3, are commonly used since the m^3 is very large.

$1\ m^3 = 1\ m \times 1\ m \times 1\ m$

$= 100\ cm \times 100\ cm \times 100\ cm$

$= 1\ 000\ 000\ cm^3$

Other units like litres (*l*) and millilitres (m*l*) are also used.

1 m*l* = 1 cm^3

1 000 *ml* = 1 litre

$1\ m^3 = 1\ 000\ 000\ cm^3$

Example 6

Express each of the following volumes in cm^3:

(a) 27 mm^3

(b) 0.0005 m^3

Solution

(a) $1\ mm^3 = \frac{1}{10}\ cm \times \frac{1}{10}\ cm \times \frac{1}{10}\ cm$

$= \frac{1}{1\ 000}\ cm^3$

$= 0.001\ cm^3$

Therefore, $27\ mm^3 = 27 \times 0.001\ cm^3$

$= 0.027\ cm^3$

(b) $1\ m^3 = 100\ cm \times 100\ cm \times 100\ cm$

$= 1\ 000\ 000\ cm^3$

Therefore, $0.0005\ m^3$

$= 0.0005 \times 1\ 000\ 000\ cm^3$

$= 500\ cm^3$

Example 7

Express each of the following volumes in m^3 .

(a) $9\ 000\ cm^3$

(b) $27\ cm^3$

Solution

(a) $1\ m^3 = 100\ cm \times 100\ cm \times 100\ cm$

Therefore, $9\ 000\ cm^3 = \frac{9\ 000}{1\ 000\ 000}$

$= 0.009\ m^3$

(b) $27\ cm^3 = \frac{27}{1\ 000\ 000}$

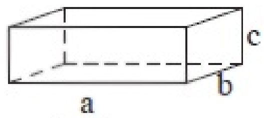
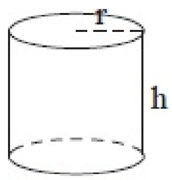
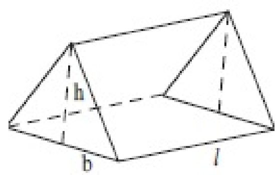
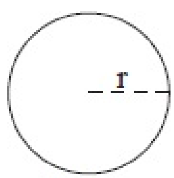
$= 0.000027\ m^3$

Volume of Regularly-Shaped Solids

The volume of regularly-shaped solids can be obtained by applying the appropriate formula. Table 2.4 shows some regular objects and their corresponding formulae for volume.

Table 2.4: Regular objects and their volumes

Object	**Volume (V)**

Cuboid	$V = (ab)c$ $= abc$
Cylinder	$V = (\pi r^2)\,h$ $= \pi r^2 h$
Triangular prism	$V = \frac{1}{2}\,bhl$
Sphere	$V = \frac{4}{3}\,\pi r^3$

Example 8

A block of glass is 5.0 cm long, 4.0 cm thick and 2.5 cm high. Calculate its volume.

Solution

Volume of the glass block = area of cross-section × height

$= 5.0 \times 4.0 \times 2.5$

$= 50.0\ \text{cm}^3$

Example 9

Find the volume of cylindrical tin of radius 7.0 cm and height 3.0 cm.

Solution

Volume of the tin = area of cross-section × height

$$= \frac{22}{7} \times 7 \times 7 \times 3$$
$$= 462.0 \text{ cm}^3$$

Example 10

Find the volume of a triangular prism shown in table 2.4 if b = 6.0 cm, h = 5.0 cm and *l* = 12.0 cm.

Solution

Volume = area of cross-section × height

$$= \frac{1}{2} \times 6.0 \times 5.0 \times 12.0$$
$$= 180.0 \text{ cm}^3$$

Example 11

Find the volume of a sphere whose radius is 3.0 cm.

Solution

$$\text{Volume of sphere} = \frac{4}{3}\pi r^3$$
$$= \frac{4}{3} \times \frac{22}{7} \times 3.0 \times 3.0 \times 3.0$$
$$= 113.14 \text{ cm}^3$$

Example 12

A sphere of diameter 6.0 cm is moulded into a thin uniform wire of diameter 0.2 mm. Calculate the length of the wire in metres. $\left(\text{Take } \pi = \frac{22}{7}\right)$

Solution

The volume of the sphere and the wire are equal.

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

$$= \frac{4}{3} \times \frac{22}{7} \times 3.0 \times 3.0 \times 3.0$$

Volume of the wire = $\pi r^2 l$

$$= \frac{22}{7} \times 0.01 \times 0.01 \times l$$

Therefore, $\frac{22}{7} \times 0.01 \times 0.01 \times l$

$$= \frac{4}{3} \times \frac{22}{7} \times 3.0 \times 3.0 \times 3.0$$

So, $l = \frac{4 \times 3.0 \times 3.0 \times 3.0}{3 \times 0.01 \times 0.01}$

$= 360\ 000$ cm

$= 3\ 600$ m

Example 13

The volume of mercury thread in a capillary tube is 1 cm^3. If the length of the mercury thread is 1 m, calculate the radius of the bore of the capillary tube.

Solution

Volume of mercury = $\pi r^2 h$

$\pi r^2 h = 1 \text{ cm}^3$

$$= \left(\frac{1}{100} \times \frac{1}{100} \times \frac{1}{100}\right) \text{m}^3$$

$= 0.000001 \text{ m}^3$

$$\frac{22}{7} \times r^2 \times 1 \text{ m}^3 = 0.000001 \text{ m}^3$$

$$r^2 = \frac{7 \times 0.000001}{22 \times 1}$$

$$= \frac{0.000007}{22}$$

$= 0.000000318$

$r = 0.000564$ m

Exercise 2.4

1. Determine the volumes of the following items:
   - (a) A glass block from your laboratory.
   - (b) A triangular prism from your laboratory.
   - (c) The volume of a football or a netball.
   - (d) The volume of a cylindrical tin in your school.
2. (a) Obtain some plasticine and mould it to form a sphere. Find the radius of the sphere and calculate its volume.
   - (b) Mould the same plasticine into a cylinder. Determine the volume of the cylinder.
   - (c) Comment on the answers you obtain in (a) and (b) above.

Measurement of Volume of Liquids

Liquids have no definite shape, but assume the shape of the containers in which they are put.

One of the methods which can be used to measure the volume of a liquid is to pour the liquid into a container with a uniform cross-section, as shown in figure 2.9.

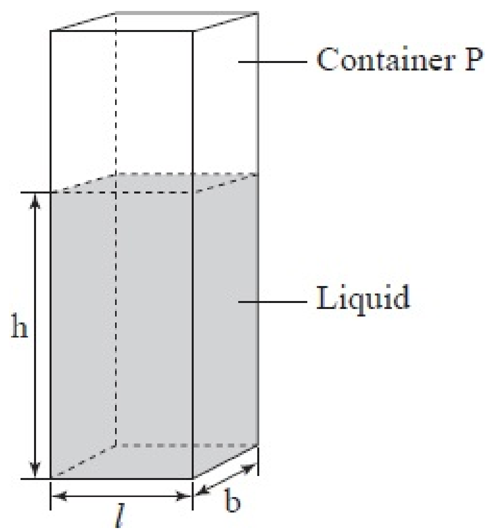


Fig. 2.9: A container with a regular base

The height of the liquid, h, is measured. The volume of the liquid is then obtained by applying the formula;

V = area of cross-section × height

V = Ah, where A = *l* × b and h is the height.

Therefore, V = *l* bh

Experiment 2.4: To investigate the relationship between volume and height

Apparatus

Rectangular container and a cylinder.

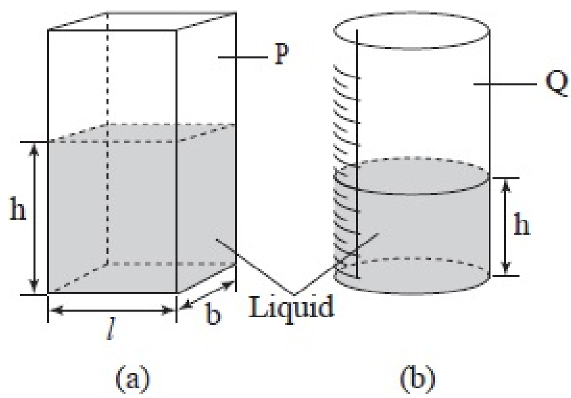


Fig. 2.10: Relationship between volume and height

Procedure

- Take two containers P and Q with rectangular base and cylindrical base respectively. Container Q is calibrated, see figure 2.10 (a) and (b).
- Pour some water into P and find its volume V.
- Transfer the water from P to Q and record the height h of water in Q.
- Repeat the experiment for different values of volume V, and each time record the corresponding value of h as in table 2.5.

Table 2.5

Volume V (cm^3)				
Height h (cm)				
$\frac{v}{h}$ (cm)				

Draw a graph of V against h.

Results and conclusion

The graph of V against h is a straight line, indicating that height increases uniformly with the increase in volume V.

In practice, it is convenient to make measuring vessels in cylindrical form, marked in such a way that volumes can be read off directly.

Measuring devices which are marked off like this are called **measuring cylinders**. They are used to measure the volumes of liquids.

Measuring cylinders are made of glass or transparent plastic and graduated in cm^3 or m*l*. Measuring flasks, pipettes, burettes and beakers [figure 2.11 (a), (b), (c), (d) and (e)] can also be used to measure volumes of liquids. Measuring flasks and pipettes are used to transfer known volumes of liquids. The burette delivers volumes of up to 50 cm^3.

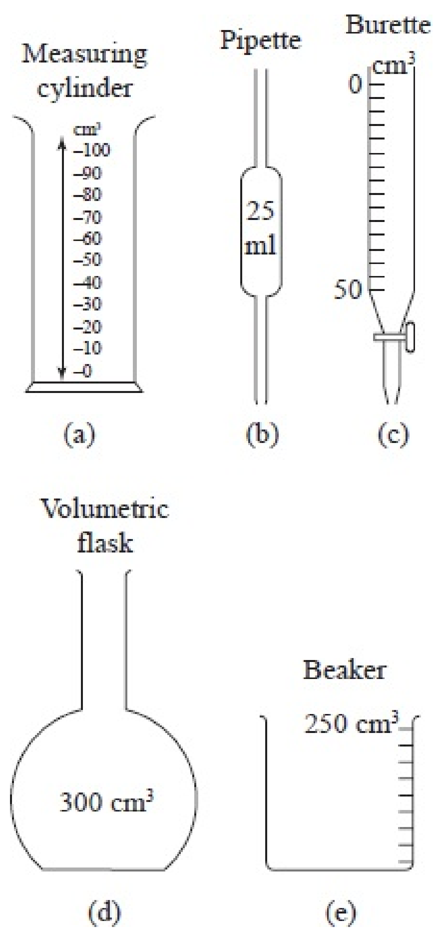


Fig. 2.11: Instruments for measuring volumes of liquids

Note:

(i) The scale of the burette begins from zero at the top and increases downwards to the maximum value. For example, a reading of 31.0 m*l* on the burette means that the volume of the liquid poured from the burette is 31.0 m*l* and the volume left in the burette is (50 – 31) m*l*, i.e., 19.0 m*l*.

(ii) While using the measuring vessels shown in figure 2.11, the reading of volume is taken with the eye positioned level with the bottom of the meniscus, see figure 2.12. In the figure, the volume of the liquid is 24.0 cm^3.

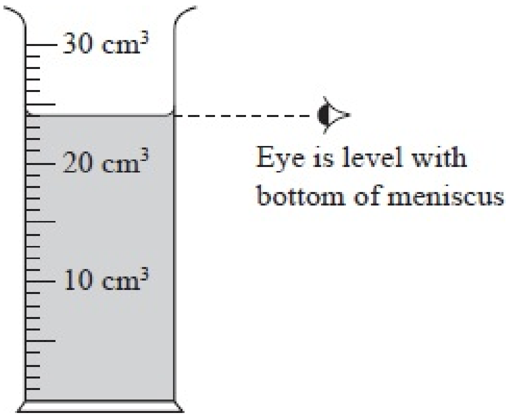


Fig. 2.12: Reading the measuring cylinder

Measuring the Volume of an Irregularly-Shaped Solid

Volumes of irregular solids are measured using the displacement method. The method works with solids that are not soluble in water, do not absorb water, do not react with water or sink in water.

Experiment 2.5: To determine the volume of an irregularly-shaped object

(a) Using a measuring cylinder

Apparatus

Measuring cylinder, stone, thread and Eureka can.

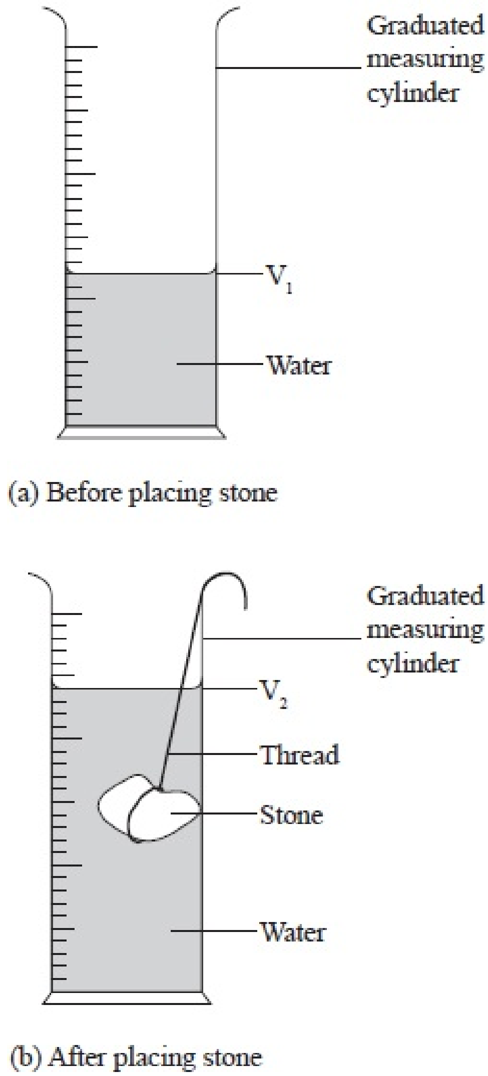


Fig. 2.13: Volume of irregular shapes

Procedure

- Partly fill a measuring cylinder with water. Note the volume V_1 of the water, see figure 2.13 (a).
- Tie a stone (that can be fitted into the measuring cylinder) with a thread and lower it gently into the cylinder until it is wholly submerged. Ensure that there are no air bubbles surrounding the stone.
- Record the new volume V_2.

Result

The volume of the stone

$V = V_2 – V_1$.

(b) Using a Eureka can

A Eureka or displacement can is a container with a spout from the side. It is used to measure volumes by displacement method. It is also known as an overflow can.

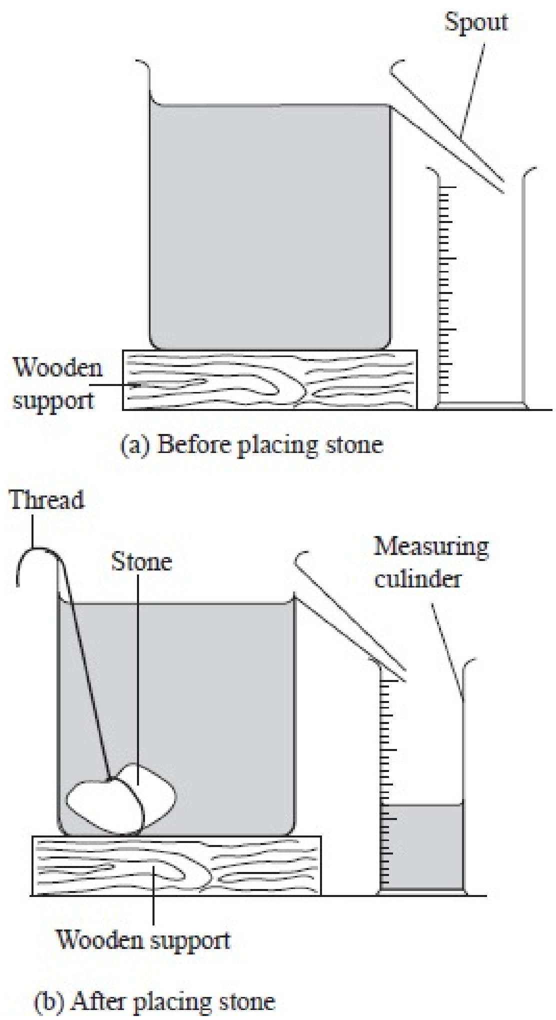


Fig. 2.14: Use of Eureka can for measuring volume

Procedure

- Fill the Eureka can with water until it flows out of the spout, see figure 2.14 (a). Once the flow has stopped, place a measuring cylinder under the spout of the can.
- Tie the solid whose volume you want to determine with a thread and lower it gently into the can until it is completely submerged.

Result

The volume of water collected in the measuring cylinder is the volume of the object.

Experiment 2.6: To determine the volume of an object that floats on water using the displacement can

Apparatus

Eureka can, measuring cylinder, floating object and a sinker (small metal block).

When finding the volume of an object that floats on water, e.g., a cork, another object that sinks in water is attached to it so that both are totally submerged. This object is known as a **sinker**.

- Fill the Eureka can with water and allow excess water to flow out through the spout, see figure 2.15 (a).
- After it has ceased to flow, place a measuring cylinder under the spout.
- Lower the sinker, tied with a thread, gently into the can.
- Measure the volume V_1 of the water that overflows into the measuring cylinder.
- Remove the sinker and tie it to the cork, see figure 2.15 (b).

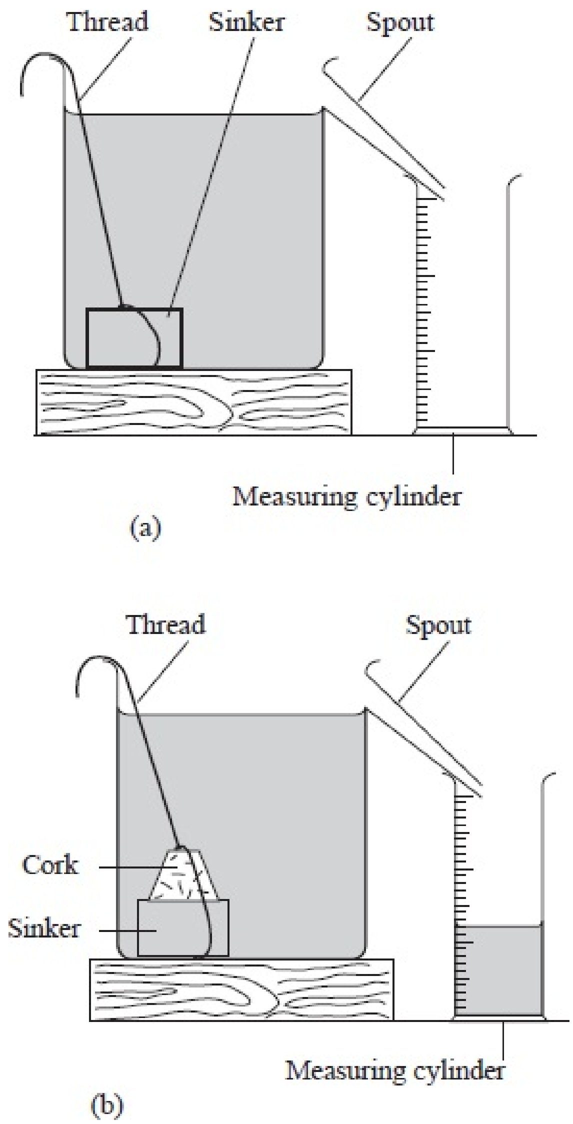


Fig. 2.15: Volume of an object that floats on water

- Fill the Eureka can again and allow excess water to flow out.
- When water ceases to flow from the spout, place a clean dry measuring cylinder under the spout.
- Lower the sinker and cork tied together into the Eureka can gently.
- Measure the volume V_2 that overflows into the measuring cylinder.

Results

The water collected in the measuring cylinder is the volume of sinker and cork. Call it V_2.

Therefore, the volume of the cork

$V = V_2 - V_1$.

Exercise 2.5

1. Describe how you would measure the volume of a cork using a sinker, a thread, a measuring cylinder and water only.
2. Describe how you would calibrate the cylinder Q in figure 2.10.
3. Describe how you would measure 30 cm^3 of a liquid using a burette.
4. Explain why displacement method is unsuitable for determining the volume of solids such as charcoal, ice, wooden blocks and bricks.
5. A wire of radius 3.0 mm and length 200 m is melted into a sphere. Calculate the radius of the sphere in metres.
6. A sphere of radius 10.0 cm is moulded into a uniform cylindrical wire of same radius r. Calculate the length of the wire in millimetres.
7. Convert each of the following volumes to m^3:
   (a) 1 500 000 000 cm^3
   (b) 20.0 *l*
   (c) 1.0 m*l*
   (d) 9 000 000 000 mm^3
   (e) 1 000 000 *l*

Mass

The mass of an object is the quantity of matter in it. Matter is anything that occupies space. The mass of an object depends on its size and the number of particles it contains.

The SI unit of mass is the kilogram (symbol kg). A kilogram is the mass of a piece of metal (platinum-iridium) kept at Sevres, near Paris, in France at the International Office of Weights and Measurements.

The commonly used sub-multiples and multiples of the kilogram are given in the table below.

Table 2.6: Multiples and sub-multiples of the kilogram

Unit	Symbol	Equivalence in kilogram

1 tonne	t	1 000
1 gram	g	0.001
1 milligram	mg	0.000001

The mass of an object is the same everywhere because the number of particles in an object remains constant. An object will have the same mass on the earth as on the moon. For example, an astronaut who has a mass of 90 kg on earth will have the same mass on the moon.

Measurement of Mass

There are two common balances for measuring mass, namely, the electrical and the mechanical types.

Figure 2.16 (a) shows the top pan balance (electrical type). The object whose mass is to be measured is placed on the pan. The mass of the object is read on the display. This type of a balance is very accurate.

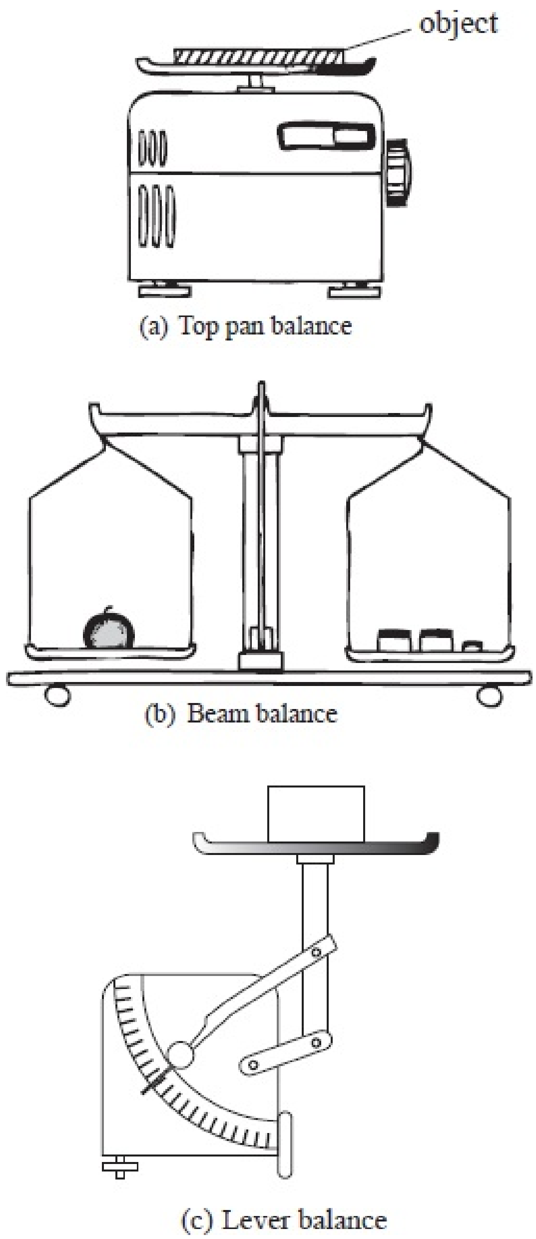


Fig. 2.16: Types of balances

Figure 2.16 (b) shows a simple form of a beam balance (mechanical type). The object whose mass is to be measured is balanced against a known standard mass on an equal arm lever as shown. The beam balances when the mass of the object is equal to the known standard mass.

Figure 2.16 (c) shows a lever balance in which a combination of levers moves the pointer around a scale when the mass is placed on the pan.

Exercise 2.6

1. Define mass and state its SI unit.
2. Convert each of the following as indicated:
   (a) 10 tonnes into kg.
   (b) 200 000 mg into kg.
   (c) 256 000 g into tonnes.
   (d) 0.000342 tonne into mg.
   (e) 1.25 g into mg.

Density

The density of a substance is its mass per unit volume. Its symbol is rho(ρ) and its SI unit is kilogram per cubic metre (kgm^{-3}).

Another commonly used unit is gram per cubic centimetre (gcm^{-3}). From the definition, the density of a substance is given by;

$$\text{Density} = \frac{\text{mass}}{\text{volume}},$$

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

Example 14

The density of water is 1 gcm^{-3}. Express this density in kgm^{-3}.

Solution

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

$$\text{Density of water} = \frac{\text{mass}}{\text{volume}}$$

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

$$1\ \text{cm}^3 = \frac{1}{1\ 000\ 000}\ \text{m}^3$$

$$\text{Density of water} = \frac{\frac{1}{1\ 000}\ \text{kg}}{\frac{1}{1\ 000\ 000}\ \text{m}^3}$$

$$= 1\ 000\ \text{kg/m}^3$$

Example 15

The density of a material is 22.5 gcm^{-3}. Express this in SI units.

Solution

$1\ gcm^{-3} = 1\ 000\ kgm^{-3}$

$22.5\ gcm^{-3} = 22.5 \times 1\ 000\ kgm^{-3}$

$= 22\ 500\ kgm^{-3}$

Example 16

A block of glass of mass 187.5 g is 5.0 cm long, 2.0 cm thick and 7.5 cm high. Calculate the density of the glass in kgm^{-3}.

Solution

$$\text{Density of the block} = \frac{\text{mass}}{\text{volume}}$$

$$\text{Mass} = \frac{187.5}{1\ 000}\ \text{kg}$$

$$\text{Volume} = \frac{5 \times 2 \times 7.5}{1\ 000\ 000}\ \text{m}^3$$

$$\therefore \text{Density} = \frac{187.5 \times 1\ 000\ 000}{5 \times 2 \times 7.5 \times 1\ 000}$$

$$= \frac{187\ 500}{75} = 2\ 500\ \text{kgm}^{-3}$$

Example 17

The density of mercury is 13.6 gcm^{-3}. Find the volume of 2 720 g of mercury in m^3.

Solution

$$\text{Volume of the mercury} = \frac{\text{mass}}{\text{density}}$$

$$= \frac{2\ 720}{13.6}\ \text{cm}^3$$

$$= 200\ \text{cm}^3$$

$$\text{But } 1\ \text{cm}^3 = \frac{1}{1\ 000\ 000}\ \text{m}^3$$

$$\therefore 200\ \text{cm}^3 = \frac{200}{1\ 000\ 000}\ \text{m}^3$$

$$= 0.0002\ \text{m}^3$$

Example 18

The mass of 25 cm^3 of ivory was found to be 0.045 kg. Calculate the density of ivory (in SI units) giving your answer in Kg/m^3.

Solution

$$\text{Volume} = \frac{25}{1\,000\,000}\ m^3$$

$$\text{Mass} = 0.045\ kg$$

$$= \frac{45}{1\,000}\ kg$$

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

$$= \frac{45}{1\,000} \times \frac{1\,000\,000}{25}$$

$$= 1\,800\ kgm^{-3}$$

Example 19

The density of concentrated sulphuric acid is 1.8 gcm^{-3}. Calculate the volume of 3.1 kg of the acid.

Solution

Density = 1.8 gcm^{-3}

Mass = 3 100 g

$$\text{Volume} = \frac{\text{mass}}{\text{density}}$$

$$= \frac{3\,100}{1.8}$$

$$= 1\,722\ cm^3 \text{ or } 0.001722\ m^3$$

Measurement of Density

To Measure the Density of a Solid

The mass and the volume of the object is found by the method described above. The density of the object is then calculated from the formula:

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Table 2.7: Densities of some common substances

Substance	Density	
	gcm^{-3}	kgm^{-3}
Platinum	21.4	21 400
Gold	19.3	19 300
Lead	11.3	11 300
Silver	10.5	10 500
Copper	8.93	8 930
Iron	7.86	7 860
Aluminium	2.7	2 700
Glass	2.5	2 500
Ice	0.92	920
Mercury	13.6	13 600
Sea water	1.03	1 030
Water	1.0	1 000
Kerosene	0.80	800
Alcohol	0.79	790
Carbon dioxide	0.00197	1.97
Air	0.00131	1.31
Hydrogen	0.000089	0.089

Experiment 2.7: To find the density of a liquid

Apparatus

Clean dry beaker, balance, measuring cylinder, a burette or a pipette.

Procedure

- Find the mass m_1 of a clean dry beaker using a balance.
- Measure a known volume V of the liquid using either a measuring cylinder, a burette or a pipette.
- Transfer the liquid into the beaker.
- Find the mass m_2 of the beaker with the liquid.

Result

Mass of the liquid = $m_2 - m_1$

Density of the liquid = $\frac{m_2 - m_1}{V}$

Example 20

A rectangular tank measures 12.5 m long, 10.0 m wide and 2.0 m high. Calculate the mass of water in the tank when it is full. Density of water is 1 000 kgm^{-3}. (Assume the measurements are internal)

Solution

Volume of water in tank = 12.5×10×2

= 250 m^3

Mass = density × volume

= 1 000 × 250

= 250 000 kg

Density Bottle

A density bottle is a small glass bottle fitted with glass stopper which has a hole through which excess liquid can flow out.

Normally, the density bottle has its capacity indicated on the side.

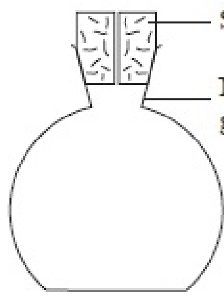


Fig. 2.17: A density bottle

Experiment 2.8: To find the density of a liquid using a density bottle

Measure the mass m_1 of a clean dry density bottle with its stopper.

Fill the bottle with liquid and replace the stopper. Dry the bottle on the outside (excess liquid overflows through the hole in the stopper).

Measure the mass m_2 of the bottle plus the liquid.

If the capacity of the bottle is V, then;

$$\text{Density of liquid} = \frac{m_2 - m_1}{V}$$

Precautions

(i) The bottle is held by the neck when wiping it dry. This is because when held in the hands, it may expand due to body warmth.

(ii) The outside of the bottle must be wiped carefully.

(iii) It must be ensured that there are no air bubbles when the bottle is filled with liquid.

Experiment 2.9: To measure the density of a solid using a density bottle

This method is used for solids in form of grains, beads or turnings.

Apparatus

Density bottle and lead shot, beam balance.

Procedure

- Measure the mass m_1 of a clean dry empty density bottle, see figure 2.18 (a).
- Fill the bottle partly with lead shot and measure the mass m_2.
- Fill up the bottle with water up to the neck and measure its mass m_3, see figure 2.18 (c).
- Empty the bottle and rinse it.
- Fill it with water and replace the stopper. Wipe the outside dry and measure the mass m_4 of the bottle filled with water, see figure 2.18 (d).

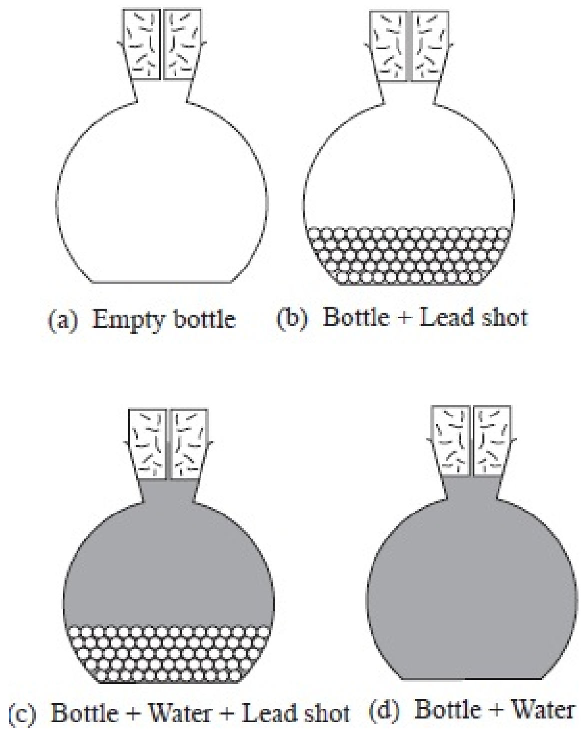


Fig. 2.18: Use of density bottle

Results

Mass of water = $(m_4 – m_1)$ g

Volume of water = $m_4 – m_1$ (since density of water is 1 $gcm^{–3}$)

Therefore, volume of bottle

= $(m_4 – m_1)$ cm^3

Mass of lead shot = $(m_2 – m_1)$ g

Mass of water present when bottle is filled with lead shot and water = $(m_3 – m_2)$ g

Volume of water = $(m_3 – m_2)$ cm^3

Volume of lead shot

= $(m_4 – m_1) – (m_3 – m_2)$

Therefore, density of lead shot

$$= \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$$

It should be noted that this method is unsuitable for solids which are either soluble in water or react with it.

Example 21

The mass of a density bottle is 20 g when empty and 45 g when full of water. When full of mercury, its mass is 360 g. Calculate the density of mercury.

Solution

Mass of water = 45 – 20

= 25 g

Volume of water = 25 cm^3 (density of water is 1 gcm^{-3})

Therefore, volume of bottle = 25 cm^3

Mass of mercury = 360 – 20

= 340 g

Volume of mercury = 25cm^3 (volume of the density bottle)

Density of mercury $= \frac{340}{25}$

= 13.6 gcm^{-3}

= 13 600 kgm^{-3}

Example 22

The mass of an empty density bottle is 20 g. Its mass when filled with water is 40.0 g and 50.0 g when filled with liquid X. Calculate the density of liquid X if the density of water is 1 000 kgm^{-3}.

Solution

Mass of water $= 40.0 - 20.0$ g

$= 20.0$ g

$= 0.02$ kg

Density of water $= 1\ 000$ kgm^{-3}

Therefore, volume of water $= \frac{0.02}{1\ 000}$

$= 0.00002\ m^3$

This is also the volume of the bottle.

Mass of liquid $= 50.0 - 20.0$

$= 30.0$ g

$= 0.03$ kg

Volume of liquid = volume of bottle

$= 0.00002\ m^3$

Therefore, density of liquid $= \frac{0.03}{0.00002}$

$= 1\ 500\ kgm^{-3}$

Densities of Mixtures

A mixture is obtained by putting together two or more substances such that they do not react with one another. The density of the mixture lies between the densities of its constituent substances and depends on their proportions. It is assumed that the volume of the mixture is equal to the sum of the volumes of the individual constituents.

Density of the mixture

$$= \frac{\text{mass of the mixture}}{\text{volume of the mixture}}$$

Example 23

100 cm^3 of fresh water of density 1 000 kgm^{-3} is mixed with 100 cm^3 of sea water of density 1 030 kgm^{-3}. Calculate the density of the mixture.

Solution

Mass of fresh water = density × volume

$$= 1\,000\ \frac{\text{kg}}{\text{m}^3} \times \frac{100}{1\,000\,000}\ \text{m}^3$$

$$= 0.1\ \text{kg}$$

Mass of sea water

$$= 1\,030\ \frac{\text{kg}}{\text{m}^3} \times \frac{100}{1\,000\,000}\ \text{m}^3$$

$$= 0.103\ \text{kg}$$

Mass of the mixture = mass of fresh water + mass of sea water

= (0.1 + 0.103) kg

= 0.203 kg

Volume of mixture = volume of fresh water + volume of sea water

= 100 cm^3 + 100 cm^3

= 200 cm^3

$$= \frac{200}{1\,000\,000}\ \text{m}^3$$

Therefore, density of mixture

$$= \frac{\text{mass of mixture}}{\text{volume of mixture}}$$

$$= \frac{0.203 \times 1\,000\,000}{200}$$

$$= \frac{2030}{2}\ \text{kgm}^{-3}$$

$$= 1\,015\ \text{kgm}^{-3}$$

Example 24

Bronze is made by mixing molten copper and tin. If 100 kg of the mixture contains 80% by mass of copper and 20% by mass of tin, calculate the density of bronze. (Density of copper is 8 900 kgm^{-3} and density of tin 7 000 kgm^{-3})

Solution

Mass of copper in the mixture

$= 100 \times 80\%$

$= 80$ kg

Mass of tin in the mixture $= 100 \times 20\%$

$= 20$ kg

Volume of copper

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

$$= \frac{80}{8\,900}$$

$= 0.00899\ m^3$

$$\text{Volume of tin} = \frac{\text{mass of tin}}{\text{density of tin}}$$

$$= \frac{20}{7\,000}$$

$= 0.00286\ m^3$

Volume of bronze = volume of copper + volume of tin

$= (0.00899 + 0.00286)\ m^3$

$= 0.01185\ m^3$

$$\text{Density of bronze} = \frac{\text{mass of bronze}}{\text{volume of bronze}}$$

$$= \frac{80 + 20}{0.01185}$$

$$= \frac{100}{0.01185}$$

$= 8\,439\ kgm^{-3}$

Exercise 2.7

1. Explain how you would determine the density of solid common salt.
2. Fill the following table:

Substance	Mass	Volume	Density
Gold	9.6 g	0.5 cm^3	___
Copper	___	5 cm^3	8.9 gcm^{-3}
Air	0.0006 g	0.5 cm^3	___
Lead	___	1.5 cm^3	11.29 gcm^{-3}
Glycerine	10 g	___	1.26 gcm^{-3}
Alcohol	1 000 g	___	0.8 gcm^{-3}
Water	220 kg	___	1.0 gcm^{-3}
Mercury	0.068 kg	___	13.6 gcm^{-3}

3. A density bottle has a mass of 17.5 g when empty. When full of water, its mass is 37.5 g. When full of liquid X, its mass is 35 g. If the density of water is 1 000 kgm^{-3}, find the density of liquid X.
4. Describe the experiment to find the density of air.

Time

Time is a measure of duration of an event. Some ancient time-measuring instruments were the sundial and the hourglass.

In modern measurement of time, it has been found necessary to obtain reference of time from an atomic clock.

The SI unit to time is second(s). Multiple and sub-multiple units of the second are shown in table 2.8.

Table 2.8: Multiple and sub-multiple units of the second

Time	Symbol	Equivalent Seconds
Microsecond	µs	0.000001
Millisecond	ms	0.001
Minute	min	60
Hour	hr	3 600
Day	day	86 400
Week	wk	604 800

Measurement of Time

In laboratories, intervals of time are measured using either a stopwatch or stop-clock, depending on the accuracy required.

Modern stopwatches are digital. They are preferred due to their ease of handling and reading. Stop-clocks are used when high precision is not required.

Fig. 2.18: Digital stopwatch

Activity

Time some activities in your school using a stopwatch and stop-clock.

Revision Exercise 2

1. Outline how you would measure the circumference of a beaker and test-tube using a thread.
2. Describe how you would measure the diameter of a tennis ball.
3. Define mass and show how it can be measured.
4. The mass of a lump of gold remains constant wherever it may be shifted to. Explain.
5. A length 550 cm of thin thread wraps around a cylinder exactly 25 times. Calculate the circumference and the radius of the cylinder. $\left(\text{Take } \pi = \frac{22}{7}\right)$
6. The water level in a burette is 30 cm^3. If 55 drops of water fall from the burette and the average volume of one drop is 0.12 cm^3, what is the final water level in the burette?
7. Convert the following:
    (a) 1 000 kg into g.
    (b) 1 000 000 m into km.
    (c) 0.0000037 kg to mg.
    (d) 0.00000125 m to mm.

8. If a ream of 500 papers weighs 2.5 kg, find the mass of single sheet in:
   (a) kg.
   (b) mg.
9. Water has a density of 1 000 kgm^{-3}. What does this mean? What is its density in gcm^{-3}?
10. In finding the density of liquid, why is the method of using a density bottle more accurate than the one of using a measuring cylinder?
11. What mass of lead has the same volume as 1 600 kg of alcohol? (Use the values of densities given in table 2.7)
12. An empty density bottle has a mass of 25 g. Its mass is 50 g when full of water and 45 g when full of another liquid. What is the density of the liquid in kgm^{-3}?
13. Describe an experiment to find the density of copper turnings using a density bottle and kerosene.
14. The mass of a density bottle is 20.0 g when empty, 70.0 g when full of water and 55.0 g when full of a second liquid. Calculate the density of the liquid.
15. The mass of a density bottle of volume 50 cm^3 is 10.0 g when empty. Aluminium turnings are poured into the bottle and the total mass is 60.0 g. Water is then added into the turnings till the bottle is full. If the total mass of the bottle and its contents is 90.0 g, calculate the density of the aluminium turnings.
16. 1 800 cm^3 of fresh water of density 1000 kgm^{-3} is mixed with 2 200 kgm^{-3} of sea water of density 1 025 kgm^{-3}. Calculate the density of the mixture.

Chapter 3 Force

You may have observed a person kicking a ball in the field or a group of people participating in a tug of war. You may also have seen a mason lifting a stone at a construction site or people pushing a car stuck in mud. These activities, some of which are shown in figure 3.1, involve either pushing or pulling.

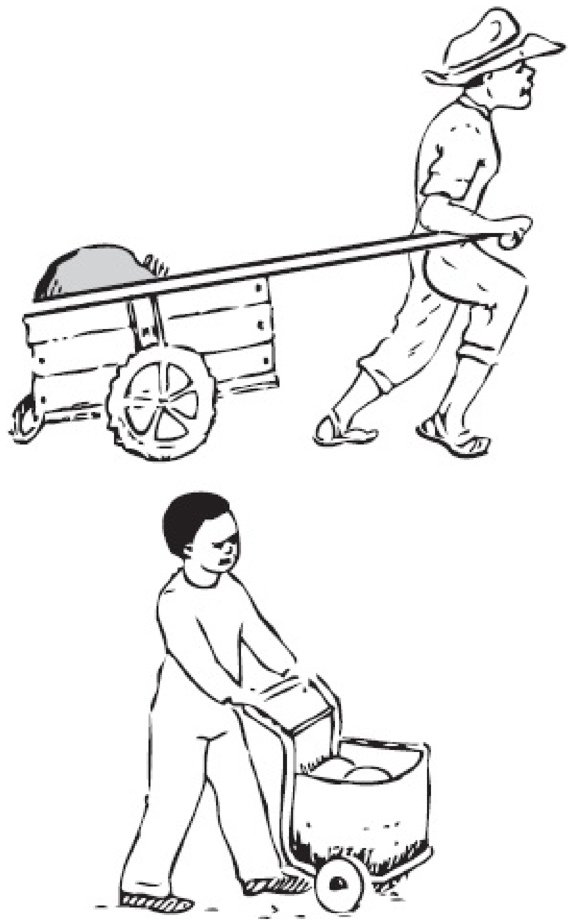


Fig. 3.1: Pull and push

A force is a push or pull. The SI unit of force is the newton (N). A force acts in a particular direction and may have any of the following effects on an object:

(i) Make a stationary object start moving or increase the speed of a moving object.

(ii) Slow down or stop a moving object.

(iii) Change the direction of a moving object.

(iv) Distort (change the shape of) an object.

Force is, therefore, that which changes a body's state of motion or shape. Some forces are small while others are large. Forces, therefore, have size (magnitude).

A force is represented by a line with an arrow showing the direction in which it acts, thus:

Types of Forces

There are many types of forces some of which are listed below:

- Gravitational force.
- Tension.
- Upthrust force.
- Frictional force.
- Magnetic force.
- Centripetal force.
- Cohesive and adhesive forces.
- Surface tension.
- Molecular force.
- Electric force.
- Nuclear force.
- Electrostatic force.

Gravitational Force

This is the force of attraction between two bodies of given masses (m_1 and m_2), see figure 3.2.

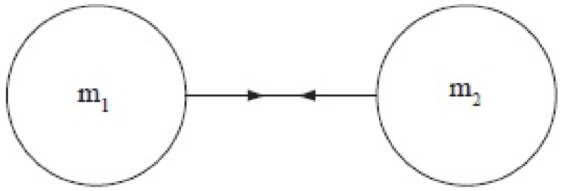


Fig. 3.2: Force of attraction between two bodies

When two objects are thrown up from or near the earth's surface, they always fall downwards towards the ground. This is because of the force of attraction which the earth exerts on any body near its surface. This force which pulls the body towards the centre of the earth is called the **gravitational force** of the earth.

An object near or on the surface of the moon also experiences the gravitational force of the moon. Each planet exerts its own gravitational pull on an object on it.

On the earth's surface, gravitational force is the force of attraction between a body and the earth. The pull of gravity on the body towards the centre of the earth is called **weight**. The weight of an object varies on different planets because planets have different gravitational pull.

Tension

Tension is the quantity of the pulling force exerted by a string, spring or cable on an object. Some materials can withstand greater tension than others. Steel can withstand very high tension and is difficult to break. Similarly, nylon can withstand more tension than cotton. Tension is as a result of two opposing forces applied, one at each end of a body, see figure 3.3.

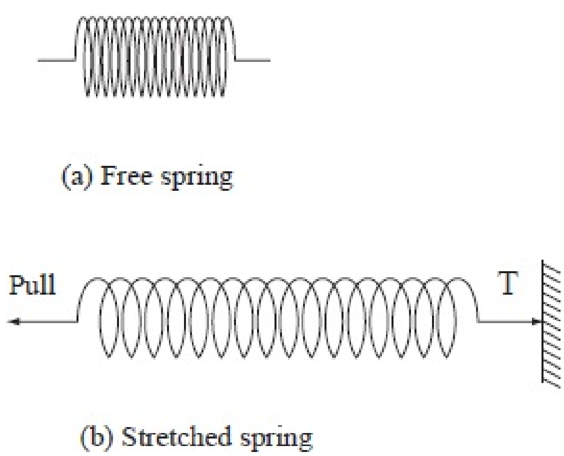


Fig. 3.3: Tension on a spring

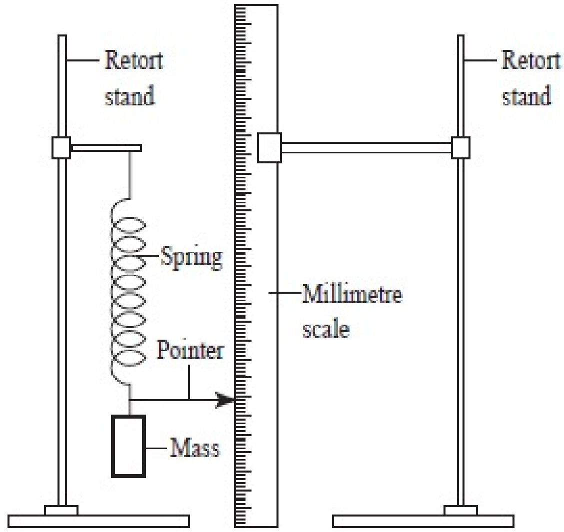


Fig. 3.4: A loaded steel spring

Experiment 3.1: To study the relationship between mass and extension of a spring

Apparatus

Spring with a pointer, metre rule, two retort stands and six 50 g masses.

Procedure

- Set up the apparatus as shown in figure 3.4.
- Record the position of the pointer when there is no mass.
  P_0 =____________cm
- Add 50 g masses, one at a time, and record the position of the pointer P every time a 50 g mass is added. Do not overstretch the spring.
- Obtain the extension, e = P – P_0.
- Record the results as in table 3.1.

Table 3.1

Mass added (g)	Pointer position (cm) when loading	Extension
0 50 100 250 200		

250 300		

What happens to the spring each time a load is added?

- Draw a graph of extension (y-axis) against mass added (x-axis).

Conclusion

The length of a spring increases when loaded since the weight of the load acts on the spring, forcing it to stretch. The graph of extension against mass is a straight line, see figure 3.5.

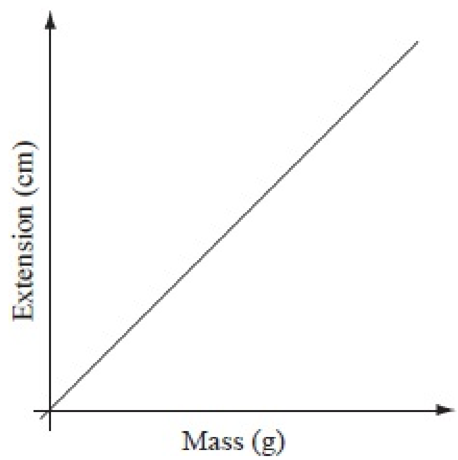


Fig. 3.5

Stretch resulting from tension is made using bows and catapults as shown in figure 3.6.

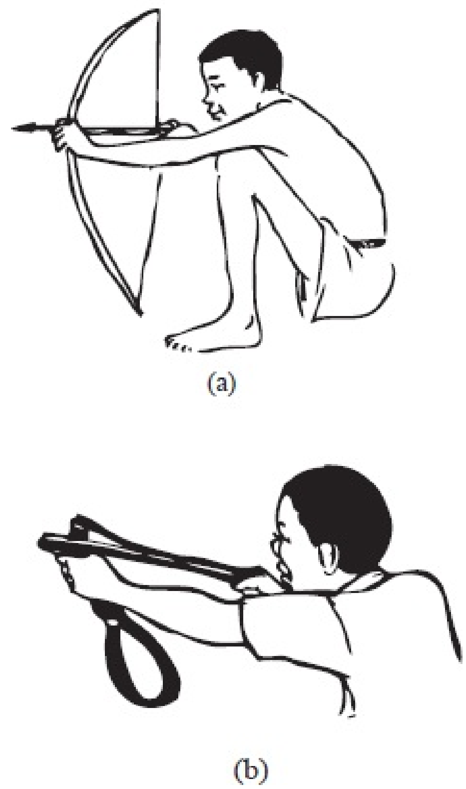


Fig. 3.6: Application of stretching forces

Some forces compress bodies and are called **compressive forces**. A compressed or stretched object will tend to regain its original shape when the stretching or compressing force is removed. Materials that can be compressed or extended without breaking are called **elastic** materials.

Upthrust

There is always an upward force acting on an object immersed in a fluid (liquid or gas). This upward force is called **upthrust**. An object in a vacuum will not experience upthrust.

Experiment 3.2: To illustrate upthrust in liquids

Apparatus

Spring balance, metal cube, water, paraffin, beaker.

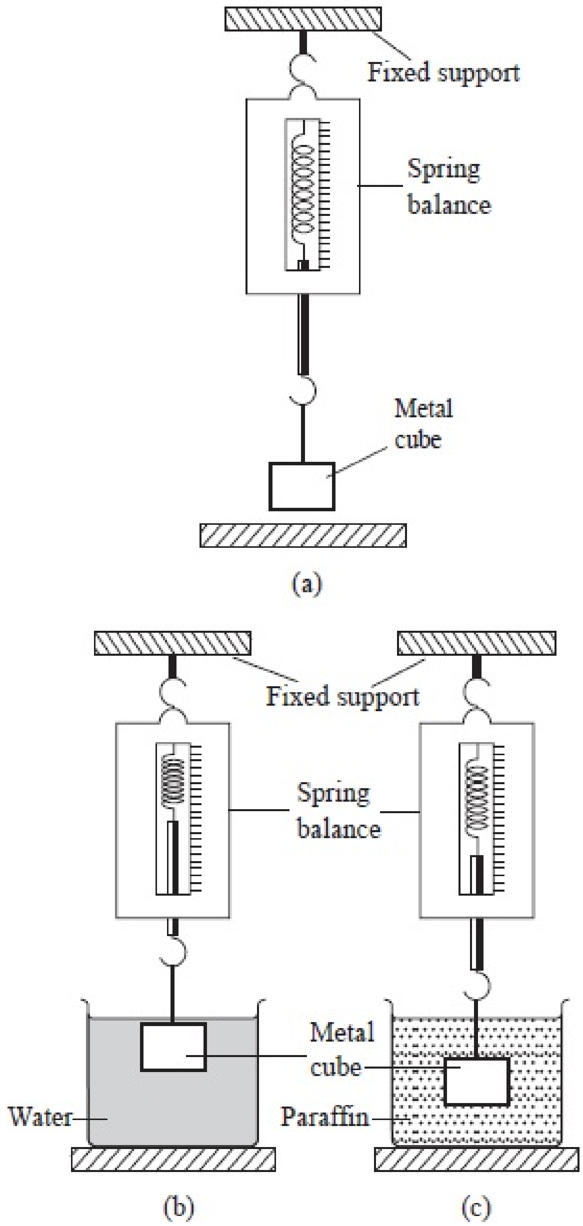


Fig. 3.7: Upthrust in liquids

Procedure

- Set up the apparatus as shown in figure 3.7 (a). Record the reading of the spring balance.
- Lower the metal cube into the beaker of water as in figure 3.7 (b) and record the reading on the spring balance.
- Remove the metal cube from the water and dry it. Repeat with paraffin and other liquids.

- Compare the readings.

Explanation

The reading of the spring balance is determined by the medium in which the object is. If the medium is air, the reading is larger than when the medium is a liquid. The reading also varies from one liquid to another. The reading of the balance is highest when the object is in air and lowest when the object is completely submerged in water.

The difference in the readings when the object is immersed in liquid and when the object is in air is due to upthrust force.

Example 1

A body weighs 100 N in air and 80 N when submerged in water. Calculate the upthrust acting on the body.

Solution

Weight in air = 100 N

Weight in water = 80 N

Upthrust = weight in air – weight in water

= (100 – 80) N

= 20 N

Cohesive and Adhesive Forces

The force of attraction between molecules of the same kind is known as **cohesive force**, e.g., between a water molecule and another water molecule, while force of attraction between molecules of different kinds is called **adhesive forces**, e.g., between water molecules and glass molecules.

Experiment 3.3: To investigate the behaviour of water on different surfaces

Apparatus

Clean glass slide, waxed glass slide, dropper, water.

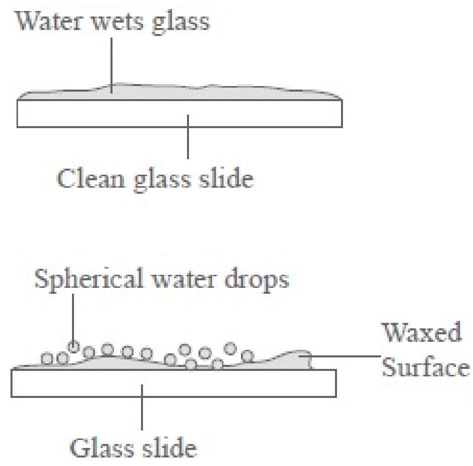


Fig. 3.8: Water drops on glass slides

Procedure

- Using a dropper, place a few drops of water onto a clean glass slide.
- Similarly, place a few drops of water on the waxed glass slide.
- Observe the shapes of the drops on the glass slides. What do you notice?

Observation

Water on the clean glass slide spreads on the glass surface (wets the surface). However, small drops of water collect into small spherical balls on the waxed surface.

If mercury is used, small mercury drops in a clean glass dish surface collect into spherical balls. Larger mercury drops form oval balls as in figure 3.9.

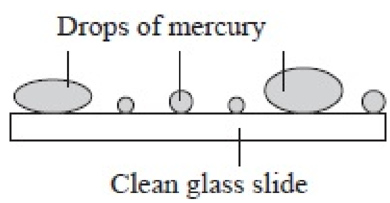


Fig. 3.9: Mercury drops on a glass slide

Note:

Mercury is poisonous and should not be handled in an ordinary laboratory.

Explanation

Water wets the glass surface because the adhesive forces between the water molecules and the glass molecules are greater than the cohesive forces between water molecules. Water does not wet the waxed glass surface because the cohesive force is greater than the adhesive force. The stronger cohesive forces in mercury form spherical drops of mercury even on clean glass surface. The weak adhesive force between mercury and glass makes mercury not to wet the glass.

Experiment 3.4: To demonstrate cohesive and adhesive forces of liquids in narrow tubes

Apparatus

Narrow tubes with different sizes of bore, beaker, water, glycerol, kerosene and methylated spirit.

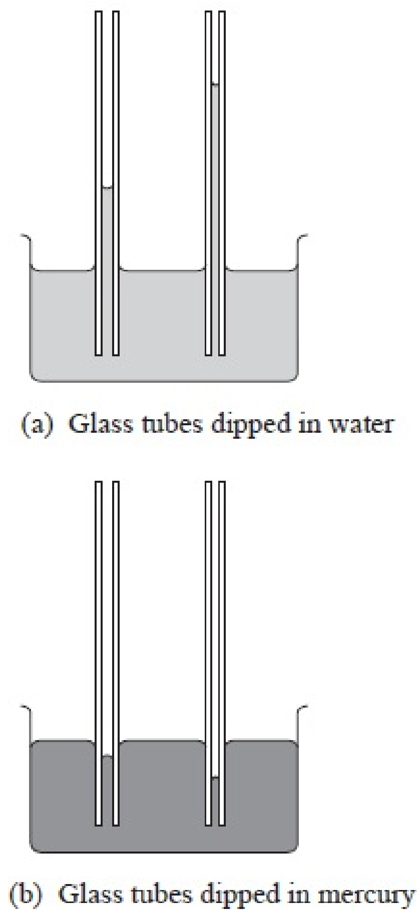


Fig. 3.10: Cohesion and adhesion in mercury and water

Procedure

- Dip the length of clean narrow tube into water.
- Look at the shape of water inside the narrow tube.

- Compare the water level inside the tube with that outside it.
- Try another narrow tube with a different bore, i.e., a different diameter, see figure 3.10.
- Repeat the experiment with other liquids, e.g., glycerol, kerosene or methylated spirit.

Observation

The level of water inside the tubes is higher than outside the tubes.

A meniscus is formed at top of water level. The water curves upwards from the reading level (a concave meniscus). The rise in the tube with a smaller bore is higher than in the tube with a larger bore.

Different liquids rise by different heights, depending on the diameter of the glass tube. If mercury is used, the level of mercury inside the tubes goes lower than that outside the tubes. The surface of the mercury in the tubes will curve downwards, i.e., the meniscus curves downwards from the reading level (a convex meniscus).

The level of mercury in the tube with the smaller bore will be lower than that in the tube with a larger bore.

Explanation

Since the adhesive force between the water and glass molecules is greater than the cohesive force between the water molecules, the water rises up the tube so that more water molecules can be in contact with the glass. This 'wets' the glass. Liquids such as glycerol, kerosene and methylated spirit wet the glass (or the vessel) and will rise in a narrow tube.

On the other hand, the force of cohesion within the mercury is greater than the force of adhesion between the mercury and glass. The mercury, therefore, sinks down the tube to enable mercury molecules to keep together. Liquids which do not 'wet' the container will be depressed inside the tube.

Frictional Force

Friction is a force that opposes relative motion between two surfaces in contact. Practical applications of friction in our daily lives include walking and braking.

Friction is caused by the interlocking of the surfaces and attractive force between the surface molecules.

Experiment 3.5: To investigate frictional force

Apparatus

Wooden block, spring balance, rollers.

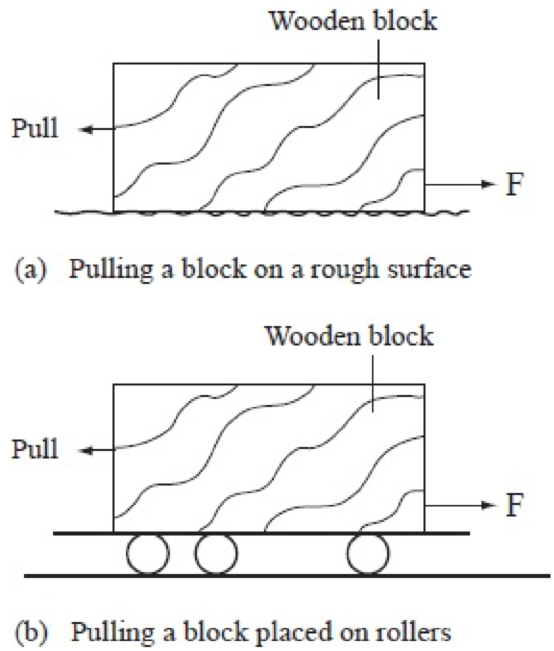


Fig. 3.11

Procedure

- Place a wooden block on a horizontal surface, such as a bench.
- Using a spring balance, pull the block gently as shown in the figure 3.11 (a), gradually increasing the force. What finally happens to the block?
- Repeat the experiment, this time with the block resting on rollers as shown in figure 3.11 (b). In which case do you require less force for the block to start moving? How else, apart from using rollers, can you reduce the force needed to make the block start moving?

Conclusion

In figure 3.11 (a), the wooden block starts moving when the applied force is just greater than a frictional force between the block and the surface of the bench. Frictional force can be reduced by using rollers, oiling or smoothening.

Experiment 3.6: To investigate friction in liquids

Apparatus

Two measuring cylinders, two ball bearings, water, glycerine.

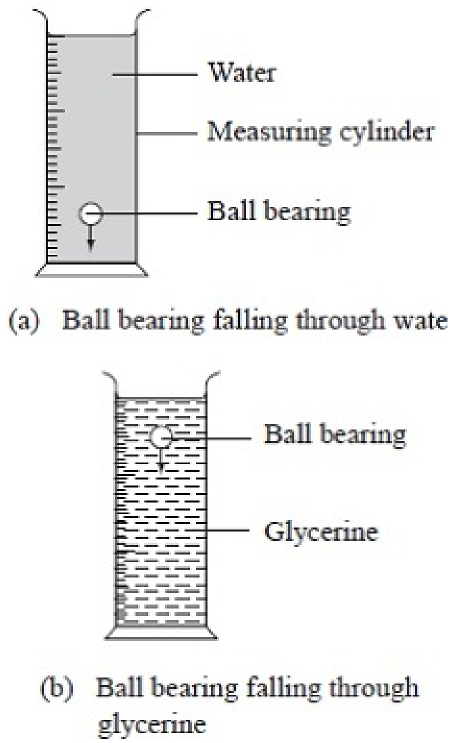


Fig. 3.12: Frictional force in liquids

Procedure

- Fill two glass jars or measuring cylinders, one with water and the other with glycerine, to the same level.
- Hold two small identical ball bearings, just above the jar.
- Release them at the same time and observe their motion through the liquids, see figure 3.12. Which ball bearing reaches the bottom of the jar first?

Conclusion

When the ball bearing is introduced into the liquid, a layer of the liquid forms on the surface of the bearing. As it moves through the liquid, it rubs against the liquid molecules. Due to the movement of the body, there is an opposing force between the layer of the liquid molecules on the body and the layer of the liquid molecules in the measuring cylinder. The opposing force (frictional force) involving a fluid is called **viscous drag** (**viscosity**). Viscous drag limits the speed with which a body can move in a liquid.

Magnetic Force

The force which causes attraction or repulsion by a magnet is called **magnetic**

force. A magnet has two types of poles, a north pole and a south pole. Like poles repel while unlike poles attract. Some materials are attracted by a magnet while others are not. Those which are attracted are called **magnetic** materials while those not attracted are called **non-magnetic** materials.

Experiment 3.7: To investigate magnetic force

Apparatus

Two pieces of magnet, string, iron bar, iron fillings.

Procedure

- Suspend a bar magnet as shown in figure 3.13.

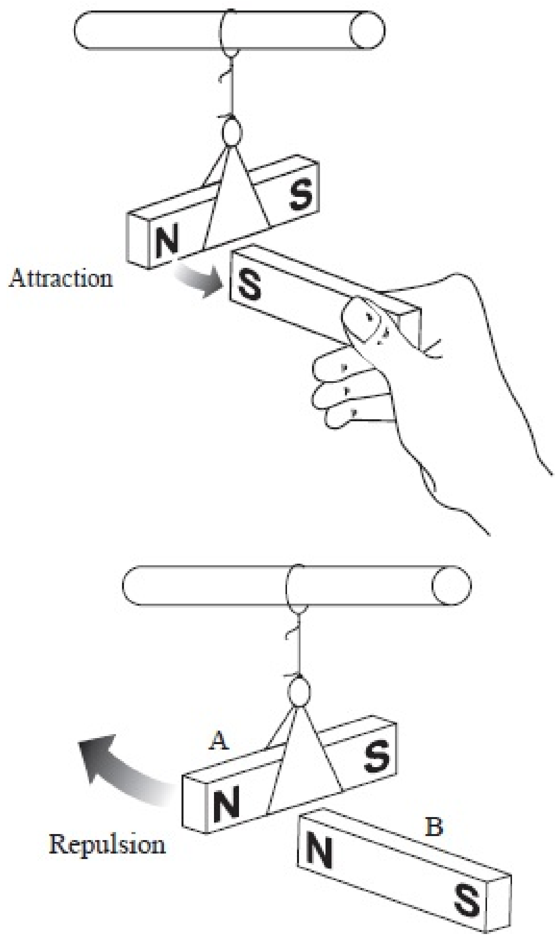


Fig. 3.13 (a): Attraction and repulsion forces of a magnet

- Bring one end of another magnet near the poles of the suspended magnet in turns. Observe what happens in both cases.
- Bring the unsuspended magnet near an iron bar or iron fillings and observe

again what happens.

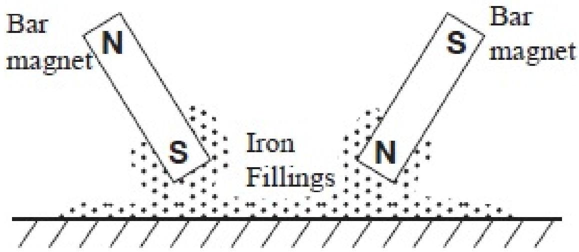


Fig. 3.13 (b): Iron fillings concentrate more at the ends of a bar magnet

Observation

There is attraction on one end and repulsion on the other. The iron fillings or iron bar are attracted by magnetic force.

Electrostatic Force

A plastic pen or ruler rubbed on dry hair or fur picks up small pieces of paper lying on a table when it is brought near them. The same pen or ruler attracts a thin stream of water from a tap.

The rubbing creates static charges. The force of attraction or repulsion due to these changes is called **electrostatic force**.

When a glass window is wiped with a dry cloth on a dry day, dust particles are attracted on it. Also, when shoes are brushed, they tend to attract dust particles. This is because electrostatic charges formed on the rubbed surface attract dust.

Centripetal Force

Centripetal Force is a force which constrains a body to move in a circular path or orbit. This force is directed towards the centre of the orbit. Examples of where centripetal forces is applied include a stone tied on a string (sling), separation of ghee from milk and the merry-go-round, see figure 3.14.

Fig. 3.14: Children enjoying a merry-go-round

Surface Tension

It is commonly observed that liquids form drops, water wets some surfaces but runs off others, some insects like the pond skater manage to rest on the surface of the water without sinking, water rises up a narrow glass tube but mercury is pushed down to a lower level in the same tube and a steel razor blade floats on water, even though steel is denser than water.

The above observations will be explained by the following experiment.

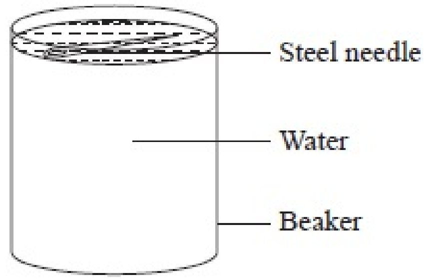
Experiment 3.8: To investigate the behaviour of a liquid surface

Apparatus

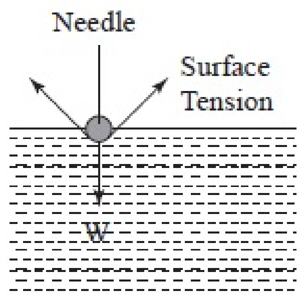
Beaker, steel needle or razor blade, water, kerosene or soap solution.

Procedure

- Fill a beaker with clean water to the brim.



(a) Steel needle floating on water



(b) Section through the needle

Fig. 3.15: Surface tension

- Place a dry steel needle or razor blade at the edge of the beaker and carefully introduce it on the surface of the water. Take care not to break the surface of the water. Observe what happens to the needle.
- Put a few drops of kerosene or soap solution on the surface of the water near the needle (not directly on the needle). Note what happens.
- Depress the tip of the needle into the water and note what happens.

Observation

The needle floats on the surface of the water and remains floating so long as the water surface is not broken, see figure 3.15. When the surface of the water where the needle lies is observed carefully (a magnifying lens would help), the water surface is found to be slightly depressed and stretched like an elastic skin.

When drops of paraffin or soap solution are put on the surface of the water around the needle, the needle sinks on its own after a few seconds. If, alternatively, the tip of the needle is depressed lightly into the water, the needle sinks very quickly to the bottom of the water.

Explanation

The steel needle or the razor blade floats because the surface of the water behaves like a fully stretched, thin, elastic skin. This skin always has a tendency to shrink, i.e., to have a minimum surface area or elastic membrane. The force which causes the surface of a liquid to behave like a stretched elastic skin is called **surface tension**. This force is due to the force of attraction between individual molecules of the liquid (cohesion).

The needle or the blade sinks when a drop of kerosene or soap solution is put in the liquid near the needle because the kerosene or soap solution reduces the surface tension of the water. When the tip of the needle is pressed into the water, it pierces the surface skin and sinks.

Molecular Explanation of Surface Tension

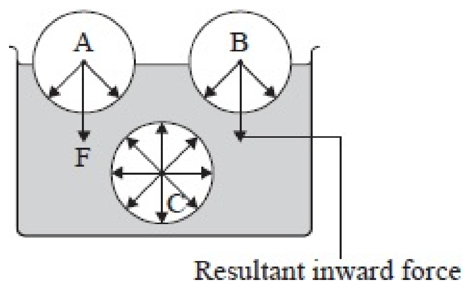


Fig. 3.16: Molecular force in liquid

A molecule, say C, deep in the liquid is surrounded by molecules on all sides so that the net force on it is zero. However, molecules of the surface, say A and B, will have fewer molecules on the vapour side and hence will experience a resultant inward force, causing the surface of the liquid to be in tension.

Experiment 3.9: To study the behaviour of soap bubbles

Apparatus

Glass funnel, soap or detergent solution.

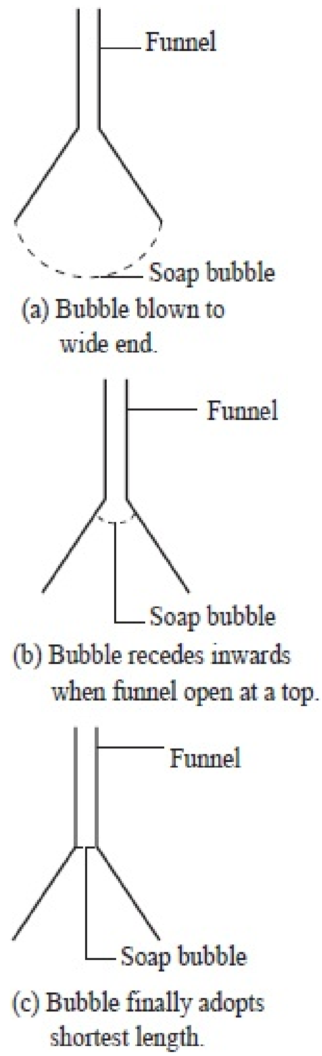


Fig. 3.17

Procedure

- Take a glass funnel and dip it in liquid soap or detergent solution.
- Take it out and blow a soap bubble to the wide end, see figure 3.17 (a).
- Hold the funnel with the bubble downward and leave the top open. Observe what happens.

Observation

The bubble flattens to a film and the film slowly rises up the funnel.

Explanation

The soap bubble behaves as if its surface is tightly stretched. As it tries to make its surface as small as possible, it rises up the funnel.

Experiment 3.10: To study the behaviour of soap films

Apparatus

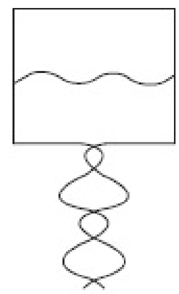
Copper wire, thread, soap solution and needle.

Procedure

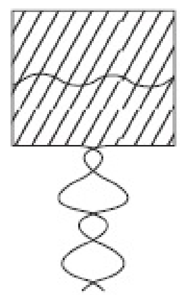
- Make a rectangular loop of copper wire.
- Tie a thread loosely across it, as in figure 3.18 (a).
- Dip the loop in a soap solution and bring it out so that the loop is filled with a soap film, see figure 3.18 (b).
- Break the soap film on one side of the thread by touching it with a hot needle.
- Note the new shape of the thread.

Observation

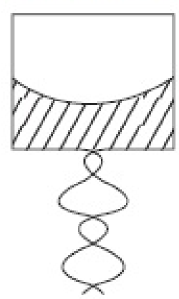
When the film is broken on one side, the thread assumes a perfect curve, see figure 3.18 (c).



(a) Wire loop with thread loosely tied across it.



(b) Wire loop filled with soap film.



(c) Wire loop filled with soap film punctured at one side of the thread.

Fig. 3.18

Explanation

In figure 3.18 (b), the thread lies in any position in the soap film because the thread is being pulled on both sides by equal forces of surface tension. However, when one side of the film is broken, the surface tension acts only on one side of the thread. As the water tries to make its surface as small as possible, it pulls the thread in such a way that it forms a perfect curve. The soap film exhibits surface tension.

Experiment 3.11: To examine the appearance of water drops coming out of a tube

Apparatus

Burette, clamp, stand.

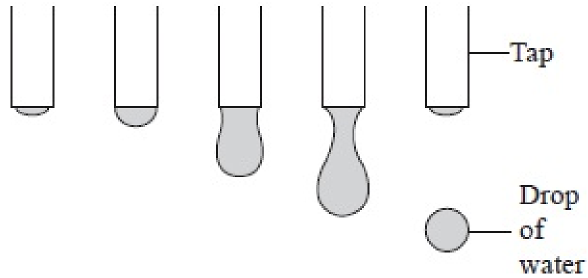


Fig. 3.19

Procedure

- Fill a burette with water.
- Clamp it on a stand and turn the tap slowly so that a drop of water forms on its mouth. Observe how each drop grows and eventually drops.

Observation

The growth of the water drop appears as if the mouth of the burette is covered with an elastic membrane which stretches as more and more water gets into it. When it can hold no more water, it falls.

The following observations are also due to surface tension of water:

(i) A glass tumbler can be filled with water above the brim, see figure 3.20 (a).

(ii) When a soft brush such as an artists brush is placed in water, the bristles spread out but when it is taken out, they cling together, see figure 3.20 (b).

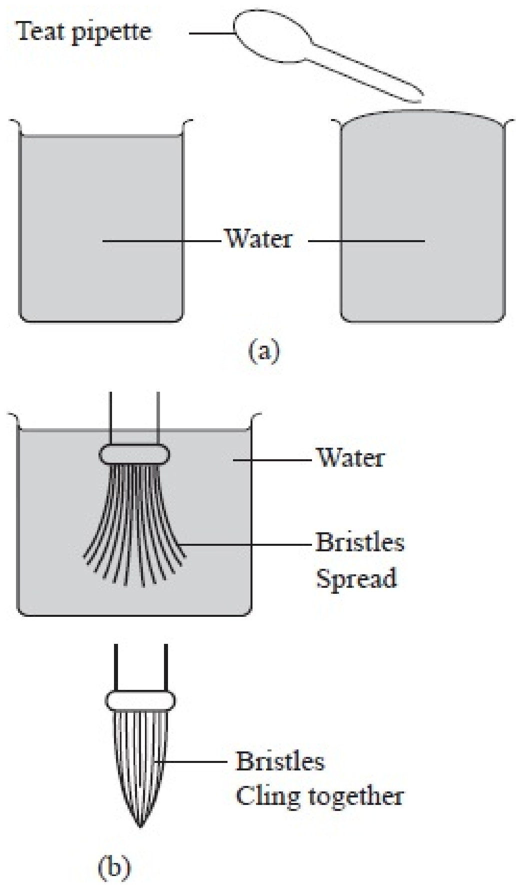


Fig. 3.20: Effects of surface tension

Surface Tension of Different Liquids

The difference in surface tension of different liquids can be visualised in the following demonstrations.

The surface tension of soap is less than that of water

A match stick or a small toy boat rubbed at one end with soap and placed on the surface of water starts moving immediately. It moves in one direction only and in such a way that the end that is not rubbed with soap is always in front. Any attempt to make it move in the opposite direction will fail, see figure 3.21 (a).

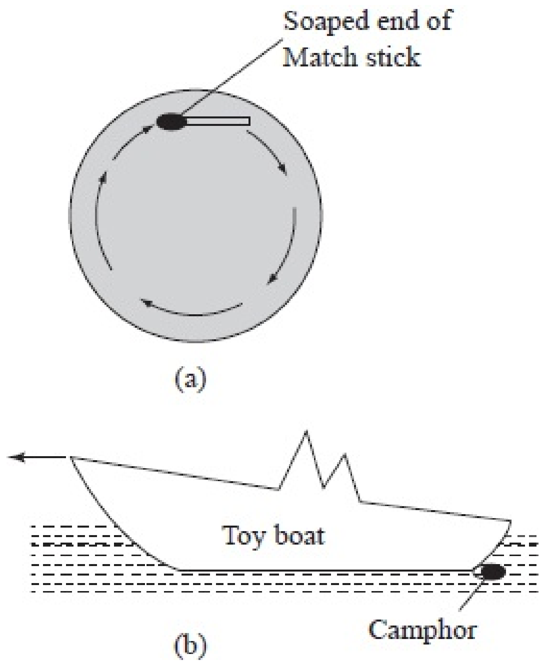


Fig. 3.21: Effects of surface tension

Explanation

The soap at the end of the stick immediately dissolves in water, thereby lowering the surface tension at the end of the stick. The surface tension at the other end which is now greater pulls the stick and makes it move in that direction. The movement gradually weakens and ultimately ceases. This happens when the whole surface of water is covered with soap solution.

The camphor has the same effect as that of soap.

Oil Spreads on Water

A few drops of oil from a fine tube form a circular patch when they fall on a clean water surface.

Explanation

The forces along the surface of oil are weaker than those of the water surface. The oil is thus pulled outwards into a thin film.

Factors Affecting Surface Tension

1. *Impurities*

   Impurities reduce the surface tension of a liquid. Detergents, for instance, weaken the cohesive forces between liquid molecules.

2. *Temperature*

   With rise in temperature, the kinetic energy of the molecules of a liquid is increased. The inter-molecular distance increases and the force of cohesion is decreased. Hence, the surface tension is lowered.

Consequences of Surface Tension

1. Water insects can rest on the surface of water without breaking the surface. The insects also skate across the surface of water at high speed.
2. Mosquito larvae float on water surface. Oiling the water surface using kerosene lowers surface tension, thus making the larvae sink. Oiling still water, therefore, controls the breeding of mosquitoes.

Action and Reaction

Examine carefully the following cases in which forces are applied:

1. When a block of wood is placed on a table, its weight (action) acts on the table. It is pressed on the surface downwards. The reaction (force in the opposite direction) of the table acts on the block, see figure 3.22 (a).
2. When you hold a hose-pipe which is projecting a powerful jet of water, you notice that there is a steady force of reaction from the jet. This is the force which is harnessed in some garden sprinklers, see figure 3.22 (b).

In both cases, there are two forces acting in opposite directions.

One of the forces is called **action** and the other **reaction**. Action and reaction are equal and opposite, i.e., when one force acts on a body, an equal and opposite force acts on the body.

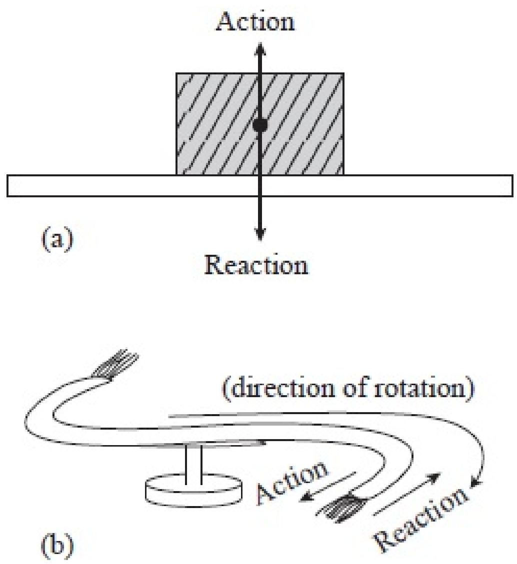


Fig. 3.22: Action and reaction

Exercise 3.1

Table 3.2 shows types of forces and the nature of work to be done. Match the type of force with the type of work it can do.

Table 3.2

Work to be done	*Type of force*
Separate a mixture of iron fillings and sand.	Elastic tension.
Fire a gun.	Magnetic force.
Cause tides in the seas (oceans).	Gravitational force of attraction between the earth and the moon.
Absorb shock in vehicles.	Upthrust force.
Swim.	Action and reaction.
Water rising a narrow tube.	Centripetal force.
Toy boat moving on water surface.	Cohesive and adhesive force.

Mass and Weight

Mass and Weight

While mass is the quantity of matter present in an object, weight is a measure of the pull of gravity on the object. This pull of gravity is always directed towards the centre of the earth. Thus, weight has both direction and size.

The SI unit of weight is the newton (symbol N). Weight is measured by a spring balance calibrated in newtons.

Due to the shape and rotation of the earth, the weight of an object varies from place to place. The earth is not a perfect sphere, it is flattened at the poles such that the distance between the centre of the earth and the poles is shorter than that between the centre of the earth and the equator. Thus, a body weighs more at the poles than at the equator.

Relationship between Mass and Weight

Experiment 3.12: To determine the gravitational field strength ‘g’ of a place

Apparatus

Six 20 g masses, spring balance calibrated in newtons, retort stand.

Procedure

- Take a 20 g mass and obtain the corresponding weight by use of the spring balance.
- Repeat each time adding a 20 g mass.
- Tabulate the results as in table 3.2.

Table 3.3: To determine the gravitational strength ‘g’

Mass m (g)	20	40	60	80	100	120
Mass m (kg) Reading on the spring balance W (N)						
$\frac{W}{m}$ (N/kg)						

- Plot a graph of weight in newtons (y-axis) against mass in kilograms (x-axis).
- Find the slope of the graph.

The value of the slope is called the **gravitational field strength** (intensity). This is the gravitational force on a unit mass at that place on the earth.

On the earth's surface, an object of mass m has a gravitational pull of mg on it, where g is acceleration due to gravity (free fall). Thus, the weight W = mg.

The earth pulls each kilogram of mass on its surface with a force of about 9.8 N, which is approximately 10 Nkg^{-1}. Compare this with the value of W/m from the experiment.

For example, the weight W of an object whose mass is 50 kg is given by:

$$W = mg$$
$$= 50 \times 10$$
$$= 500\ N$$

Similarly, the mass m of an object whose weight is 900 N is given by:

$$m = \frac{W}{g} = \frac{900}{10}$$
$$= 90\ kg$$

Example 2

Calculate the weight of each of the following:

(a) A cat of mass 1.5 kg.

(b) A pencil of mass 5.0 g.

(c) A lorry of 8 tonnes.

(Use g = 10 Nkg^{-1})

Solution

(a) Weight W = mass × pull of gravity

$$= 1.5 \times 10$$
$$= 15\ N$$

(b) Mass of pencil = $\frac{5}{1\ 000}$

$$= 0.005\ kg$$

Weight $= 0.005 \times 10$

$$= 0.05\ N$$

(c) Weight of lorry = 8 × 1 000 × 10

$$= 80\ 000\ N$$

Example 3

An astronaut weighs 900 N on earth. On the moon, he weighs 150 N. Calculate the moon's gravitational strength.

(Take g = 10 Nkg^{-1})

Solution

The mass of astronaut

$$= \frac{\text{weight of astronaut}}{\text{earth's gravitational strength}}$$

$$= \frac{900}{10}$$

$$= 90 \text{ kg}$$

Weight of the astronaut on the moon = mass of the astronaut × moon's gravitational strength

∴ The moon's gravitational strength

$$= \frac{\text{weight of astronaut on the moon}}{\text{mass of astronaut}}$$

$$= \frac{150}{90}$$

$$= 1.67 \text{ Nkg}^{-1}$$

Table 3.4

Differences between Mass and Weight

Mass	**Weight**
It is the quantity of matter in the body.	It is the pull of gravity on a body.
It is measured in kilograms.	It is measured in newtons.
It is the same everywhere.	It changes from place to place.
It is measured using a beam balance.	Measured using a spring balance.
Has magnitude only.	Has both magnitude and direction.

Exercise 3.2

(Take g = 10 Nkg^{-1})

1. Calculate the weights of the following masses: 2 kg, 450 g, 0.75 kg, 3 000 000 mg.
2. A body weighs 75 N. Calculate its mass.
3. The mass of an object is 50 kg. If its weight is 1 000 N on a certain planet, calculate the gravitational field strength of the planet.

Scalar and Vector Quantities

A **scalar quantity** is a quantity which has magnitude (size) only but no direction. It can be specified by a number and a unit. If the mass of a car is 800 kg or the area of a circle is 314 cm^3, then the values represent the magnitude of mass and area respectively. Mass and area are scalar quantities. Other examples of scalar quantities are density, volume, energy, time, pressure, temperature and length. Scalar quantities are added by the normal rules of arithmetic. For example, 3 kg added to 2 kg make 5 kg and 4 hours added to 2 hours make 6 hours.

A **vector quantity** is a quantity which has direction as well as magnitude. It can be specified by a number, unit and direction. If the weight of a car is 8 000 N, 8 000 gives the number, N is its unit and it is directed towards the centre of the earth. Other examples of vector quantities are force, velocity, displacement, acceleration, momentum and magnetic field strength.

All vector quantities obey a special rule for addition and subtraction, which takes account of direction as well as magnitude (size). A vector quantity is represented on a diagram by a straight line with an arrow.

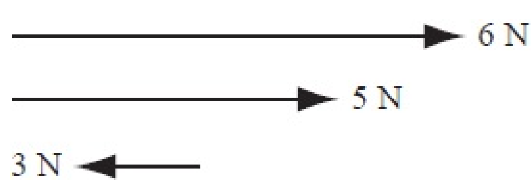


Fig. 3.26: Vector quantities

Figure 3.26 shows different vector quantities. The length of the line represents the magnitude of the vector quantity (when drawn to scale) and the arrow shows the direction and line of action of the vector.

The sum of two or more vectors is the **resultant vector**. Parallel forces which act on the same object can be added arithmetically, taking account of their directions. Figure 3.27 gives examples of addition of parallel forces acting on a body.

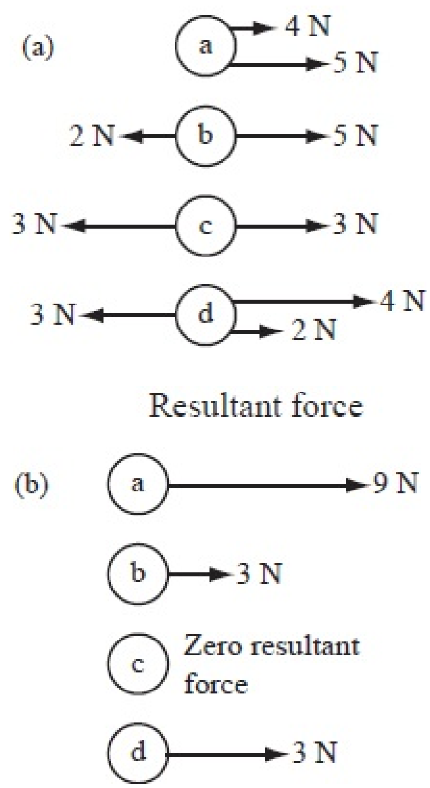


Fig. 3.27: Adding parallel forces

Note that when forces are acting in opposite directions, the resultant is their difference.

To specify resultant force, both magnitude and direction are given. For example, the resultant force on figure 3.27 (b) is 3 N, acting in the same direction as the 5 N force.

Revision Exercise 3

1. Define force and give its SI unit.
2. Name all the forces acting on the following bodies:
   (a) A box placed on a table.
   (b) A mass suspended from a spring balance.
   (c) A moving car negotiating a bend.
3. Define cohesive force and adhesive force.
4. Explain why a man using a parachute falls through air slowly while a stone falls through air very fast.
5. Explain each of the following using the behaviour of molecules where

possible:

(a) A steel needle placed carefully on the surface of water does not sink.

(b) When a small drop of detergent is placed on water, the needle moves rapidly away from it and sinks when more detergent is added. (Assume that the detergent does not affect the density of water)

(c) A match-stick rubbed at one end with soap starts moving immediately in one direction when placed on the surface of water.

(d) When it is raining, it is advisable not to touch a canvas tent from inside.

(e) Bristles of a paint brush spread when the brush is in water and cling together when it is taken out of the water.

(f) Water wets clean surfaces of glass but not waxed ones.

(g) Water rises up in narrow tubes but mercury, which is also a liquid, falls in narrow tubes to a level below that of the liquid surface.

7. (a) Define surface tension.

   (b) How does temperature rise and impurities affect the surface tension of water?

   (c) How can the surface tension of water be increased?

8. Define the terms:

   (a) mass.

   (b) weight.

9. The mass of a lump of gold is constant everywhere, but its weight is not. Explain this.

10. A man has a mass of 70 kg. Calculate:

    (a) his weight on earth, where the gravitational field strength is 10 N/kg.

    (b) his weight on the moon, where the gravitational field strength is 1.7 N/kg.

11. A mass of 7.5 kg has weight of 30 N on a certain planet. Calculate the acceleration due to gravity on this planet.

12. Define the following terms, giving examples:

    (a) Vector quantity.

    (b) Scalar quantity.

13. (a) Define a resultant vector.

    (b) Find the resultant of a force of 4 N and a force of 8 N acting on the same point on an object if:

(i) the forces act in the same direction in the same straight line.

(ii) the forces act in opposite directions but in the same straight line.

14. Show diagramatically how forces of 7 N and 9 N can be combined to give a resultant force of:

(a) 16 N

(b) 2 N

Chapter 4 Pressure

The term pressure is used in day-to-day life. To understand its meaning, consider the following examples of experiences with force on solids.

(i) A person makes deeper marks while walking on soft ground in high-heeled shoes than in flat shoes.

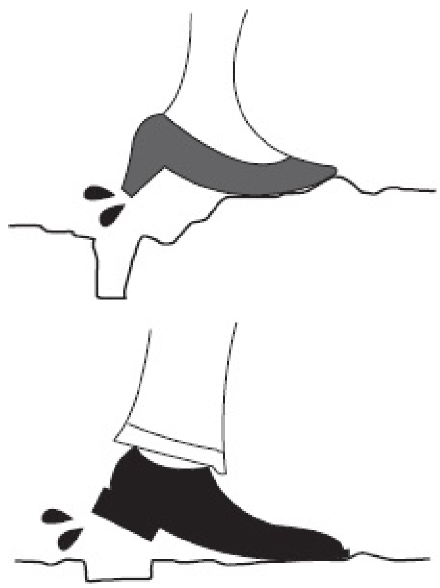


Fig. 4.1: High and flat-heeled shoes

(ii) It is easier to push a sharp pin through a cardboard than it is to push a blunt one through the same material using the same force, see figure 4.2 (a) and (b).

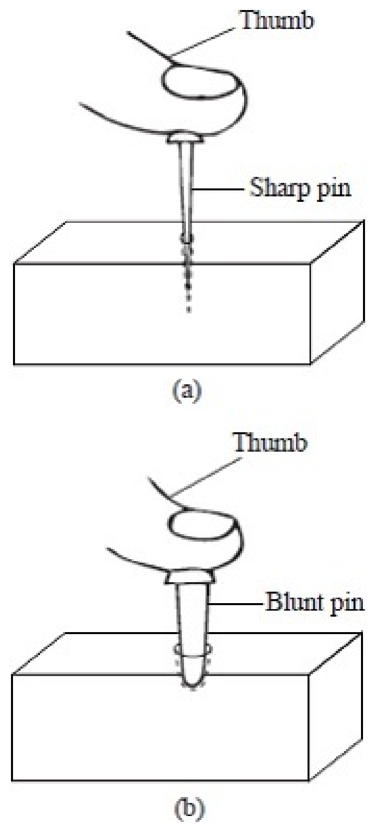


Fig. 4.2: Effect of force on an area

In all the above cases, a given force acting on an area causes a penetration, depression or distortion. The effect is greater when the force acts on a smaller area than when it acts on a larger area.

In general, when a force is applied on a given area, pressure is exerted on the surface.

Pressure is defined as the **force acting normally (perpendicularly) per unit area.**

Units of Pressure

From the definition,

$$\text{pressure P} = \frac{\text{force (F)}}{\text{area (A)}}$$

Therefore, the SI unit of pressure

$$= \frac{\text{SI unit of force}}{\text{SI unit of area}}$$

$$= N/m^2 \text{ or } Nm^{-2}$$

The SI unit of pressure is thus newton per square metre (Nm^{-2}), which is also called the Pascal (Pa).

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

Other units include the mmHg, the cmHg and an atmosphere (atm).

Example 1

A man of mass 84 kg stands upright on a floor. If the area of contact of his shoes and floor is 420 cm^2, determine the average pressure he exerts on the floor. (Take g = 10 Nkg^{-1})

Solution

$$\text{Pressure} = \frac{\text{force}}{\text{area}}$$

$$\begin{aligned}
\text{Force} &= \text{weight of the man} \\
&= 84 \times 10\ \text{N} \\
&= 840\ \text{N} \\
\text{Area} &= 420\ \text{cm}^2 \\
&= \frac{420}{10\ 000} \\
&= 0.042\ \text{m}^2
\end{aligned}$$

$$\begin{aligned}
\text{Thus, pressure} &= \frac{840}{0.042} \\
&= \frac{840 \times 1\ 000}{0.042 \times 1\ 000} \\
&= \frac{840\ 000}{42} = 20\ 000\ \text{Nm}^{-2}
\end{aligned}$$

Example 2

A metallic block of mass 40 kg exerts a pressure of 20 Nm^{-2} on a flat surface. Determine the area of contact between the block and the surface.

(Take g = 10 Nkg^{-1})

Solution

Force = weight of the block
$= 40 \times 10$ N
$= 400$ N

Since $P = \frac{F}{A}$; $A = \frac{F}{P}$

$= \frac{400}{20}$

$= 20\ m^2$

Example 3

A brick 20 cm long, 10 cm wide and 5 cm thick has a mass of 500 g. Determine the:

(a) greatest pressure that can be exerted by the brick on a flat surface.

(b) least pressure that can be exerted by the brick on a flat surface. (Take $g = 10\ Nkg^{-1}$)

Solution

(a) Dimensions of the brick are 0.20 m, 0.10 m and 0.05 m.

Weight of the brick $= \frac{500}{1\,000} \times 10$

$= 5$ N

From the formula $P = \frac{F}{A}$;

P is greatest when area A is smallest.

Area of the smallest face of the brick

$= 0.10 \times 0.05$

$= 0.005\ m^2$

Therefore, $P = \frac{F}{A_{smallest}}$

$= \frac{5}{0.005}$

$= 1\,000\ Nm^{-2}$

(b) Pressure is least when area A is greatest.

Therefore, $P = \frac{5}{0.20 \times 0.10}$

$= 250\ Nm^{-2}$

From the above examples, it is clear that:

(i) If area is held constant, the higher the force, the higher the pressure and the lower the force, the lower the pressure.

(ii) If force is kept constant, the smaller the area, the greater the pressure and the larger the area, the smaller the pressure.

Exercise 4.1

1. A force of 100 N is applied to an area of 100 mm^2. Determine the pressure exerted on the area in Nm^{-2}.
2. A girl standing upright exerts a pressure of 13 600 Nm^{-2} on the floor. Given that the total area of contact of shoes and the floor is 0.0368 m^2, determine:
   (a) the mass of the girl.
   (b) the pressure she would exert on the floor if she stood on one foot.
3. Trucks which carry heavy loads have many wheels. Explain.
4. A block of copper of density 8.9 g/cm^3 measures 5 cm × 3 cm × 2 cm. Given that the force of gravity is 10 Nkg^{-1}, determine:
   (a) the maximum pressure.
   (b) the minimum pressure that it can exert on a horizontal surface.
5. Calculate the amount of force that must be applied on a blade of length 4 cm and thickness of 0.1 mm to exert a pressure of 5 000 000 Pa.

Pressure in Liquids

Pressure is also exerted in liquids. This varies with depth among other factors.

Experiment 4.1: To show variation of pressure in liquid

Apparatus

A tall tin, a small nail, water.

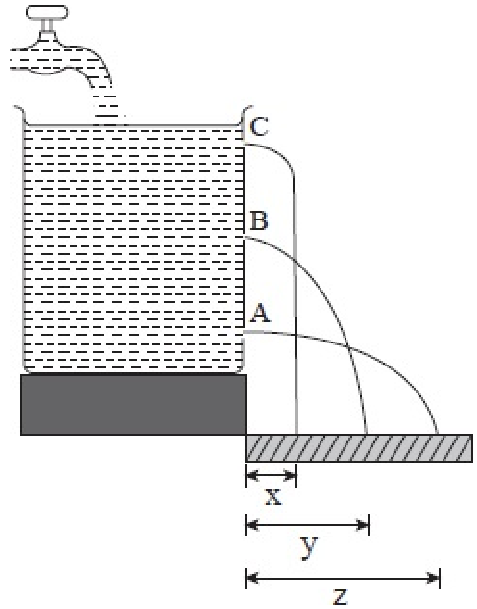


Fig. 4.3: Pressure and depth

Procedure

- Using the nail, make three holes, A, B and C, of the same diameter along a vertical line on one side of the tin.
- Fill the tin with water as shown in figure 4.3.
- With the tin full of water, observe the jets of water from the holes A, B and C.

Observation

The lower hole, A, throws water the farthest distance z, followed by B distance y and lastly C distance x.

Conclusion

Pressure of water at A is greater than pressure at B and pressure at B is greater than at C. Hence, pressure increases with depth.

Increase in pressure with depth explains why dam walls are constructed thicker at the bottom than at the top. See figure 4.4 below.

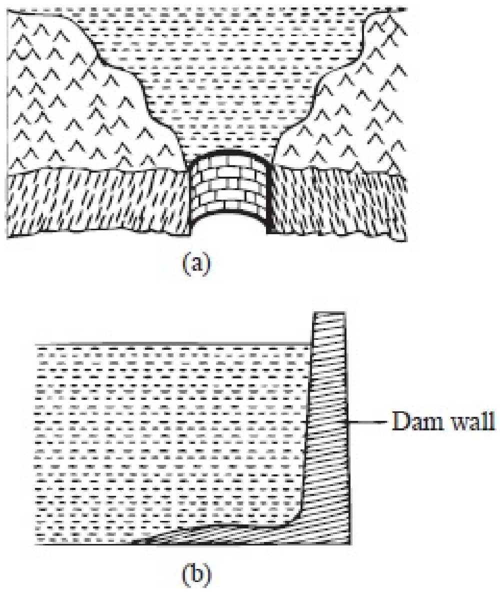


Fig. 4.4: Curved wall and section of a dam

Additionally, the walls of the dam are curved to increase the surface area, hence reduce the pressure.

Liquid Levels

When a liquid is poured into a set of open and connected vessels with different shapes (and area of cross-section), it flows until the levels are the same in all the vessels, as shown in figure 4.5.

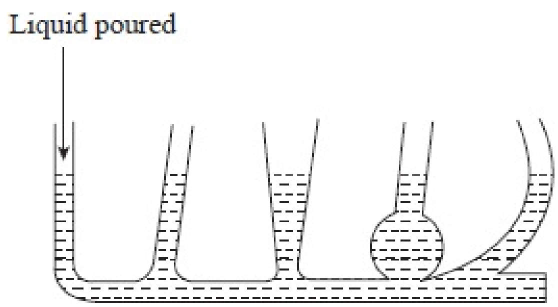


Fig. 4.5: A liquid finds its own level

This shows that the liquid flows to find its own height regardless of the shape of the vessel.

Liquid Levels in a U-tube

When water is poured into one arm of a U-tube, it will flow into the other arm.

The water will settle in the tube with the levels on both arms being the same, see figure 4.6 (a).

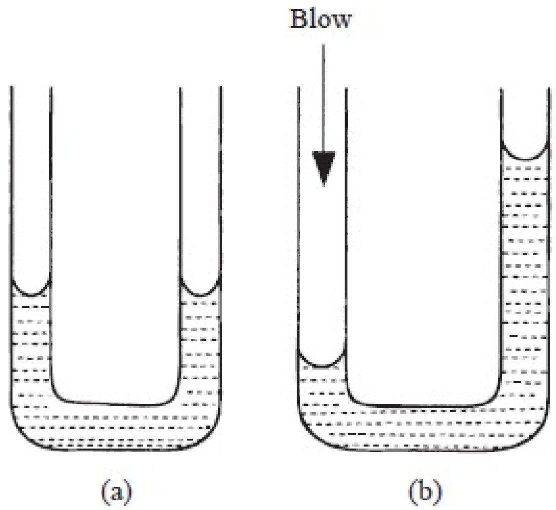


Fig. 4.6: Effect of pressure on liquid levels

When one arm of the U-tube is blown into with the mouth, the level moves downwards, while in the other arm it rises, see figure between 4.6 (b). This is caused by the pressure difference between the two arms. The pressure increases on the arm that is blown into and causes water to rise on the other arm.

Experiment 4.2 (a): To investigate the variation of liquid pressure with depth and density

Apparatus

A tall jar, liquids of different densities, thistle funnel, U-tube, rubber tubing.

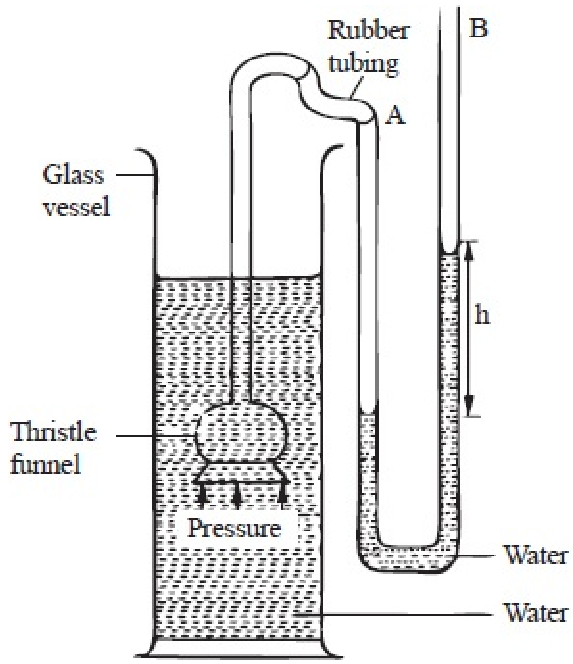


Fig. 4.7: Pressure variation in a liquid

Procedure

- Fill the glass vessel with water.
- Connect the thistle funnel to a U-tube filled to some level with water.
- Lower the funnel to different depths from the surface and notice the difference in levels, h, of water in the U-tube, see figure 4.7.
- Replace the water in the glass vessel with a denser liquid, such as sodium chloride solution (brine).
- Lower the funnels to the same depths as above and compare the heights obtained.

Observations

(i) The deeper the funnel goes below the surface, the greater the difference in levels, h.

(ii) The differences in levels, h, obtained with brine at a particular depth is greater than that obtained with water at that depth.

Conclusion

Pressure in a liquid increases with the density of the liquid and with depth.

Experiment 4.2 (b): To show the distribution of pressure at a point in a

liquid

Apparatus

A tall jar, water, thistle funnels, U-tube, rubber tubing.

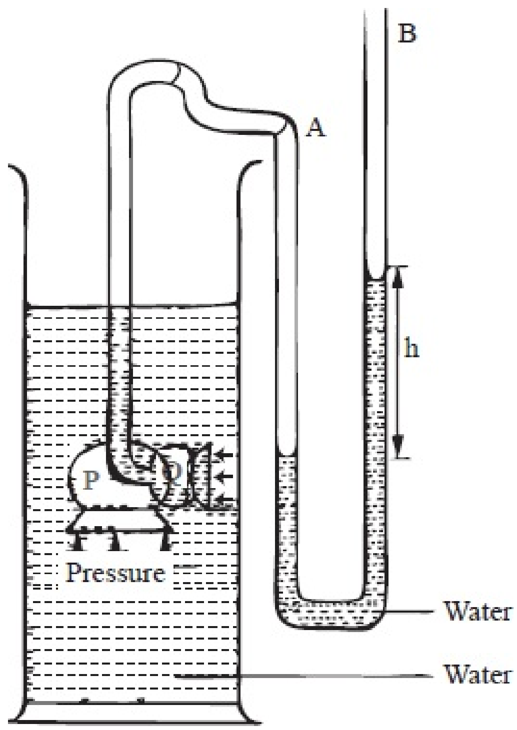


Fig. 4.8: Pressure distribution

Procedure

- Fill the glass vessel with water.
- Connect one of the thistle funnels to a U-tube filled to some level with water.
- Lower the funnel P to a depth from the surface of the water and notice the difference in levels, h, of the water in the U-tube.
- Replace the funnel with Q whose mouth is pointing in a different direction.
- Lower the funnel Q into the water so that the mouth of the funnel is at the same point as the straight one P. Observe the difference in the levels of the water in the U-tube.

Observations

At the same depth in a given liquid, difference in levels obtained is the same regardless of the direction which the funnel faces.

Conclusion

Pressure in liquids increases with density and depth.

In summary:

(i) pressure in a liquid increases with depth below its surface.

(ii) pressure in a liquid increases with the density of the liquid.

(iii) the distribution of pressure in a liquid at a particular depth is the same in all directions.

Derivation of Fluid Pressure Formula P = hρg

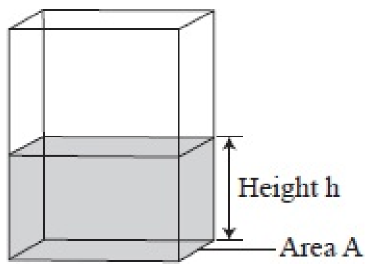


Fig. 4.9: Liquid column

If A is the cross-section area of the column, h the height of the column and ρ the density of the liquid, then;

Volume of the liquid

= cross-section × height = Ah

Mass of the liquid

= volume of the liquid × density

= Ahρ

Therefore, weight of the liquid column

= mass of the liquid × gravitational force per unit mass

= Ahρg

From the definition of pressure, $P = \frac{F}{A}$

$$P = \frac{\text{weight of liquid column}}{\text{area}}$$

$$= \frac{Ah\rho g}{A}$$

$$= h\rho g$$

Therefore, pressure P exerted by the column on A is given by, $p = h\rho g$

From the formula $P = h\rho g$, it can be seen that the pressure due to a liquid column is directly proportional to:

(i) height h of the column.

(ii) the density ρ of the liquid.

Pressure does not depend on the cross-section area of the container which holds the liquid.

The formula is also used to determine pressure due to a column of gas.

Example 4

A diver is 10 m below the surface of the water in a dam. If the density of water is 1 000 kgm^{-3}, determine the pressure due to the water on the diver. (Take g = 10 Nkg^{-1})

Solution

Pressure on the diver is given by;

$P = h\rho g$

$= 10 \times 1\,000 \times 10$

$= 100\,000\ Nm^{-2}$

Example 5

The density of mercury is 13 600 kgm^{-3}. Determine the liquid pressure at a point 76 cm below the surface of mercury. (Take g = 10 Nkg^{-1})

Solution

Pressure is given by $P = h\rho g$

$= 0.76 \times 13\,600 \times 10$

$= 103\,360\ Nm^{-2}$

Transmission of Pressure in Liquids

Consider:

Fig. 4.10 shows a round bottomed flask fitted with a piston and holes of same diameter drilled along the same level.

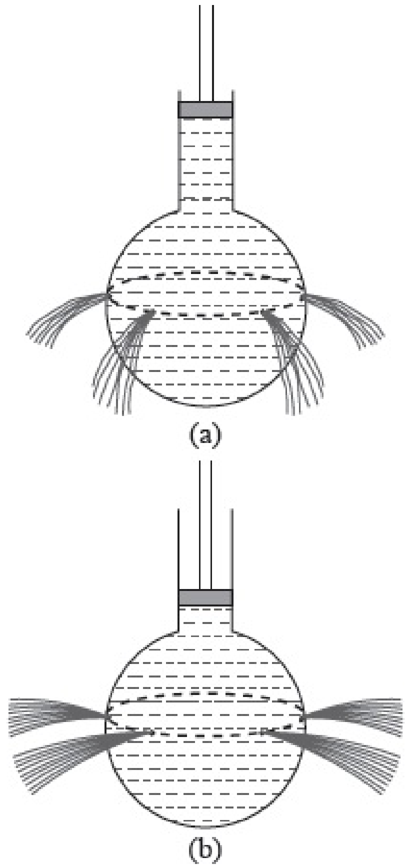


Fig. 4.10

Initially, the water squirts out at the same rate with some force. When the plunger is pushed in, the liquid squirts out at the same rate but with increased force. If the plunger exerts a force F and the piston area is A, then the additional pressure $P = \frac{F}{A}$, developed is transmitted equally to all parts of the liquid forcing the liquid out of the holes with the same increased force.

Experiment 4.3: To investigate how pressure is transmitted in liquids (Pascal's principle)

Using Identical Syringes

Apparatus

Two identical syringes, rubber tubing, water, pairs of different masses, two stands and clamps.

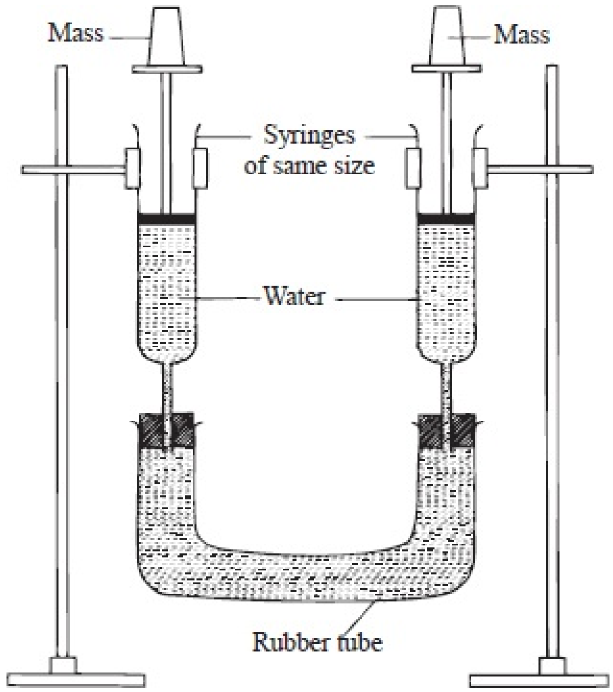


Fig. 4.11: Transmission of pressure in liquids

Procedure

- Set up the apparatus as shown in figure 4.11.
- Place a mass m on one of the plungers and observe what happens.
- Place an identical mass on the other plunger and observe what happens.
- Repeat with the other pairs of identical masses.

Observation

(i) When the first mass is placed on the plunger, the plunger moves downwards and the second plunger moves up.

(ii) When an identical mass is placed on the second plunger, the first plunger with the mass on it moves upwards and stops when their levels are the same.

The pressure in the two syringes is the same. This is because the masses and the diameters of the syringes are the same.

Using Syringes of Different Diameters

Apparatus

Syringes of different diameters, two stands and clamps, different masses, water, rubber tubing.

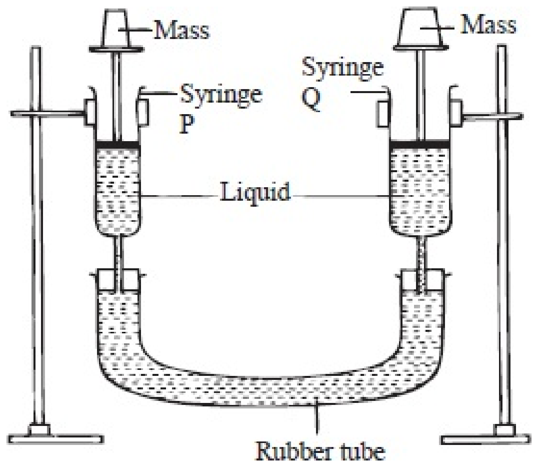


Fig. 4.12: Effects of transmitted pressure

Procedure

- Replace one of the syringes in Experiment 4.3 (a) with syringe of different diameter, and set up the apparatus as shown in figure 4.12.
- Starting with a large mass on syringe Q, put masses on syringe P until Q just starts to move upwards. Note the mass on P and Q as in table 4.1.

Table 4.1

	Syringe P	*Syringe Q*
Area A of piston (m^2)		
Weight F on piston (N)		
$\frac{F}{A}$		

From the table, compare the value of $\frac{F}{A}$ in P and Q.

Conclusion

At balance, the pressure due to the mass in P is equal to the pressure due to the other mass in Q.

From the foregoing experiment, pressure applied at one part of an enclosed liquid is transmitted equally to all other parts of the enclosed liquid. This is called the **principle of transmission of pressure in liquids (Pascal's**

Principle). Gases may transmit pressure in a similar way when they are confined and incompressible.

Hydraulic Machines

The principle of transmission of pressure in liquids is made use of in hydraulic machines where a small force applied at one point of a liquid produces a much larger force at some other point of the liquid.

Hydraulic Lift

The hydraulic lift consists of a small piston S of cross-section area A_1 and a large piston L of cross-section area A_2. When a force is applied on piston S, the pressure generated by the force is transmitted throughout the liquid to piston L, see figure 4.13.

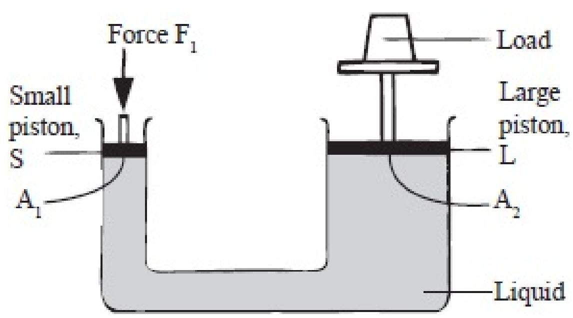


Fig. 4.13: Hydraulic lift

Consider a force F_1 applied on the small piston of cross-section area A_1. Then, pressure P_1 generated on the liquid by the piston S due to F_1 is given by;

$$P_1 = \frac{F_1}{A_1}$$

This pressure is transmitted by the liquid to the larger piston L. Therefore, pressure of liquid acting on the area A_2 of the large piston is equal to P_1. Thus, the force F_2 produced on the large piston is given by;

F_2 = pressure × area

$= P_1 \times A_2$

But $P_1 = \frac{F_1}{A_1}$

So, $F_2 = \frac{F_1}{A_1} \times A_2$

Therefore, $\frac{F_2}{F_1} = \frac{A_2}{A_1}$

Hydraulic lifts are used to hoist cars in garages. Hydraulic presses on the other hand are used to compress certain materials such as cotton bales into the required shapes and sizes.

Example 6

A small force of 100 N applied on the small piston of area A_1 equal to 0.25 m^2 produces a bigger force F_2 on a larger piston of area A_2 equal to 10 m^2. See figure 4.14 below. Calculate F_2.

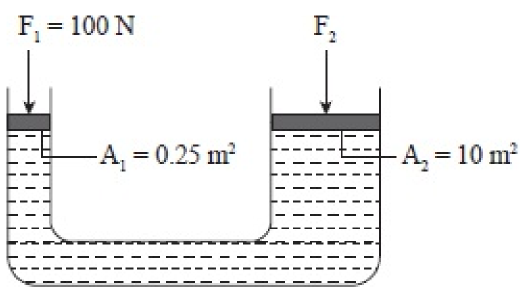


Fig.4.14

$\frac{F_2}{F_1} = \frac{A_2}{A_1}$

$F_2 = \frac{A_2}{A_1} \times F_1$

$= \frac{10}{0.25} \times 100$

$= 4\,000$ N

Note:

A small force applied on the small piston produces a much bigger force on the larger piston.

Hydraulic Brake System

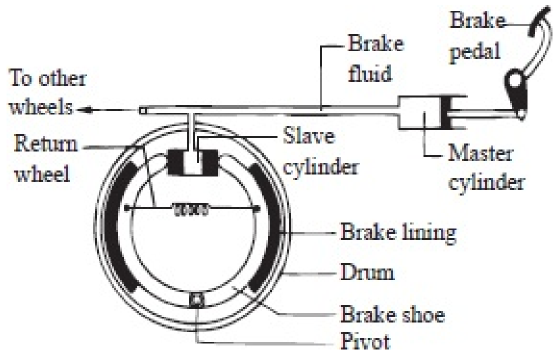


Fig. 4.15: Vehicle hydraulic brake system

A vehicle hydraulic brake system is shown in figure 4.15.

The force applied on the brake pedal exerts pressure on the master cylinder. The pressure is transmitted by the brake fluid to the slave cylinder. This causes the pistons of slave cylinder to open the brake shoe and hence the brake lining presses on the drum. The rotation of the wheel is thus resisted.

When the force on the foot pedal is withdrawn, the return spring pulls back the brake shoe which then pushes the slave cylinder piston back.

The advantage of this system is that the pressure exerted in master cylinder is transmitted equally to all the four wheel cylinders. Hence, the braking force obtained is uniform.

The liquid to be used as a brake fluid should have the following properties:

(i) Be incompressible, to ensure pressure exerted at one point is transmitted equally to all other parts in the liquid.

(ii) Have low freezing point and high boiling point.

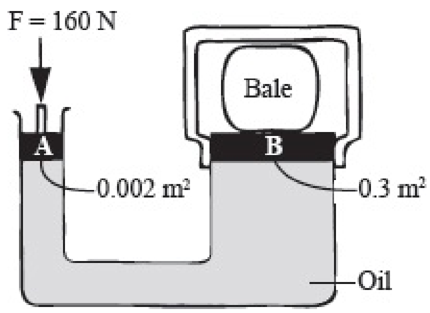
(iii) Should not corrode the parts of the brake system.

Exercise 4.2

1. Calculate the pressure due to water experienced by a diver working 15 m below the surface of the sea. (Take g = 10 Nkg^{-1} and density of sea water = 1.03 gcm^{-3})
2. An outlet of diameter 1 m is made 20 m below the surface of water in a dam. Determine the force with which the water spews out when it is fully opened due to water pressure (Take g = 10 Nkg^{-1} and density of water = 1 gcm^{-3})
3. Explain why water storage tanks in houses are erected as high as possible.
4. Describe a simple experiment to demonstrate that the pressure in a liquid

increases with depth.

5. The figure below shows a simple hydraulic press used to compress a bale. The cross-section areas of A and B are 0.002 m^2 and 0.30 m^2 respectively.



Determine the:

(a) pressure exerted on the oil by the force applied at A.

(b) pressure exerted on B by the oil.

(c) force produced on B compressing the bale.

Atmospheric Pressure

The term atmosphere means the air surrounding the earth. The air is bound around the earth by the earth's gravity.

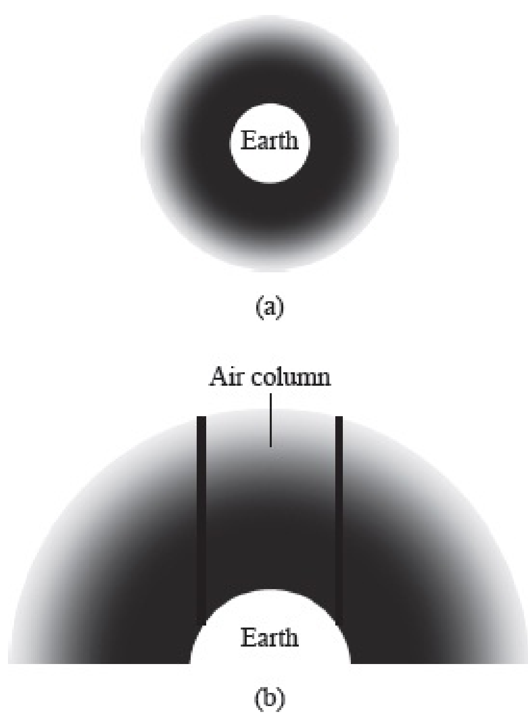


Fig. 4.16: Atmosphere

Figure 4.16 (a) shows the earth's atmosphere. The atmosphere thins outwards, indicating the density of air decreases with the distance from the surface of the earth.

Consider a column of air as in figure 4.16 (b), extending vertically into space to the end of the atmosphere. This column of air stands on the earth's surface like a liquid in a tube and exerts pressure on the surface of the earth. The pressure exerted on the surface of the earth by the weight of the air column is called **atmospheric pressure**.

The existence of atmospheric pressure is demonstrated by the experiment below.

Experiment 4.4: To demonstrate the existence of the atmospheric pressure

Apparatus

Tin container with a tight-fitting cork, water, tripod stand, Bunsen burner.

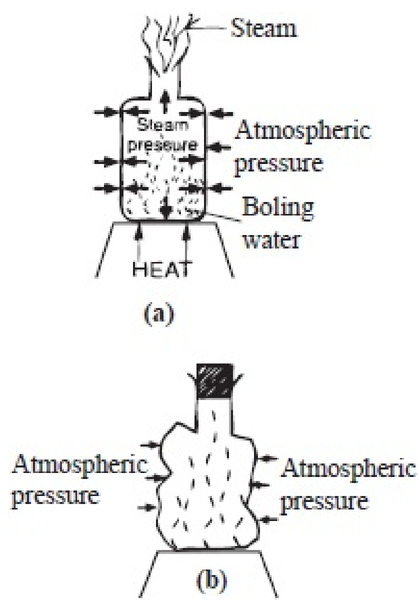


Fig. 4.17: Crushing can experiment

Procedure

- Remove the cork from the container and pour in some little water.
- Boil the water for several minutes.
- Replace the cork and allow the container to cool. You may pour cold water on it to cool it faster. Observe what happens to the container.

Observation

During cooling, the container is crushed in.

Explanation

Steam from boiling water drives out most of the air inside the container, see figure 4.17 (a). When the cork is first replaced, the steam pressure inside the container balances the atmospheric pressure outside. On cooling, the steam condenses.

A partial vacuum is therefore created in the container. Since pressure inside the container is less than atmospheric pressure outside, the container is crushed, see figure 4.17 (b).

Maximum Column of Liquid that can be Supported by Atmospheric Pressure

When water is sucked up a straw as in figure 4.18, the air pressure inside the straw reduces.

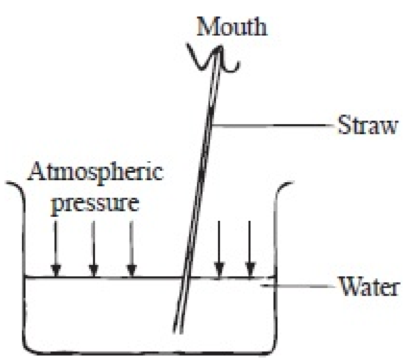


Fig. 4.18: The working of the drinking straw

The atmospheric pressure acting on the water surface is now greater than the pressure inside the straw. Water is thus pushed up the straw by the atmospheric pressure.

If the straw was long enough and sealed at the top, it would be possible to estimate the height of water in the straw that would be supported by atmospheric pressure.

A more convenient method is to use a glass tube sealed at one end, as in figure 4.19 (a).

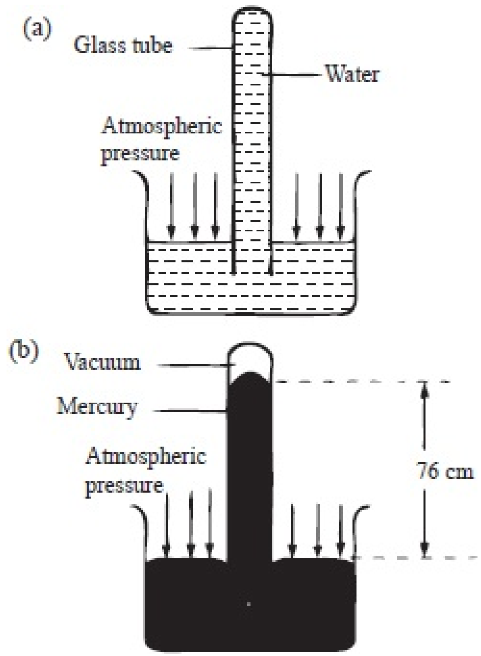


Fig. 4.19: Water and mercury columns supported by atmospheric pressure

Fill glass tubes of different lengths completely with water and invert them in a water reservoir. You will realise that the water column can be very large, in fact too large for your available apparatus to accommodate.

However, if mercury, which is much denser than water is used, the column supported is found to be much shorter, see figure 4.19 (b). In this figure, the mercury column in the tube exerts pressure at point B. For the height of this column to remain constant, there must be a counter pressure to hold it up. This counter pressure is provided by the atmosphere. At sea level, the atmospheric pressure supports approximately 76 cm of mercury column or approximately 10 m of water column.

Example 7

A girl in a school situated in the coast region (sea level) plans to make a barometer using sea-water of density 1 030 kgm^{-3}. If the atmospheric pressure is 103 000 Nm^{-2}, Determine the minimum length of the tube that she will require.

Solution

Pressure in liquid is given by $P = h\rho g$

But P = atmospheric pressure

Therefore, $h\rho g$ = atmospheric pressure

$h \times 1\ 030 \times 10 = 103\ 000$

So, $h = \frac{103\ 000}{10\ 300} = 10$ m

Example 8

A sea diver is 35 m below the surface of sea-water. If density of the sea-water is 1.03 g/cm^3 and g is 10 Nkg^{-1}, determine the total pressure on him. Take atmospheric pressure to be 103,00 N/m^{-2}

Solution

Pressure in liquid is given by P = hρg

But total pressure = atmospheric pressure, P_a + liquid pressure

$= P_a + h\rho g$

$= 103\ 000 + (35 \times 1\ 030 \times 10)\ Nm^{-2}$

$= 463\ 500\ Nm^{-2}$

Example 9

The air pressure at the base of a mountain is 75.0 cm of mercury while at the top it is 60.0 cm of mercury. Given that the average density of air is 1.25 kgm^{-3} and the density of mercury is 13 600 kgm^{-3}, calculate the height of the mountain.

Solution

Pressure difference due to column of air (height of mountain)

= Pressure difference due to mercury column

Pressure at the top of the mountain

$= 0.60 \times 13\ 600 \times 10$

$= 81\ 600\ Nm^{-2}$

Pressure at the base of the mountain

$= 0.75 \times 13\ 600 \times 10$

$= 102\ 000\ Nm^{-2}$

Pressure difference

$= 102\ 000 - 81\ 600$

$= 20\ 400\ Nm^{-2}$

Pressure due column of air

$$= 20\ 400\ Nm^{-2}$$

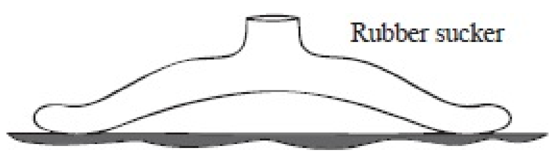
$$h_a e_a g = 20\ 400$$

$$h_a = \frac{20\ 400}{1.25 \times 10} = 1\ 632\ m$$

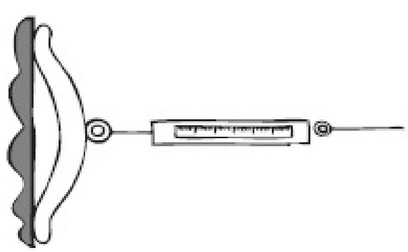
The height of the mountain is 1 632 m

Exercise 4.3

1. Explain why there is a big difference between heights of water and mercury column that can be supported by atmospheric pressure.
2. The barometric height at sea level is 76 cm of mercury while that at a point on a highland is 74 cm of mercury. Determine the altitude of the point. (Take g as 10 N/kg, the density of mercury as 13 600 kgm^{-3} and density of air is 1.25 kgm^{-3})
3. The figure below shows a rubber sucker. Explain why the sucker sticks on a clean flat surface.



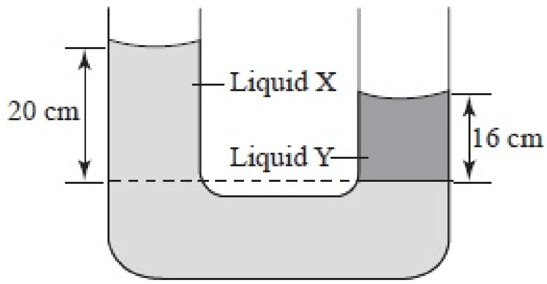
4. A sucker stuck on a flat surface was pulled by means of a spring balance as shown in figure below. When the sucker was just about to be pulled off the surface, the spring balance reading was 40 N. Given that the area of the sucker was 4.4 cm^2, determine the air pressure in Nm^{-2}.



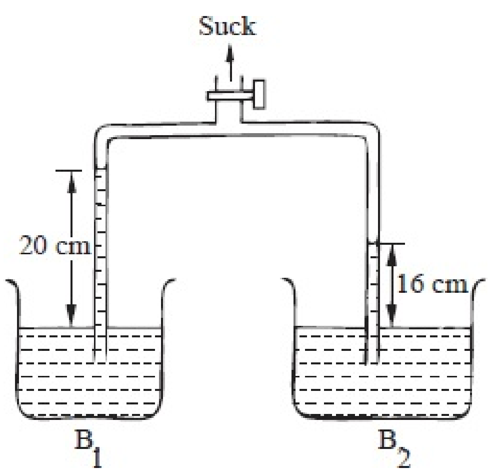
5. Explain what is meant by a barometric liquid. Give an example of one such liquid, stating its properties.

6. A student in a place where the mercury barometer reads 75 cm wanted to make an alcohol barometer. If alcohol has a density of 800 kgm^{-3}. Find the minimum length of the tube that could be used.

7. The diagram below shows a U-tube filled with two liquids X and Y. If the density of liquid Y is 1.26 gcm^{-3}, determine the density of liquid X. Explain the effect of increasing the diameter of one arm of the U-tube on the height of the liquid column?



8. Two liquids were sucked up in two identical tubes as shown in the figure below. Given that the liquid in beaker B_2 is water (density 1 gcm^{-3}), determine the density of liquid in beaker B_1.



Measurement of Pressure

U-tube Manometer

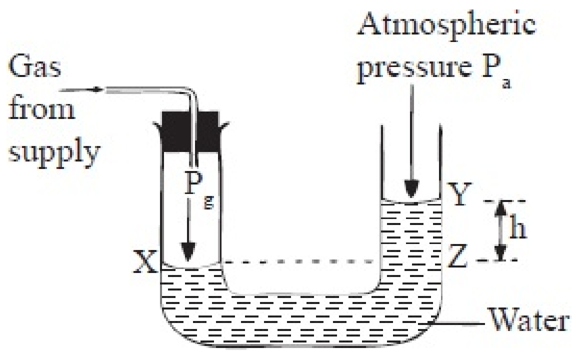


Fig. 4.20: Measurement of gas pressure

A manometer is an instrument that can measure fluid pressure. It consists of a U-tube filled with water or any other suitable liquid, see figure 4.20.

Suppose one limb of the manometer is connected to a gas supply. Due to the pressure of the gas P_g, the water level in the other limb rises to, say, Y. This difference in water levels is the difference between gas pressure P_g and the atmospheric pressure P_a.

Since X and Z are at the same horizontal level, pressure at X equals pressure at Z. Pressure at X is pressure of gas P_g.

Pressure at Z = atmospheric pressure + pressure due to the column of water

Therefore, $P_g = P_a + h\rho g$

Since density of water, ρ, and g are known, we can determine pressure of gas if the atmospheric pressure is known.

Suppose

h = 20.0 cm and P_a = 103 000 Nm^{-2}. Then, taking the density of water as 1 000 kgm^{-3},

P_g = 103 000 + 0.20 × 1 000 × 10

= 105 000 Nm^{-2}

Mercury Barometer

It has been shown that atmospheric pressure supports a liquid column in a tube. When this arrangement is used to measure pressure, it is called a **barometer**.

At sea level, a column of mercury and water supported by atmospheric pressure is approximately 76 cm and 10 m respectively. Mercury, which is about

14 times denser than water, is chosen for atmospheric pressure measurements since it gives a much shorter and measurable column.

Simple Mercury Barometer

The simple mercury barometer comprises a thick-walled glass tube of about one metre long and sealed at one end.

It is carefully filled with mercury to the top and any bubbles of air in the tube removed by closing the open end and inverting it severally. It is necessary to remove the bubbles because they make the barometer defective.

The tube is refilled and the open end closed tightly. It is then inverted into a dish filled with mercury and supported upright with a stand and clamp, see figure 4.21. The tightly closed end is then opened while under the surface of the mercury. The column of mercury in the tube drops to create a vacuum in the space above the column.

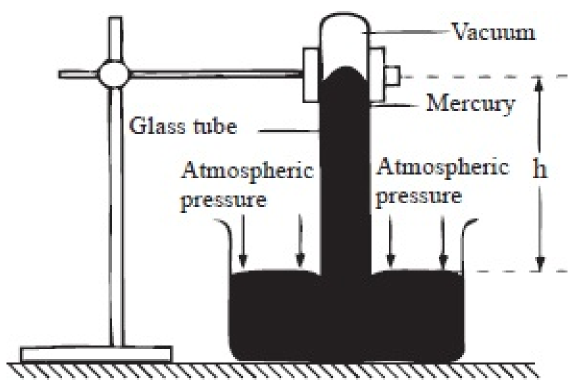


Fig. 4.21: Simple mercury barometer

The height h of the column (barometric height) is a measure of the atmospheric pressure.

At sea level, h = 76 cmHg.

Since density ρ of mercury is 13 600 kgm^{-3},

$P_a = h\rho g$

$= 0.76 \times 13\,600 \times 10$

$= 103\,360\ Nm^{-2}$

This is the standard atmospheric pressure, and is sometimes referred to as **one atmosphere**.

Testing the Vacuum Barometer

If the barometer has air at the top, then it is faulty. The value of pressure indicated by such a barometer is less than the actual value since the trapped air also exerts pressure on the mercury column.

To test for the vacuum, the tube is tilted as shown in figure 4.22 (a) so that the topmost part of the tube is below the height that is supported by atmospheric pressure.

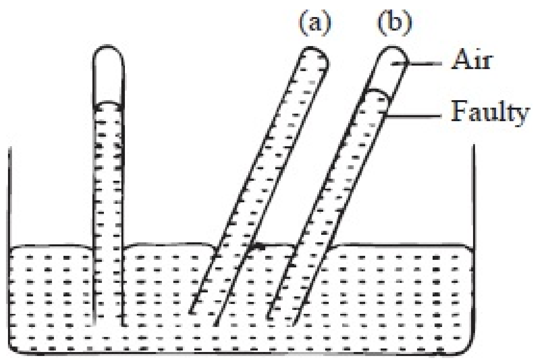


Fig. 4.22

If there is air in the tube, the mercury will not fill the tube completely. However, if the space is a vacuum, the mercury fills the tube completely.

The space above the mercury in the tube when upright is called **Toricellian vacuum** and contains a little mercury vapour.

Fortin Barometer

The simple mercury barometer cannot be used for accurate measurements of atmospheric pressure. An improved version called the **Fortin barometer** is used where high precision is required.

It was designed by Fortin, a French instrument maker. Figure 4.23 shows main parts of the barometer.

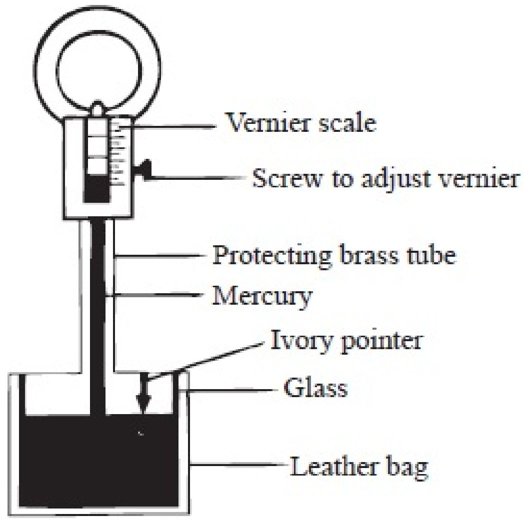


Fig. 4.23: Fortin barometer

The Fortin barometer has a:

(i) vertical glass tube containing mercury.

(ii) leather bag as the reservoir of mercury.

(iii) short fixed main scale and a movable vernier scale which facilitates accurate reading of the mercury height.

(iv) fixed ivory index with a sharp point at the bottom, which acts as the 'zero' mark of the main scale.

Before taking the reading, the level of mercury surface in the reservoir is adjusted by turning the adjusting screw until the surface of the mercury just touches the tip of the ivory index. The mirror-like mercury surface produces an image of the tip which helps to make the adjustment very accurate. The height of mercury is then read from the main scale and the vernier scale. Any change in air pressure makes the surface of mercury in the reservoir move up and down and therefore this adjustment is necessary before the barometer is read. The height of mercury is read from the top part of the meniscus.

The readings obtained from the barometer are in terms of the height of mercury column and are written as mmHg or cmHg (Hg is the chemical symbol for mercury). Therefore, the atmospheric pressure at sea level is expressed as 760 mmHg. It is important however to note that pressure is force per unit area, but not a length.

The atmospheric pressure P_a when the mercury column is 760 mm long is given by;

$P_a = h\rho g$

$= 0.76 \times 13\ 600 \times 10$ (density of mercury is 13 600 kgm^{-3} and g is 10 Nkg^{-1})

$= 103\ 360\ Nm^{-2}$

Aneroid Barometer

The mercury barometer is the most reliable type of barometer, but is not readily portable.

Fig. 4.24: Aneroid barometer

The aneroid barometer is a portable type of barometer consisting of a sealed, corrugated metal box, as shown in figure 4.24. This metal box expands a little if pressure outside is reduced, and reduces in volume a little if subjected to higher pressure from outside. The motion due to the changes in shape of the metal box is magnified by the corresponding movements of the spring strips, lever arm, chain and finally the pointer on the scale.

Normally, the pointer would indicate a particular value of the atmospheric pressure of the surrounding so that any changes in pressure would be noticeable by the movement of the pointer to either side of this atmospheric value on the scale.

The aneroid barometer movements make it adaptable to measure heights. Altimeters are basically aneroid barometers, and are used in aircrafts to measure heights.

The aneroid barometer is normally calibrated in millibars. 1 bar is a pressure of 100 000 Nm^{-2} (standard atmospheric pressure)

1 millibar (mbar) $= \frac{100\ 000}{1\ 000} = 100\ Nm^{-2}$

Pressure Gauges

Pressure gauges are portable and are used mostly for measuring gas pressure, tyre pressure, pressure of compressed air in compressors and steam pressure.

They are basically made of coiled flexible metal tubes which uncoil when the pressure inside increases. The movement of the tube is made to drive a pointer across a scale, through a combined system of levers and gears, see figure 4.25.

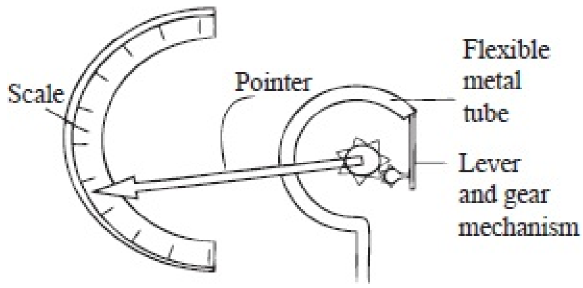


Fig. 4.25: Pressure gauge

Example 10

The pressure of a car tyre, measured with a pressure gauge, is 40 N/cm^2. Determine the total pressure of the tyre in Nm^{-2} given that atmospheric pressure is 103 360 N/m^2.

Solution

Total pressure = atmospheric pressure + gauge pressure

$= 103\,360 + (40 \times 10\,000)$

$= 103\,360 + 400\,000 = 503\,360\ N/m^2$

Applications of Pressure in Gases and Liquids

The Bicycle Pump

A bicycle pump is a simple form of a compression pump. Figure 4.26 shows the main parts of the pump.

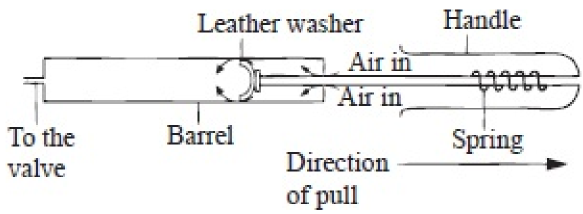


Fig. 4.26: Bicycle pump

It has a flexible leather washer which works both as a valve and a piston inside the pump barrel. Before the pump is used, it is connected to the tyre which has a rubber valve in it.

When the pump handle is drawn out as shown, the volume of air below the washer increases and its pressure is reduced below the atmospheric pressure. Air from outside the pump then flows past the leather washer into the barrel. At the same time, the higher air pressure in the tube closes the tyre valve.

When the pump handle is pushed in, the air in the pump barrel is compressed. The high pressure in the barrel presses the leather washer against the sides of the barrel. When the pressure of the compressed air becomes greater than that of air in the tyre, air is forced into the tyre through the tyre valve which now opens.

Note that there is an increase in temperature of the pump barrel during pumping. This is because of the work done in compressing air.

The Lift Pump

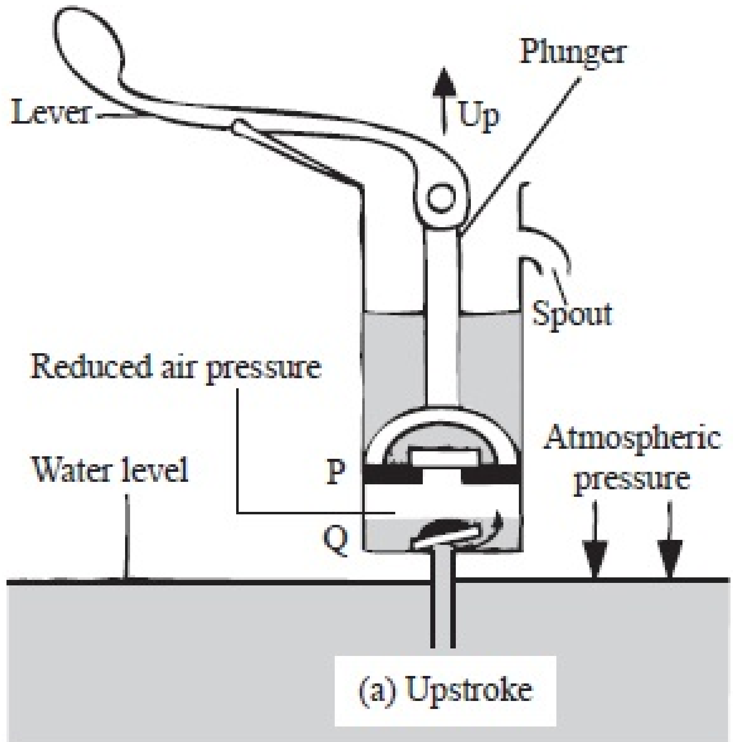
A lift pump is used to raise water from wells. It consists of a cylindrical metal barrel with a spout. It has two valves, P and Q, as shown in figure 4.27.

To start the pump, water is poured on top of the piston (priming) so that a good air-tight seal is made round the piston and valve P. The pump is operated by means of a lever as shown in the figure.

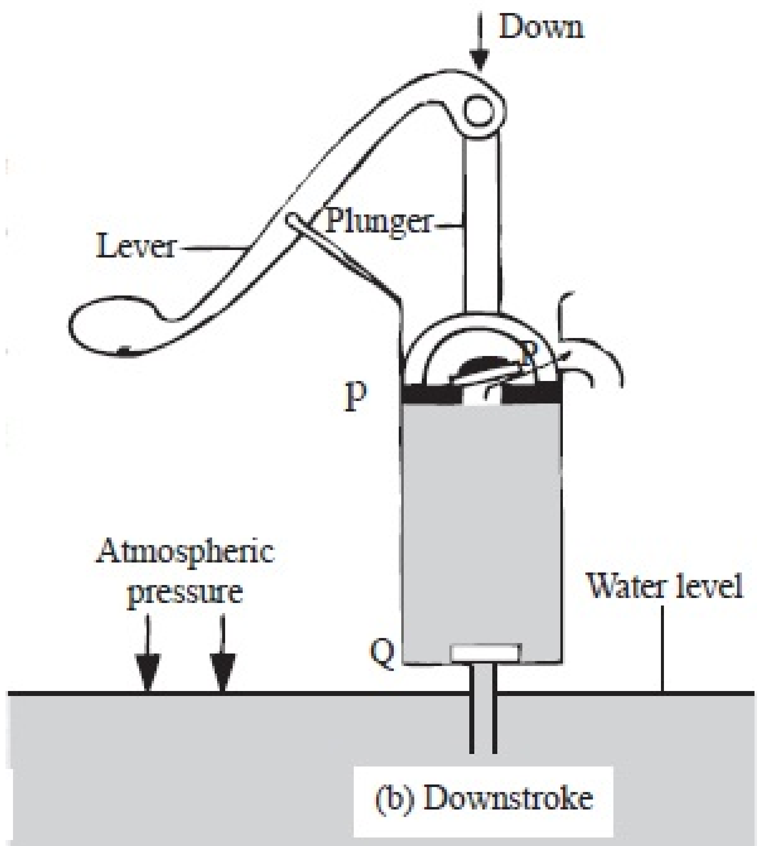
Upstroke

When the plunger moves up during the upstroke, valve P closes due to its weight and pressure of water above it. At the same time, air above valve Q expands and its pressure reduces below atmospheric pressure. The atmospheric pressure on water in the well below thus pushes water up past valve Q into the barrel, as shown in figure 4.27 (a).

The plunger is moved up and down until the space between P and Q is filled with water.



(a) Upstroke



(b) Downstroke

Fig. 4.27: Lift pump

Downstroke

During downstroke, valve Q closes due to its weight and pressure of water above, see figure 4.27 (b).

Water is forced out through valve P and thus flows out of the spout.

Limitations of this pump

The atmospheric pressure can only support a column of water of about 10 m. This is, therefore, the theoretical maximum height to which water can be raised by the pump at normal atmospheric pressure.

In practice, the possible height of water can be raised by this pump is less than 10 m because of:

(i) reduced atmospheric pressure in places high above sea level.

(ii) leakages at the valves and pistons.

The Force Pump

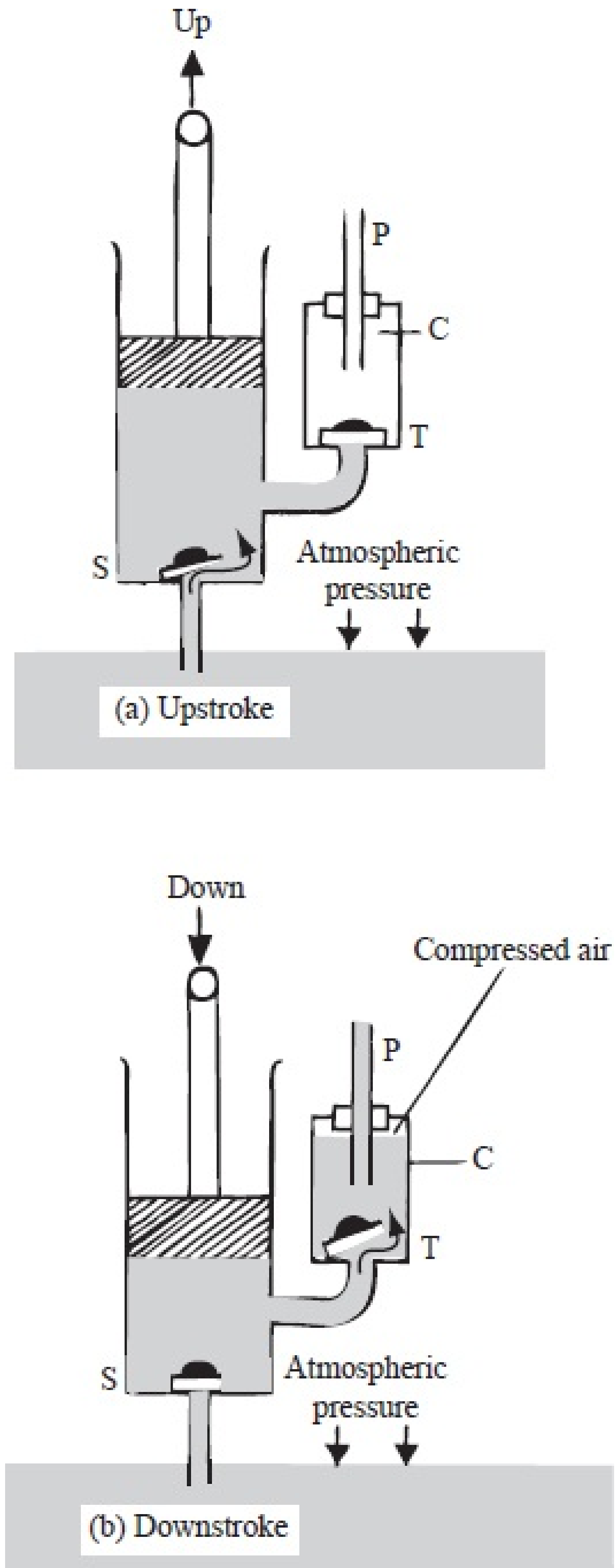
This pump can be used to raise water to heights of more than 10 m.

Upstroke

During upstroke, air above the valve S expands and its pressure reduces below atmospheric pressure. The atmospheric pressure on the water in the well below pushes water up valve S into the barrel. Note that pressure above valve T is atmospheric. Hence, this valve does not open in this stroke, see figure 4.28 (a).

Downstroke

During the downstroke, the valve S closes, see figure 4.28 (b). Increase in pressure in the water in the barrel opens valve T and forces water into chamber C so that as water fills the chamber, air is trapped and compressed at the upper part.



(a) Upstroke

(b) Downstroke

Fig. 4.28: Force pump

During the next upstroke, valve T closes and the compressed air expands, ensuring a continuous flow through P.

This pump has an advantage over the lift pump in that it enables a continuous flow of water and the height to which water can be raised by this pump does not depend on atmospheric pressure, but on the following:

(i) Amount of force applied during the downstroke.

(ii) Ability of the pump and its working parts to withstand pressure of the long column of water in chamber C.

The Siphon

A tube (usually plastic or rubber) can be used to empty tanks or draw petrol from petrol tanks of cars, as in figure 4.29. When used in this way, it is referred to as a **siphon**.

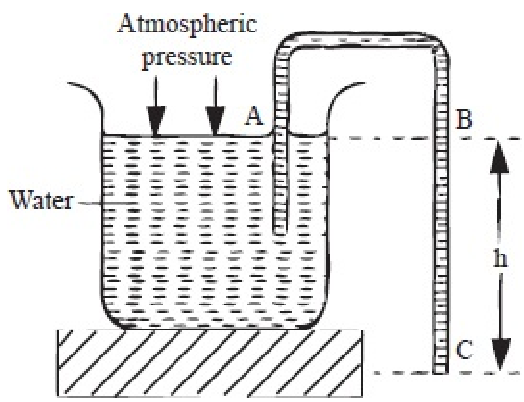


Fig. 4.29: The siphon

The pressure at the surface of the liquid is atmospheric. The tube is first filled with the liquid and end C held below the surface. Pressure at C is greater than that at the surface by an amount hρg.

The liquid will continue to run out so long as the end C is below the liquid surface. Pressure at A and B is atmospheric pressure since they are at the same horizontal level. Pressure at C is equal to atmospheric pressure plus pressure due to column h of the liquid. That is;

Pressure at C

$P_c = P_a + h\rho g$, where P_a is atmospheric pressure and ρ the density of water. The excess presure hρg thus causes the liquid to flow out of the tube at C.

The siphon will only work if:

(i) the end C of the tube is below the surface of A of the liquid to be emptied.

(ii) the tube is first filled with the liquid, without any bubbles in it.

(iii) the tube does not rise above the height of the liquid surface A.

(iv) one end of the tube is inside the liquid to be emptied.

Note:

A siphon can operate in a vacuum. To understand this, consider a chain or thick rope coiled into a bucket, raised above the ground and one end of it over a pulley, see figure 4.30. The loose end A, when it is below the bucket will have a net weight on it. This net weight resulting from the pull of gravity pulls down the chain completely out of the bucket.

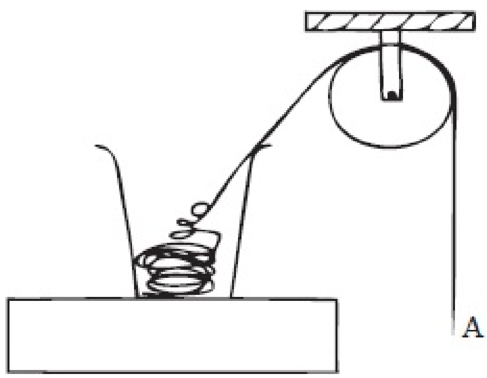


Fig. 4.30

This is how the siphon works in a vacuum.

An application of the siphon is the automatic flushing unit, shown in figure 4.31.

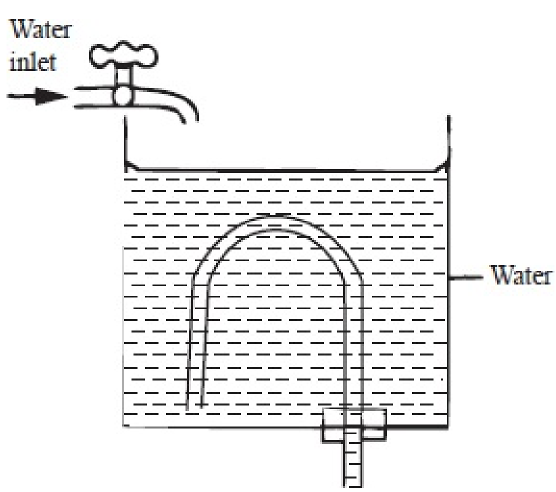


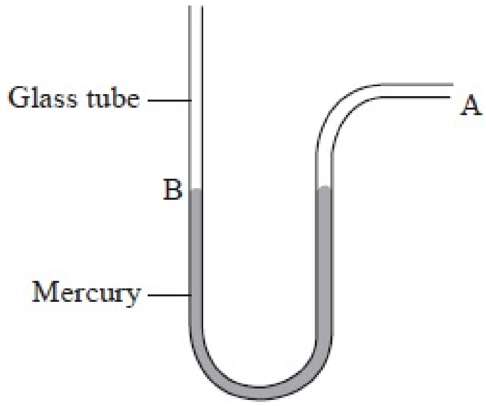
Fig. 4.31: An automatic water flushing unit

It is used where constant cleaning is necessary, like urinals. When the water in the tank fills above the top of the inverted U-tube, a pressure difference between the two arms is created. This causes the water to flow out of the tank. The tap can be adjusted to enable the flushing unit to flush at pre-determined intervals.

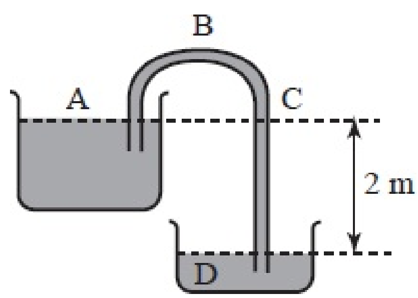
The ordinary lavatory flusher is set to work by mechanically filling the tube with water to create the necessary pressure difference.

Revision Exercise 4

1. Define pressure and state its SI unit.
2. Explain how a fountain pen is filled up with ink.
3. The atmospheric pressure on a particular day was measured as 750 mmHg. Express this in Nm^{-2}. (Assume density of mercury is 13 600 kgm^{-3} and g = 10 Nkg^{-1})
4. In a hydraulic press, a force of 200 N is applied to a master piston of area 25 cm^2. If the press is designed to produce a force of 5 000 N, determine:
   (a) the area of the slave piston.
   (b) the radius of the slave piston.
5. The barometric height of a town is 70 cmHg. Given that the standard atmospheric pressure is 76 cmHg and the density of mercury is 13 600 kgm^{-3}, determine the altitude of the town. (Density of air is 125 kgm^{-3})
6. The height h of a water manometer is 20 cm when used to measure the pressure of a gas. Calculate the height of a manometer whose liquid is glycerine of density 1.26 g/cm^3 (Take g = 10 Nkg^{-1})
7. Explain how the pressure of a gas can be examined using the apparatus shown in the figure below:



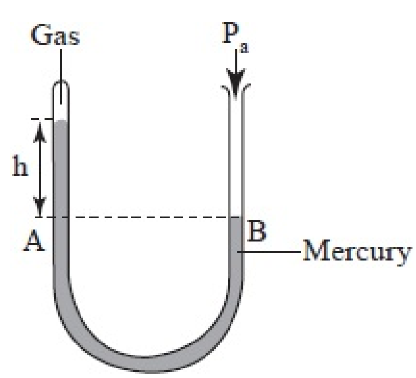
8. The figure below shows how to empty water from a large tank into a low-lying container using rubber tubing:



(a) Explain why the tube must be filled with water before the emptying process starts.

(b) Soon after the tank begins to empty, the lower end is momentarily blocked by placing a finger at end D. Determine the pressure difference between points A and D. (Take density of water to be (1000 kgm^{-3})

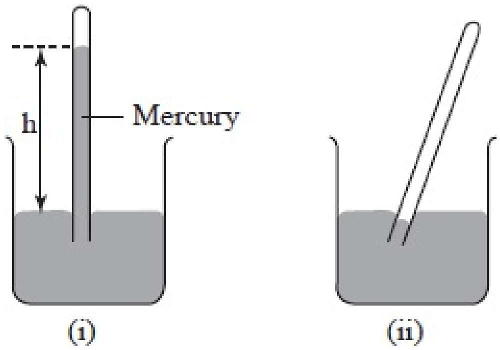
9. The diagram below shows a mercury manometer. Some dry gas is present in the closed space in limb A, while limb B is open. If atmospheric pressure P_a = 100 000 Nm^{-2}, h = 20 mm and density of mercury is 13 600 kgm^{-3}, determine pressure P_g of the gas in mmHg. (Take g = 10 Nkg^{-1})



10. (a) Explain briefly the working of a simple mercury barometer.

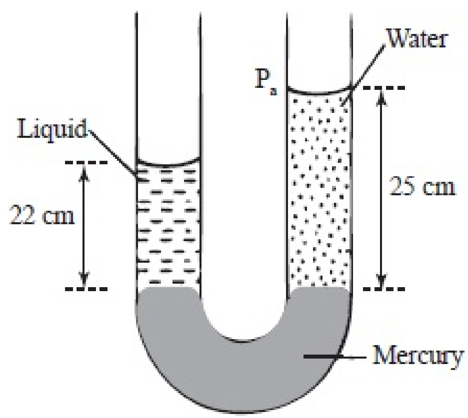
(b) Explain the test that would be made to find out whether such a barometer has any gas in the space above the mercury.

(c) Figure (i) below shows a simple mercury barometer, while figure (ii) shows the same barometer with the tube tilted from the vertical:



Mark the level of mercury in tube (ii).

11. The figure below shows a U-tube filled with water, mercury and another liquid:



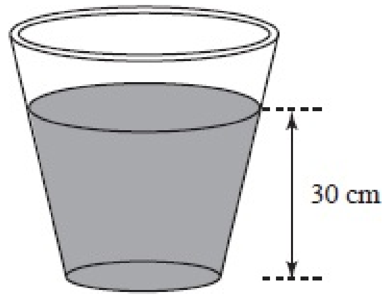
(a) Determine the density of the liquid.

(b) State a possible reason why mercury is used.

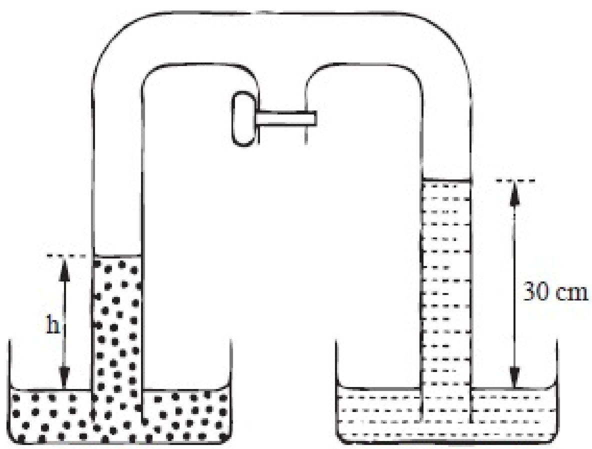
12. The figure below shows a liquid in a pail.

(a) If the liquid has a density of 1.20 gcm^{-3}, determine the pressure exerted at the bottom of the container by the liquid.

(b) Suggest a reason why pail manufacturers prefer the shape shown to other shapes.



13. The figure below shows columns of different liquids in a tube. Determine the height of liquid A if its density is 1.20 g/cm^3.



14. A roof has a surface area of 20 000 cm^2. If the atmospheric pressure exerted on the roof is 100 000 Pa, determine the force on it. (Take g = 10 Nkg^{-1})
15. Explain how a syringe draws;
    (a) injectable drug from a bottle.
    (b) blood from a patient's body.

Chapter 5

The Particulate Nature of Matter

Matter is anything that occupies space and has mass. Matter commonly exists as solid, liquid or gas. The physical objects and materials around us like glass, water and the air manifest the existence of matter in its three states.

The process of subdividing matter into smaller and smaller units continues indefinitely, suggesting that matter is not continuous, but is made up of even smaller parts.

Investigating Matter

There are several experiments that can be performed to show that matter is made up of tiny particles. Some are considered below.

Experiment 5.1: To demonstrate that matter is made of tiny particles

Apparatus

A sheet of paper and a pair of scissors.

Procedure

- Cut the piece of paper into two parts.
- Take one part and cut it again into two parts and continue the process.

Figure 5.1 shows that the piece of paper can be cut into very many tiny pieces.

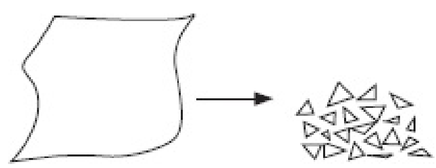


Fig. 5.1: Paper cut into smaller pieces

Observation

The process of cutting can continue until further subdivision becomes impracticable.

Conclusion

The fact that the piece of paper can be subdivided into tiny pieces suggests that matter is made up of tiny particles.

Experiment 5.2: To demonstrate dilution

Apparatus

Beaker, potassium permanganate crystals, water.

Procedure

- Pour water into the beaker till it is a quarter full.
- Dissolve a few crystals of potassium permanganate in the water until the colour is deep purple.
- Add water to top up the volume to about half full as you observe the change in colour intensity.
- Gradually add more water as you observe the change in colour intensity. Continue the process until the beaker is full.

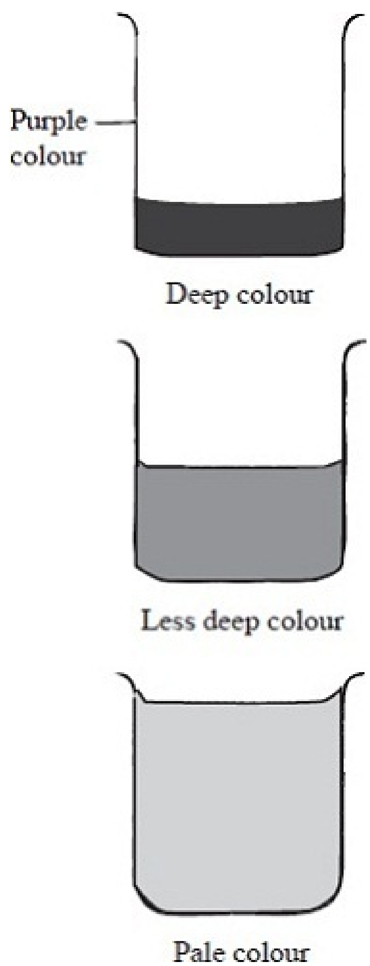


Fig. 5.2

Observation

The process of dilution can continue until the solution appears colourless. This suggests that the particles of potassium permanganate are spread out evenly on the water. Through each dilution process, the particles spread out further. As water particles increase, the particles of potassium permanganate are spread further, making the purple colour less and less deep until it appears colourless.

Conclusion

Potassium permanganate is made up of tiny particles.

Experiment 5.3: Dissolving a solid in a solvent

Apparatus

Flask with a stopper, common salt, pipette.

Procedure

- Put 100 g of salt into the flask and add water carefully using a pipette without shaking the salt, until the flask is full, see figure 5.3 (a).
- Insert the stopper to the mouth of the flask and shake to dissolve the salt.

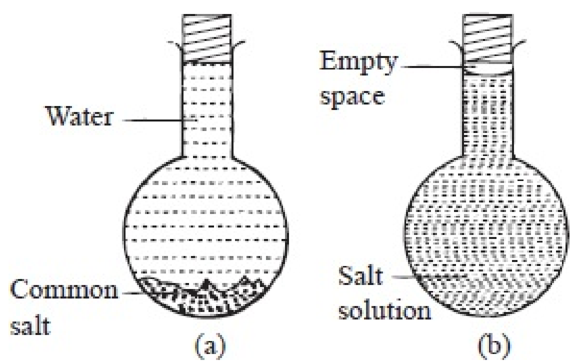


Fig. 5.3: Dissolving

Observation

From figure 5.3 (b), the volume of the solution of salt is less than the volume in figure 5.3 (a).

Conclusion

Particles of salt are able to occupy some spaces between the water particles. This suggests that the particles of water and the particles of salt differ in size. The particles of the solution pack more closely in the available space, thus reducing the volume. This further suggests that particles of salt are broken down to fit into the spaces between the water particles.

Explain the purpose of shaking the flask. State the difference, if any, that would be observed when you use warm water as a solvent.

Experiment 5.4: To demonstrate the Brownian motion in liquids

Apparatus

Beaker, hand lens, pollen grains or chalk dust, transparent lid.

Procedure

- Pour water into the beaker, about three quarters full, as shown in figure 5.4.

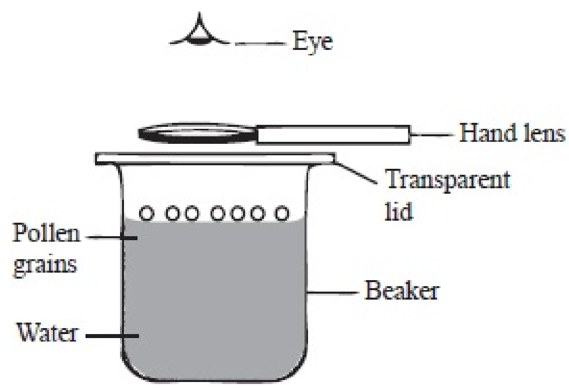


Fig. 5.4: Brownian motion

- Sprinkle pollen grains or chalk dust on the surface of the water (it is important that the grains be very small in size, light and evenly sprinkled on the water surface for good results).
- Cover the beaker with a transparent lid.
- With the help of a hand lens, observe what happens to the pollen grains on the water surface.

Observation

It is observed that the pollen grains are in constant random motion, see figure 5.5.

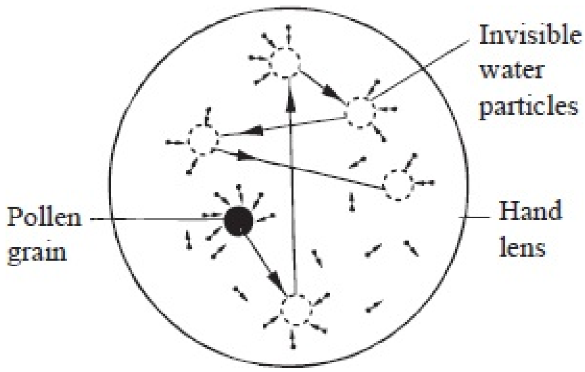


Fig. 5.5: Random motion

Conclusion

The grains are being continually hit by small invisible particles of water. The movement is random, suggesting that the particles of water are in constant random movement. This kind of motion is called **Brownian motion**, a tribute to the scientist by the name Robert Brown, who first observed the effect in 1827.

The Smoke Cell Experiment

Experiment 5.5: To demonstrate Brownian motion in air

Apparatus

Drinking straw, smoke cell, microscope and a bright light source.

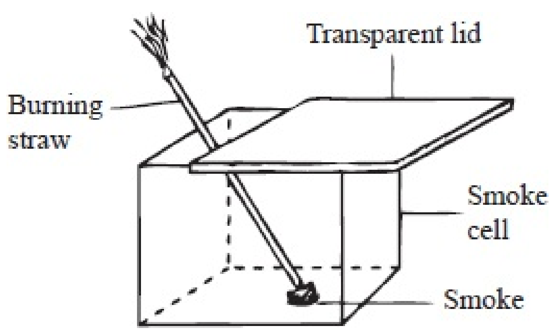


Fig. 5.6: Smoke cell

Procedure

- Burn one end of a straw and let the smoke fill the smoke cell from the other end of the straw as shown in figure 5.6. Remove the straw.
- Put a cover plate on top to seal the smoke and air in the cell.
- Now, set up the apparatus as shown in figure 5.7.

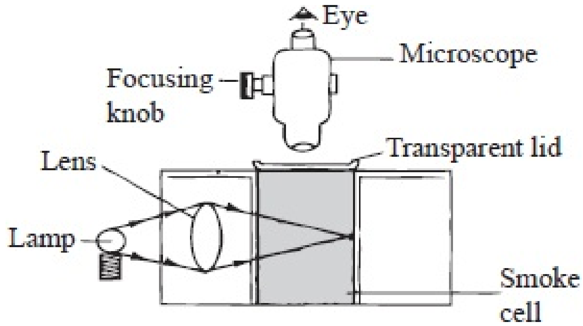


Fig. 5.7: Smoke cell experiment

- Illuminate the cell with a bright light. Use a converging lens to focus the light on the smoke cell.
- Adjust the microscope until you can see very bright specks against the grey background.

Observation

Bright specks in continuous random motion are seen in the smoke cell.

Explanation

The bright specks are particles of smoke which scatter the light shining on them and so appear as bright points. They move about in a continuous random movement because of uneven bombardment by the invisible particles or molecules in air. This suggests that air is made up of very small particles which are in continuous random motion.

Conclusion

From the experiment above, it can be deduced that matter is made up of very small particles which are in constant random motion. This is called the **kinetic Theory of Matter.**

Arrangement of Particles in the States of Matter

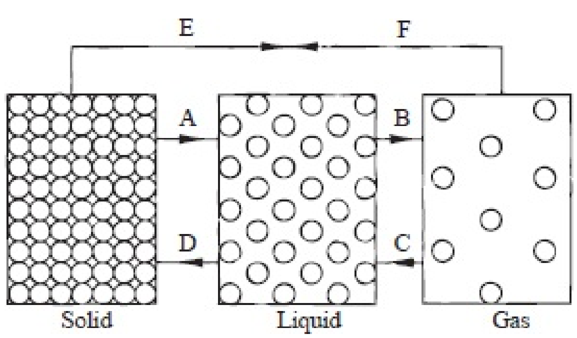


Fig. 5.8: States of matter

A – Melting

B – Vaporisation

C – Condensation

D – Solidification

E – Sublimation

F – Deposition

Solids

Particles of solids are closely packed together in an organised way, see figure 5.8. The closely knit structure is due to strong attractive forces between the particles.

The force of attraction between particles of the same kind is called **cohesive force**. In their fixed positions, the particles vibrate to and fro such that increasing the temperature of the solid increases this vibratory motion. At a certain temperature for a particular solid, the particles break away from this knit structure and the solid is said to have melted.

Liquids

The particles are further apart as shown in the figure.

They are not fixed as in solids but move about in Brownian motion and can do some work like breaking down a solute put in the liquid. It is easier to dissolve a solute in hot water because the particles have increased energy. The fact that a solid dissolves in water suggests that a solid is made up of small particles and that a liquid has randomly moving particles.

The cohesive forces between particles in liquids are weaker compared to those in solids. Because of this, liquids can flow and take up the shape of a container in which they are put. When a liquid is heated, it changes into a gaseous state by a process called **vaporisation**.

Gases

The particles are further apart and have increased random motion compared to those in the liquid state. The cohesive force between the particles is extremely small and as the particles move, they collide with each other and with the walls of the container in which they are trapped. This produces gas pressure.

The fact that it is easier to compress gas than liquids indicates that there are large inter-molecular distance in gases than in liquids. Gas molecules or particles can lose some of their energy and fall back into the liquid state by a process known as **condensation**.

Some solids directly change to gas. This process is called **sublimation** and the reverse process is called **deposition**.

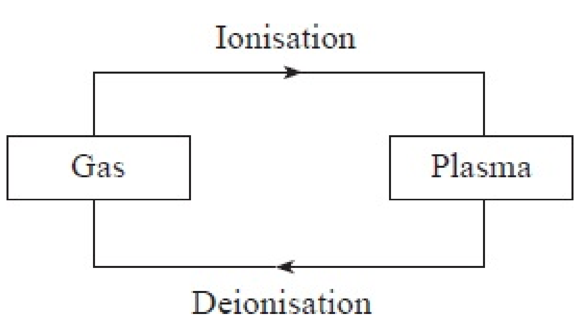
Figure 5.8 summarises the processes above.

Related to the gaseous state is another state of matter called **plasma**.

Plasma is a state of matter in which a certain portion of the particles in the gas are in the form of ions, i.e., molecules or atoms in which the number of positively charged particles is not equal to the number of negative electrons.

Heating a gas to very high temperatures may **ionise** it thus turning it into a plasma. Common forms of plasmas include lightning and some extremely hot flames. Plasma can also be artificially produced, e.g., inside fluorescent tubes and in plasma television set displays, see figure 5.9.

Fig. 5.9 : Plasma TV and fluorescent tubes



Diffusion

How would you explain the observation that if a perfume is placed at one corner of a room, it can be detected by the sense of smell throughout the room?

The process by which particles spread from regions of high concentration to those of low concentration is called **diffusion**.

Diffusion in Liquids

Experiment 5.6: To investigate diffusion in liquids

Apparatus

Funnel, beaker, copper sulphate solution.

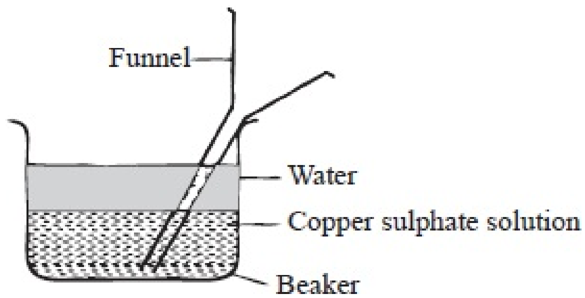


Fig. 5.10: Diffusion in liquids

Procedure

- Pour water into the beaker until it is half full.
- Pour saturated copper(II) sulphate solution down the funnel slowly and notice how the two liquids settle.
- Remove the funnel carefully so that the liquids are not disturbed.
- Repeat the same steps with another set of apparatus, but using warm liquids. Make observations several times over a period of, say, two days.

Observation and Explanation

Initially, the water layer floats on top of the saturated copper(II) sulphate solution because it is less dense. After sometime, the boundary disappears and the two liquids form a homogeneous pale blue mixture.

Formation of the mixture is faster with hot liquids because the movement of particles is faster due to increased energy. There is greater movement of water particles (molecules) from the water layer into the copper(II) sulphate layer because it has greater concentration of water molecules than copper(II) sulphate particles.

Similarly, there is greater movement of particles from copper(II) sulphate layer into the water layer because of greater concentration of copper(II) sulphate particles than water molecules.

Diffusion in Gases

Experiment 5.7: To demonstrate diffusion in gases

Note*:*

This experiment should be done in a fume cupboard or fume chamber because of the poisonous nature of bromine.

Apparatus

Two gas jars, bromine gas.

Procedure

- A gas jar containing brown bromine gas and covered with a sheet of cardboard is placed in contact with an open end of a gas jar of the same diameter with the mouth smeared with grease.
- The cardboard is removed and the jars pressed together tightly, see figure 5.11 (b).

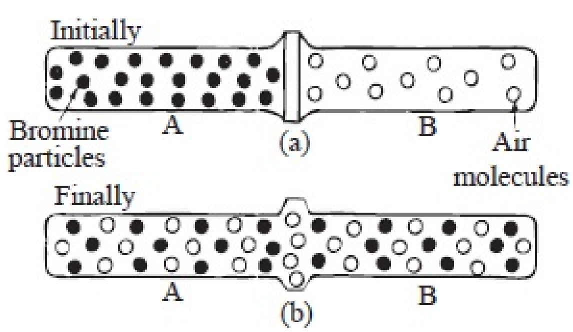


Fig. 5.11: Diffusion in gases

Observation and Explanation

The bromine gas spreads into the gas jar B at a greater speed than it returns to gas jar A because of high concentration of bromine particles.

Likewise, air spreads into gas jar A at greater rate than it returns to B because of high concentration of air particles in B. As shown in figure 5.11 (b), a homogeneous pale brown mixture forms in the two jars and because this happens in a very short time, it suggests that the random moverment of the particles is more rapid in gases than diffusion in liquids. Performing the same experiment with the jars held vertically instead of horizontally slows down the rate of diffusion because of the different densities of the gases. The less dense gas diffuses much faster into the more dense gas.

The characteristic smell of cooking gas used in laboratories can be detected when there is a leakage. This is because the gas diffuses into the air.

Diffusion in Solids

Diffusion in solids is exceedingly slow, but occurs when two metals are placed in contact with each other, e.g., lead and gold metal blocks.

Vibrating atoms break away from the substance to which they belong and enter the other substance to be trapped by its attractive forces. This process is speeded up by high temperatures.

Diffusion in liquids occurs at a faster rate than in solids. Diffusion in gases is faster due to their low density, high kinetic energy of their molecules and low cohesive forces.

Rates of Diffusion

Experiment 5.8: To investigate the rates of diffusion of ammonia gas and hydrochloric acid gas

Apparatus

Long glass tube with fitting corks, cotton wool, concentrated solution of hydrochloric acid and concentrated ammonia solution.

Procedure

- Clamp a long glass tube horizontally as shown in figure 5.12. Soak a piece of cotton wool in concentrated solution of hydrochloric acid and another in concentrated ammonia solution. Care should be taken while handling the two solutions because of their burning effect on the skin.

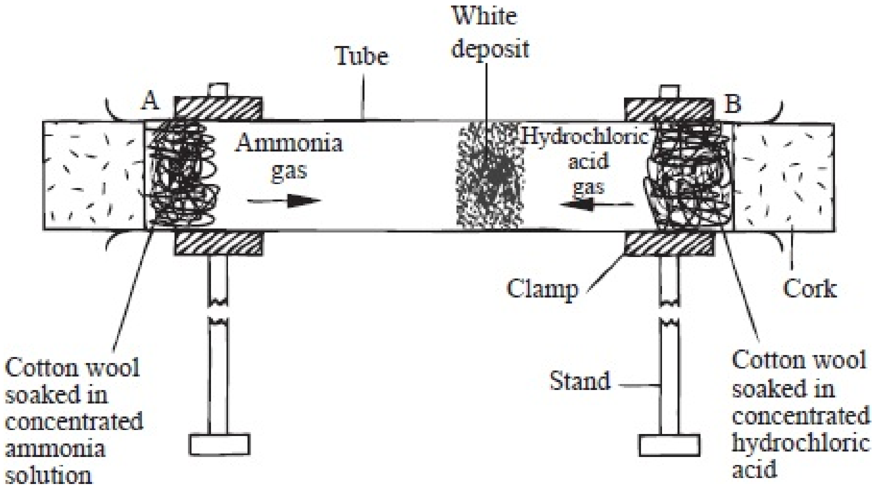


Fig. 5.12

- Simultaneously insert the soaked cotton wool pieces at the opposite ends of the horizontal glass tube and cork it. Observe what happens.

Observation and Explanation

A white deposit of ammonium chloride forms on the walls of the glass tube in the region nearer end B. This suggests that although both gases diffused, ammonia gas did so at a higher rate than the hydrochloric acid gas.

Conclusion

Different gases have different rates of diffusion. A gas of high density has heavier particles or molecules, hence moves more slowly than a lighter one.

Diffusion through Porous Materials

Figure 5.13 shows diffusion through a porous pot.

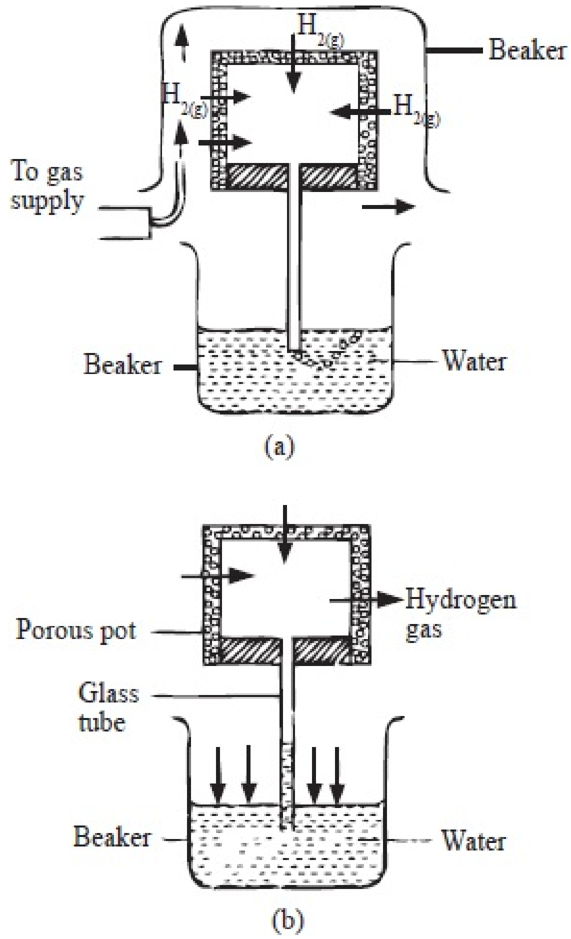


Fig. 5.13: Diffusion through porous pot

The porous pot has very fine holes through which the hydrogen gas diffuses into the pot and air diffuses out. The hydrogen gas bubbles out of the glass tube as shown in the diagram. When the gas supply is stopped, the hydrogen gas diffuses out of the pot through the fine hole at a faster rate than air gets back in the pot. This decreases the gas pressure in the pot, compelling the atmospheric pressure acting on the water surface in the beaker to push water up the tube.

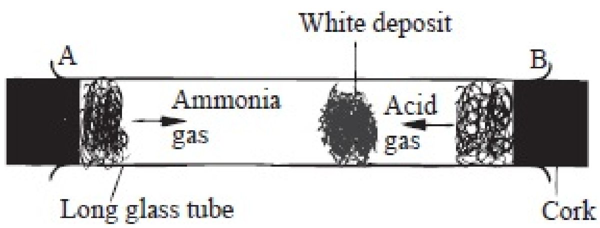
Note:

The beaker in 5.13 (a) is for confining the hydrogen gas around the porous pot.

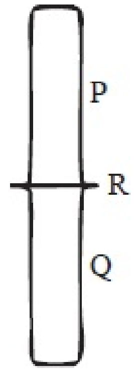
Revision Exercise 5

1. Using pollen grains placed on water, explain how their motion supports the idea that matter is not continuous.
2. Describe the smoke cell experiment and explain how you can deduce from observations that particles of air are in constant and random motion.

3. Explain how temperature affects Brownian motion?
4. State the kinetic theory of matter.
5. Explain why it is possible to compress gases but not solids or liquids.
6. (a) In terms of cohesive forces and inter-particle distances of particles in matter, distinguish between the three states of matter.
   (b) Using a block diagram and correct terminology, show how one state of matter changes to the other when the temperature is changed. Define all the terminologies used.
7. (a) Explain how diffusion supports the idea that matter is made up of particles.
   (b) Describe an experiment that would demonstrate diffusion in liquids.
8. In the figure below, ammonia gas and an acid gas diffuse and react to form a white deposit on the walls of the glass tube. The deposit forms nearer end B.



   (a) State which gas diffused faster.
   (b) Explain how the rate of diffusion depends on the density of a gas.
   (c) If the experiment was performed at a higher temperature, would you expect it to take longer or shorter time to form the white deposits? Explain.
9. A small potassium permanganate crystal is dropped into clean water. It dissolves and the colour eventually fills the whole beaker, but this takes a long time. Use the idea of particles to explain this.
10. Compare diffusion of chlorine gas into air and into vacuum. Explain your comparison.
11. Describe an experiment that gives evidence that matter is made of small particles in random motion.
12. The figure below shows a gas jar Q containing nitrogen oxide gas which is brown in colour and is denser than air and a jar P which contains air. When the cover R is removed, nothing visible happens in the first few minutes (about 10 minutes):



(a) Explain why nothing visible happens in the first few minutes.

(b) Explain what you would observe after, say 30 minutes? What do you think will have happened.

13. A glass-sided box containing a mixture of smoke and air is illuminated and viewed through a microscope. It is observed that small bright specks are seen to be moving randomly.

(a) Explain what the bright specks are.

(b) State why they move?

(c) If the mixture of smoke and air was warmed. Explain the change or changes there would be in the motion of the specks.

14. Describe the difference between solids, liquids and gases in terms of:

(a) the arrangement of molecules.

(b) distance separating the molecules.

(c) the movement of molecules.

15. (a) Indicate the processes through which the state of substances can be changed.

(b) Explain why the smell of rotten eggs broken at one end of the room soon spreads throughout the room.

Chapter 6

Thermal Expansion

Temperature

Suppose you are given two bodies, one cold and the other hot. The sense of touch will enable you to differentiate between the cold body and the hot one.

However, this method is subjective and will not give an accurate comparison. A standard scale is, therefore, necessary for the purpose.

The degree (extent) of coldness or hotness of a body on some chosen scale is called the **temperature of the body**. The temperature of a body is measured by an instrument called a thermometer.

Temperature is a basic quantity and is measured in degrees Celsius (°C) or Kelvin (K). The Kelvin is the SI unit of temperature, which is a scalar quantity.

Expansion and Contraction of solids

Metals and other solids expand (increase in size) when heated and contract (decrease in size) when cooled.

Experiment 6.1: To demonstrate expansion of solids using the ball and ring experiment

Apparatus

Ball and ring apparatus. The ball should be such that it just passes through the ring when both are at room temperature.

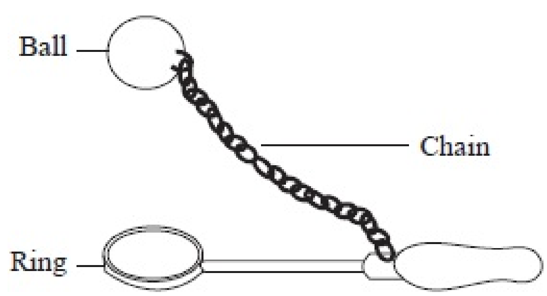


Fig. 6.1: Ball and ring

Procedure

- Heat the ball and try to pass it through the ring. Observe what happens.
- Leave it there for some time. Observe what happens.

Observation

When both the ball and the ring are at room temperature, the ball just passes through the ring. When the ball is heated, it does not go through the ring but when left there for sometime, it goes through.

Explanation

When heated, the ball expands so that it cannot go through the ring.

When left on the ring for sometime, the temperature of the ball decreases and it contracts. At the same time, the temperature of the ring increases and it expands so that the ball goes through.

Experiment 6.2: To demonstrate expansion in solids using the bar and gauge apparatus

Apparatus

Bar and gauge apparatus, Bunsen burner.

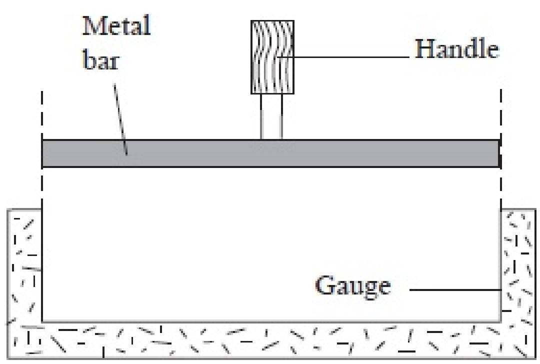


Fig. 6.2: Bar and gauge

Procedure

- Fit a metal bar in the gauge when cold as shown in figure 6.2 and note what happens.
- Heat the metal bar and try to fit in the gauge. Note the observations.

Observation

When the bar is cold, it just fits into the gauge. When heated, the bar does not fit into the gauge.

Explanation

The bar expands when heated.

To compare the Expansion of Different Metals

Figure 6.3 shows apparatus that can be used to compare the expansions of different metals. In this apparatus, a small expansion of the metal bar is magnified using a long pivoted pointer.

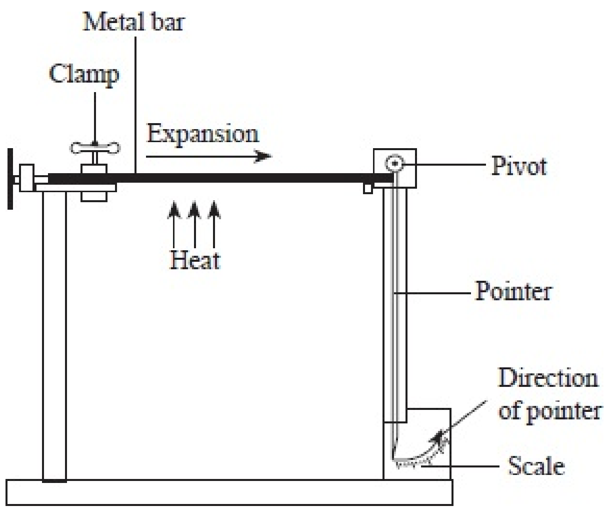


Fig. 6.3

One end of the metal bar is fixed while the other end is in contact with the pointer.

To compare expansions of different materials, rods of same length and diameter are used. Each is fixed at a time and heated from room temperature with the same burner for 5 minutes.

If the rods are allowed to cool to room temperature, the pointer will record the original scale reading. The set-up can be used to show that metals expand differently when heated through the same length of time.

Force Due to Expansion and Contraction

Experiment 6.3: To investigate the force due to expansion and contraction

Apparatus

Bar-breaking apparatus with at least two cast iron pins, Bunsen burner.

Procedure

- Fit the tensioning nut and cast iron pin on the inside position of a bar-breaking apparatus, as shown in figure 6.4 (a).

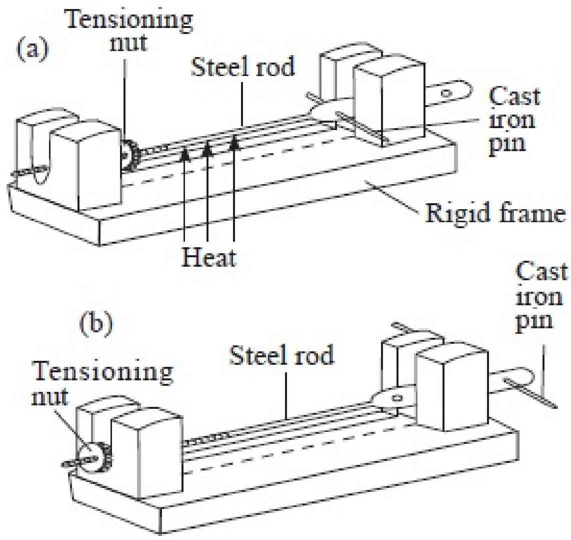


Fig. 6.4: Force due to expansion and contraction

- Tighten the tensioning nut until there is no room for expansion of the steel rod.
- Heat the steel rod strongly and note what happens to the cast iron pin. Allow the apparatus to cool and repeat the experiment with the other cast iron pin and the tensioning nut on the outside, as shown in figure 6.4 (b).
- Withdraw the flame and allow the steel rod to cool.
- You may pour cold water on it to cool it faster. Observe what happens to the pin.

Observation

The cast iron pin breaks in both cases.

Conclusion

The experiment shows that very strong forces are generated when metals expand and contract due to heating or cooling.

When expansion occurs in a material, there is an increase in volume with no change in mass, hence a decrease in density.

Linear Expansivity

When a steel rod is heated, it expands. The change in length (increase in length) of the rod is called its **linear expansion**.

The measure of the tendency of a particular material to expand is called its **expansivity**. Aluminium expands more than iron, thus aluminium has higher expansivity than iron. Table 6.1 shows linear expansivity values of some materials.

Table 6.1

Material	**Linear expansivity (K^{-1}) × 10^{-6}**
Aluminium	26
Brass	19
Copper	16.8
Iron	12
Concrete	11
Steel	11
Glass	9
Platinum alloy	9
Silica	4.2
Pyrex	3.2
Invar	1

The knowledge of linear expansivity values is applied in the designing of materials to ensure that they are able to operate well under varying thermal conditions.

Ordinary glass expands at a higher rate than Pyrex glass. When hot water is poured into a tumbler made of ordinary glass, it breaks. However, when Pyrex tumbler is used, there is no danger of it cracking. Pyrex glass with its low value of expansivity will not suffer very large forces of expansion as it undergoes temperature change.

In building construction, beams can be made out of concrete reinforced with steel because they expand at the same rate. Similarly, platinum wires are encased in glass for electrical insulation.

The Bimetallic Strip

When two metals of different linear expansivity are riveted together, they form a bimetallic strip. Brass and iron are used to make the bimetallic strip shown in figure 6.5.

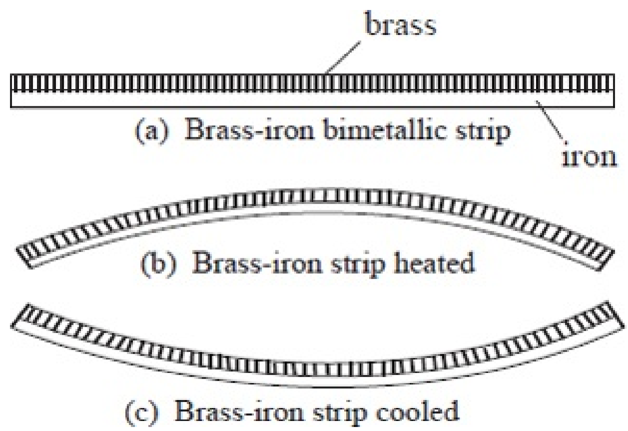


Fig. 6.5: Behaviour of bimetallic strip

On heating the bimetallic strip, brass expands more than iron. The brass thus becomes longer than the iron for the same temperature range. Hence, the bimetallic strip bends with brass on the outside of the curve.

On cooling however, the brass contracts more than the iron. It, therefore, becomes shorter than the iron and thus ends up being on the inner side of the curve.

Applications of Expansion and Contraction in Solids

Railway lines

Railway lines are constructed in sections held together by fishplates. The bolt holes in the rail are oval to allow free expansion and contraction of the rails with changes in temperature, see figure 6.6.

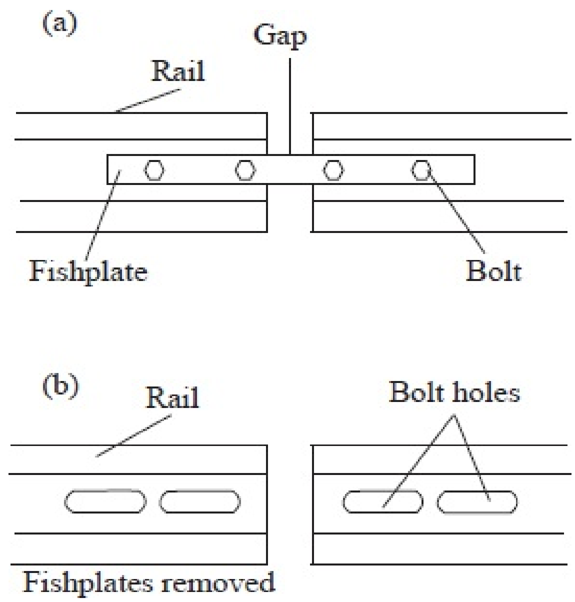


Fig. 6.6: Allowing for expansion and contraction on a railway line

This rail construction design is known as the jointed track. Some space known as **expansion joint** is left between the railway lines to allow for expansion. The jointed track does not offer high quality train ride and has largely been discarded in the developed world, but is still common in the developing world since it is relatively cheaper to install and maintain compared to other designs.

A more modern method of allowing for expansion in railway lines is to taper the ends of the rails so that they overlap, as shown in figure 6.7.

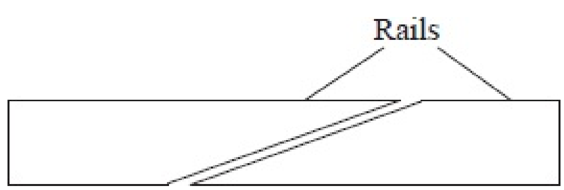


Fig. 6.7: Rails overlapping

Steam Pipes

Pipes carrying steam from boilers are fitted with loops or expansion joints, see figure 6.8. These allow the pipes to expand and contract easily when steam passes through, and when the pipe cools down.

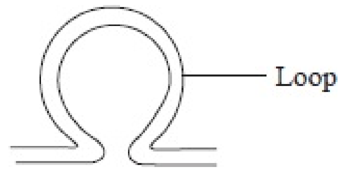


Fig. 6.8: Expansion joint

Without the loop, the forces of expansion and contraction produced would cause the pipe to fracture. Oil companies make this allowance when constructing fuel pipelines.

Telephone Wires

Telephone wires are loosely fixed to allow for contraction. During cold weather, they contract and when it is warm, they expand.

Telephone or electricity wires appear to be shorter and taunt in the morning, see figure 6.9(a). However in the hot afternoon, the wires appear longer and slack, see figure 6.9(b).

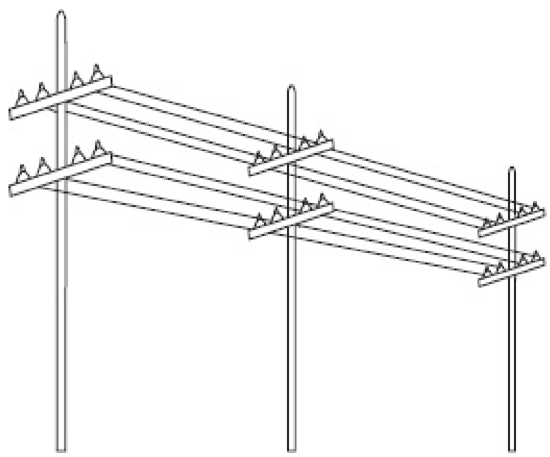


Fig. 6.9 (a): Wires in the morning

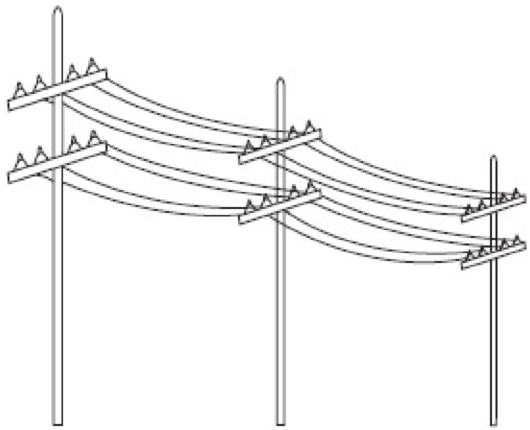


Fig. 6.9 (b): Wires on a hot afternoon

Steel Bridges

In bridges made of steel girders, one end is fixed and the other end placed on rollers to allow for expansion, see figure 6.10.

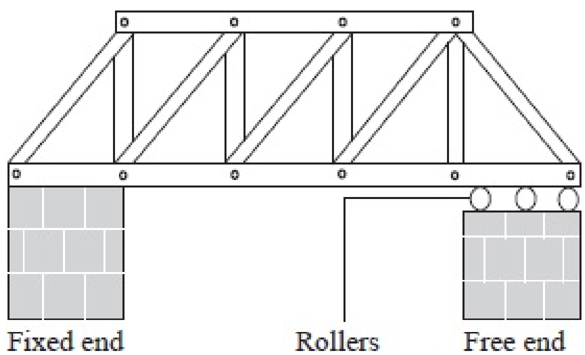


Fig. 6.10

Rivets

Thick metal plates, sheets and girders in ships are joined together by means of rivets. The rivet is fitted when hot and then hammered flat. On cooling, it contracts, pulling the two plates firmly together, see figure 6.11.

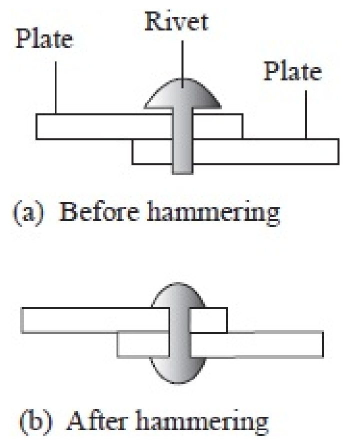


Fig. 6.11: Metals joined by rivets

The Bimetallic Strip

Bimetallic strips have several applications such as in the thermostat.

A thermostat is a device for maintaining a steady temperature. Figure 6.12 shows a thermostat used for controlling the temperature of a room warmed up by an electric heater.

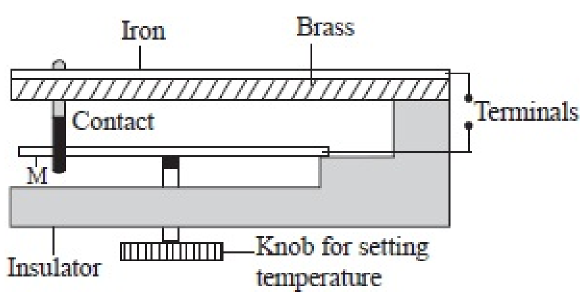


Fig. 6.12: A thermostat

A heater circuit is connected through the electric terminals shown. If the room becomes warm, the bimetallic strip bends, curving away from the lower contacts. This breaks the circuit and switches off the heater. On cooling, the bimetallic strips bends back, closing up the gap between the contacts and the heater is switched on again. The temperature at which the thermostat switches the heater on and off is adjusted by the setting knob.

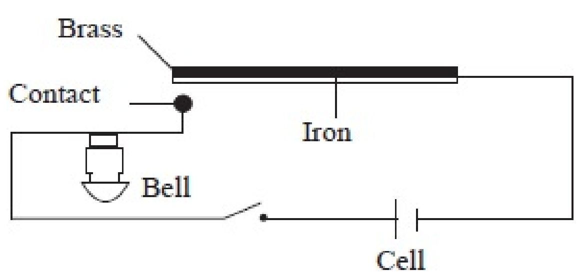
For high temperatures, the setting knob is adjusted to push the metal strip M such that the contacts are tight together. The temperatures must then rise to quite high values before the bimetallic strip can bend away sufficiently to break the circuit. A slight drop in the temperatures will result the bimetallic strip bending back to close the contacts again.

For low temperature range, the adjusting knob is released so that the position of M is lowered. The temperature then has to drop to a much lower value before the bimetallic strip bends to make contact. Thermostats are also used to control the temperature of electric irons, cookers and fridges.

Modern digital thermostats have no moving parts and are instead made up of thermistors (temperature-sensitive resistors) or semiconductors. They have a digital screen showing the temperature reading currently and the temperature that has been set as the threshold.

Exercise 6.1

1. (a) Describe how an iron tyre is fitted onto the wheel of a train.
   (b) In the laboratory, boiling tubes made of glass are subjected to strong flames for heating without cracking. Explain.
2. The figure below represents a simple fire alarm. Explain how it works.



3. State and explain the disadvantages of thermal expansion in solids.

Expansion and Contraction of Liquids

Experiment 6.5: To demonstrate the expansion of water

Apparatus

A round-bottomed flask filled with coloured water, Bunsen burner.

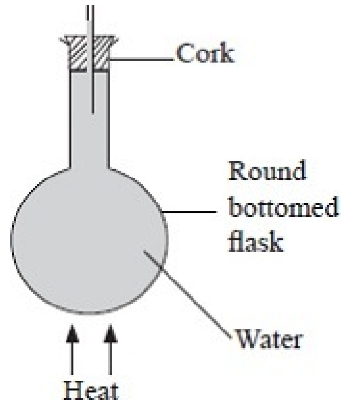


Fig. 6.13: Expansion of water

Procedure

- Fill a flask with coloured water and arrange the apparatus as shown in figure 6.13.
- Mark the level of the water in the glass tube.
- Heat the flask with the burner flame as you observe the level of water in the tube.

Observation

The level of the water in the glass tube falls slightly at first and then starts rising.

Explanation

The initial fall of the level of the water is due to the expansion of the glass flask which gets heated first. The water starts expanding when the heat finally reaches it, and it rises up the tube.

Note:

The water expands faster than glass.

Experiment 6.6: To compare the expansion of different liquids

Apparatus

Three identical glass flasks, one filled with water, another with alcohol and the third with methylated spirit, a water bath.

Procedure

- Place the flasks in a water bath in such a way that they are all covered to the same depth, as shown in figure 6.14 Ensure that the liquid levels in all the tubes are the same.

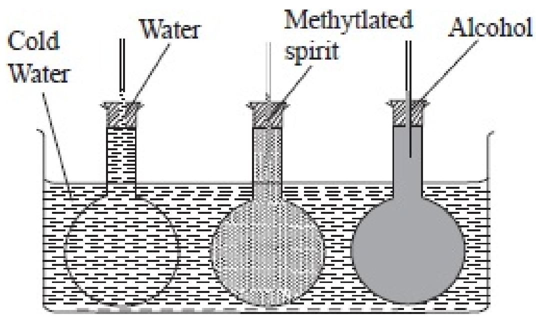


Fig. 6.14: Liquids before heating the water

- Heat the water bath while stirring and observe the liquid levels.

Observations and Conclusion

The levels of the liquids in the tubes rise by different amounts as the heating continues. This shows that some liquids expand more than others for a given rise in temperature. Of the three liquids used, methylated spirit expands most, followed by alcohol and finally water, see figure 6.15.

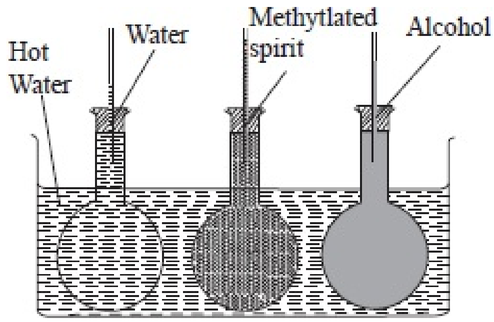


Fig. 6.15: Liquids after heating the water bath

Stirring is necessary to ensure that the temperature of water in the bath is uniform.

The Anomalous Expansion of Water

From the foregoing, solids and liquids expand when heated and contract when cooled. Water however shows an anomalous (unusual) behaviour in that it contracts when its temperature is raised from 0°C.

When ice is heated from, say, –20°C, it expands until its temperature reaches 0°C and melts with no change in temperature. The melting is accompanied by contraction. The water formed will still contract as its temperature rises from 0°C, as shown in figure 6.16.

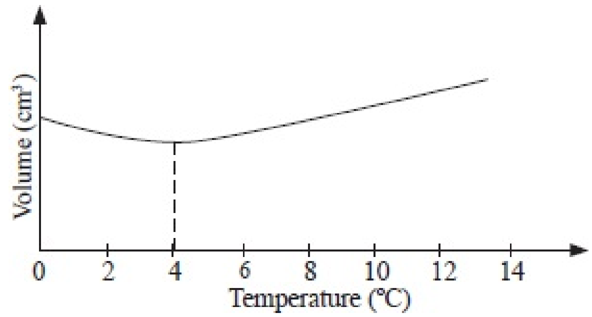


Fig. 6.16: Variation of volume of water with temperature

Above 4°C, the water expands with increase in temperature. Since volume of a given mass of water is a minimum at 4°C, water at this temperature has maximum density, slightly higher than 1 g/cm^3.

A sketch of the variation of density with temperature is shown in figure 6.17.

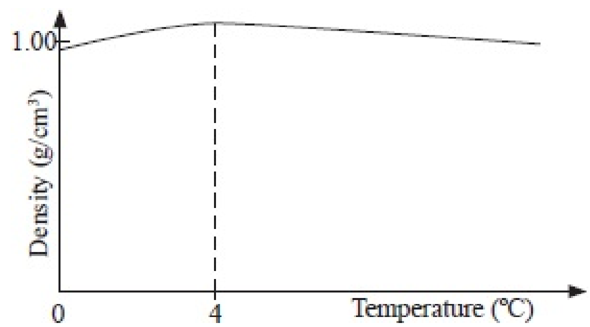


Fig. 6.17: Variation of density with temperature

At the melting point of water (0° C), there is a drastic increase in the volume, resulting in a large decrease in density as the ice forms.

Some Effects of Anomalous Expansion of Water

Freezing of lakes and ponds

In temperature latitudes, water in lakes and ponds usually freezes in winter. Ice, being less dense than water, floats on the water. Since ice is a bad conductor of heat, it insulates the water below against heat losses to the cold air above. Water at 4°C, being the most dense, remains at the bottom of lake while ice, being less dense than water, floats on the layers of water at different temperatures, as shown in figure 6.18.

Fish and other aquatic animals and plants can, therefore, survive by living in the liquid layers below the ice.

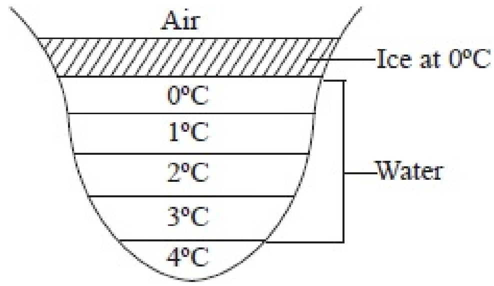


Fig. 6.18: Variation of temperature in a frozen lake

Icebergs

Since the density of ice (0.92 gcm^{-3}) is slightly less than that of water, it floats with only a small portion above the water surface. The rest and the bigger portion remains under water. A big mass of such submerged ice is known as an **iceberg.** It poses a great danger to ships as navigators cannot see the submerged part.

Weathering of Rocks

When water in a crack in rock freezes, it expands. This expansion breaks the rock into small pieces.

Water Pipes

Water pipes burst when the water flowing through the pipes freeze.

Expansion of Gases

Experiment 6.7: To show the expansion of gases

Apparatus

A round-bottomed flask with a glass tube in a tight-fitting rubber cork, a basin of water.

Procedure

- Invert the flask with the glass tube dipped into the water, as shown in figure 6.19 (a).

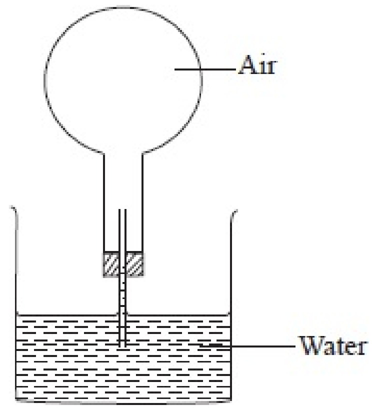


Fig. 6.19 (a)

- Warm the flask with your hands for some time and note what happens.
- Remove your hands and let the flask cool while the tube is still inserted in water. Observe what happens.

Observation

When the flask is warmed, the level of the water column inside the glass tube drops. When the flask is warmed further, bubbles are seen as in figure 6.19 (b). On cooling, the air inside the flask contracts and water rises up the glass tube.

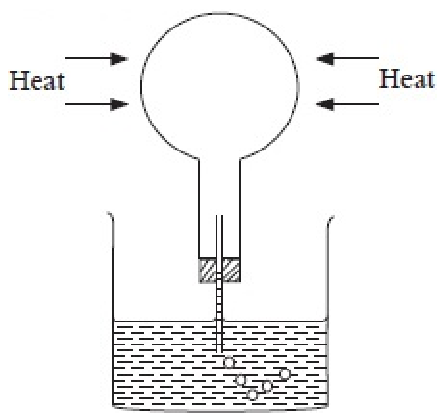


Fig. 6.19 (b)

Explanation

The level of water in the column drops, indicating that air expands. On further expansion of the air bubbles are seen at the end of the tube as air escapes from the flask.

Molecular Explanation of Expansion

The particulate nature of matter can be used to explain expansion of solids, liquids and gases.

Solids

Molecules in solids are closely packed and held together by forces of attraction. These forces are so strong that molecules do not change positions, but vibrate about their mean positions.

When a solid is heated, the vibrations of the molecules increase, resulting in increasing distance from their mean position. This leads to an increase in the size of the solid.

Liquids

In liquids, the forces of attraction between molecules are weaker than in solids, hence liquid molecules are farther apart than in solids.

When a liquid is heated in a container, the vibrations of its molecules become more vigorous. The liquid will then occupy more space.

Gases

In gases, the molecules are much farther apart than in solids and liquids. This is because the attractive forces between gas molecules are very weak. When heated, gas molecules gain more energy and move farther apart, occupying more space.

Measuring Temperature

Thermometers

A thermometer is an instrument used for measuring temperature. There are many types of thermometers each being designed for a specific purpose.

Liquid-in-Glass Thermometer

In this thermometer, the liquid in the bulb expands up a capillary tube when the bulb is heated. The liquid in the bulb must:

(i) expand or contract uniformly and by a large amount over a small range of temperature.

(ii) be seen easily (visible).

(iii) not stick to the inside of the tube (should not wet the inside of the tube).

(iv) have a wide range of temperature between boiling and freezing.

The most common liquids for use in thermometers are mercury and alcohol. Mercury freezes at –39°C and boils at 357°C while alcohol freezes at –115°C and boils at 78°C. Alcohol is, therefore, suitable for measurements of temperatures below –39°C.

The properties of the two thermometric liquids are compared in table 6.1.

Table 6.1

Alcohol	**Mercury**
Low boiling point, 78°C.	High boiling point, 357 °C.
Low melting point, –115°C	Relatively higher melting point, –39°C.
Poor thermal conductor.	Good thermal conductor
Expansion slightly irregular.	Expands regularly.
Wets glass.	Does not wet glass.
Transparent, and has to be coloured to make it easily visible.	Opaque and silvery.

Exercise 6.2

1. State the advantages of mercury over alcohol as a thermometric liquid.
2. Explain why water is never used as a thermometric liquid.

Temperature Scale

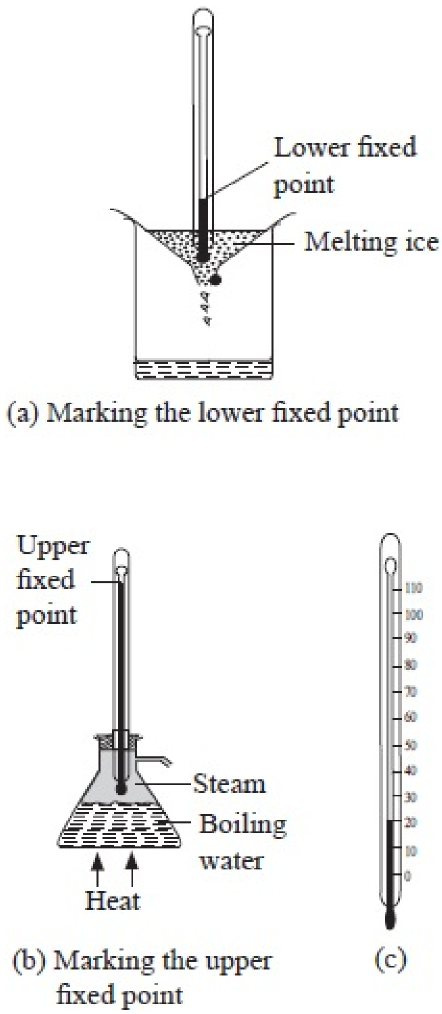
A scale of temperature is obtained by selecting two temperatures known as **fixed points**. The range between these two **fixed points** is divided into a number of equal divisions.

On the Celsius scale, the lower fixed point is the temperature of pure melting ice and is taken as 0°C. Impurities in the ice would lower its melting point.

The upper fixed point is the temperature of steam above water boiling at normal atmospheric pressure of 760 mmHg, and is taken as 100°C.

The temperature of boiling water itself is not used because any impurities in water would raise its boiling point. The temperature of the steam on the other hand is not affected by impurities in water.

Methods of finding the fixed points are shown in figure 6.20. When these points have been marked, the range between them is divided into 100 equal divisions, see figure 6.20 (c). Each division is then called a **degree**.



(a) Marking the lower fixed point

(b) Marking the upper fixed point

(c)

Fig. 6.20: Marking the lower fixed points

Features of a Common Thermometer

The basic features of a common laboratory thermometer are shown in figure 6.21.

Fig. 6.21

Bulb

The bulb carries the liquid in the thermometer. It has a thin glass wall for effective heat transmission between the liquid inside and the body whose temperature is to be taken.

Capillary Bore

The liquid expands and contracts along the capillary bore. The capillary bore is narrow for high degree of accuracy.

Glass Stem

This is a thick glass wall surrounding the capillary bore. It also serves as magnifying glass for easy reading of the scale.

Celsius and Kelvin Scale

The two most commonly used temperature scales are the Celsius and Kelvin scales.

The Celsius scale has the fixed points at 0°C and 100°C. It is also referred to as **Centigrade scale.**

In the Kelvin scale, the temperature of pure melting ice is 273 K while that of pure boiling water at normal atmospheric pressure is 373 K.

The lowest temperature in the Kelvin scale, the zero K, is also referred to as **absolute zero**. This is the temperature at which the energy of the particles in a material is zero.

To change °C to Kelvin, add 273 and to change temperature in Kelvin to degrees Celsius, subtract 273, i.e., $T = \theta + 273$, where T is the temperature in the Kelvin scale and θ the temperature on the Celsius scale.

Example 1

Convert each of the following temperatures into Kelvin:

(a) 25°C

(b) 100°C

(c) 0°C

(d) –123°C

Solution

(a) $T = \theta + 273$

$25°C = 25 + 273$

$= 298$ K

(b) $100°C = 100 + 273$

$= 373$ K

(c) $0°C = 0 + 273$

$= 273$ K

(d) $T = -123 + 273$

$= 150$ K

Example 2

Convert the following from Kelvin to °C:

(a) 350 K

(b) 100 K

(c) 1 K

(d) 0 K

Solution

$\theta = T - 273$

(a) $\theta = 350 - 273$

$= 77°C$

(b) $\theta = 100 - 273$

$= -173°C$

(c) $\theta = 1 - 273$

$= -272°C$

(d) $\theta = 0 - 273$

$= -273°C$

Note:

Temperature in the Kelvin scale cannot have a negative value because the absolute zero, 0 K, is the lowest temperature attainable.

Clinical Thermometer

This thermometer is a special type used for measuring human body temperature. Its temperature range is about 35°C – 43°C, which makes it suitable since the temperature of a healthy person is about 37°C.

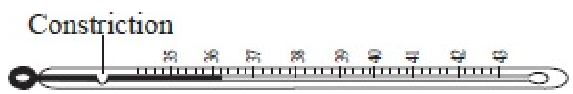


Fig. 6.22: A clinical thermometer

The tube has a constriction just beyond the bulb. When the thermometer is used to take the temperature of a patient, the mercury expands, forcing its way past the constriction. When the thermometer is withdrawn, the mercury in the bulb cools and contracts, breaking the mercury thread at the constriction. The mercury beyond the constriction stays in the tube, showing the body temperature. After the thermometer has been read, the mercury is returned to the bulb by a simple flick.

Methylated spirit may be used to sterilise the thermometer after use.

A more recent technology in the measurement of temperature is the use of the non-contact infra-red thermometer, also known as the **laser thermometer**. The thermometer operates by making use of thermal radiation emitted by the body whose temperature is being measured. The thermometer is useful in measuring temperatures of inaccessible areas, moving objects, very hot objects, rotating objects or those whose temperatures are rapidly changing. It is also useful when a fast response is required.

Six's Maximum and Minimum Thermometer

This is a special thermometer that is used to record the maximum and minimum temperatures reached in an area during a specified period, e.g., a day.

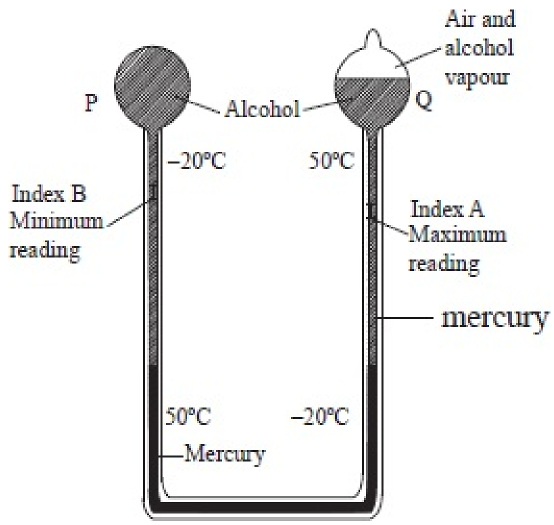


Fig. 6.23: Six's maximum and minimum thermometer

When it becomes hot, the alcohol in bulb P expands to push the mercury up the right side of the U-tube. The mercury, therefore, pushes the steel index A upwards. The steel index has a spring which holds it in position in the glass tube. When the temperature falls, the alcohol in bulb P contracts and the mercury is pulled back, rising up the left side of the U-tube. The index B is, therefore, pushed up. During contraction of the alcohol, index A is left behind (in the alcohol) by the falling mercury. The lower end of this index indicates the maximum temperature reached during the specific period. The minimum temperature is read from the lower end of index B.

To reset the thermometer, a magnet is used to return the steel indices to the mercury surfaces.

The Bimetallic Thermometer

This type of thermometer consists of a coiled bimetallic strip as shown in figure 6.24. One end of the spiral is fixed while a pointer is attached to the other end.

An increase in temperature causes the spiral to curl in a clockwise direction, forcing the pointer to move over a calibrated scale. The curling is due to the unequal expansion of the metals in the bimetallic strip.

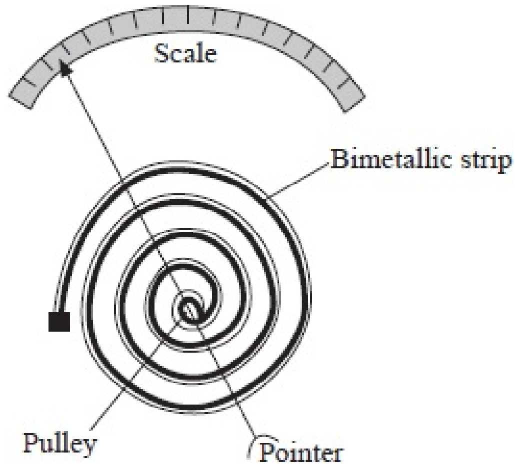


Fig. 6.24: Bimetallic thermometer

There are other special thermometers which include the constant volume gas thermometer, electronic thermometer, the resistance thermometer and the thermocouple thermometer.

Revision Exercise 6

1. State two advantages of thermal expansion.
2. Describe a method that can be used to open a tight lid of a bottle without damaging it.
3. A man wants to fit a brass ring tightly onto a steel rod of diameter equal to the inner diameter of the ring. Explain how this can be achieved.
4. State and explain the disadvantages of anomalous expansion of water.
5. State three properties of a liquid that is suitable for use in a thermometer.
6. Sketch a clinical thermometer and explain its special features.
7. Convert each of the following from Kelvin to °C:
   (a) 0 K
   (b) 167 K
   (c) 283 K
   (d) 3 450 K
8. A faulty mercury thermometer reads 10°C when dipped into melting ice and 90°C when in steam at normal atmospheric pressure. Determine the reading of this thermometer when dipped into a liquid at 20°C.
9. When marking the fixed points on a thermometer, it is observed that at 0°C,

the mercury thread is of length 1 cm and 6 cm at 100°C. Find the temperature that would correspond to a length of 4 cm.

Chapter 7

Heat Transfer

Heat and Temperature

Heat is a form of energy which passes from a body at a higher temperature to a body at a lower temperature. If a body receives heat energy, its temperature increases whereas the temperature of a body that gives away heat energy decreases, see figure 7.1. If two bodies at the same temperature are in contact, there is no net heat flow from one body to the other.

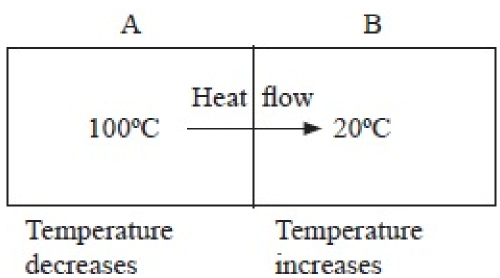


Fig. 7.1: Heat flow between bodies in contact

The SI unit of heat is the joule (J). Heat cannot be measured directly by an instrument as temperature is by a thermometer.

Modes of Heat Transfer

Heat can travel through a medium and also through a vacuum. There are three modes of heat transfer, namely, **conduction**, **convection** and **radiation**. Both conduction and convection require a material medium, but radiation can take place in a vacuum. Conduction of heat takes place in solids while convection takes place in fluids (liquids and gases).

Conduction

If you stir hot tea using a metal spoon, you will observe that the handle of the spoon becomes warm. The mechanism by which heat is transferred through the spoon can be explained in two ways:

(i) Heat energy entering the spoon from the hot end increases the vibrations of the atoms in the spoon at this end. These atoms in turn collide with neighbouring atoms, increasing their vibrations and hence passing the heat energy along.

(ii) Metals have free electrons which travel throughout the body of the metal. Heat energy injected at the hot end of the metal spoon increases the vibrations of the particles at the end. The free electrons in that region, gain more kinetic energy and because they are free to move, spread heat energy to the other parts of the spoon.

Experiment 7.1: Comparing thermal conductivities of various conductors

Apparatus

Rods of aluminium, iron, copper, rubber, glass, wood (all must be of same length and cross-section) and with a waxed on the surface, thermal conductivity tank, source of heat.

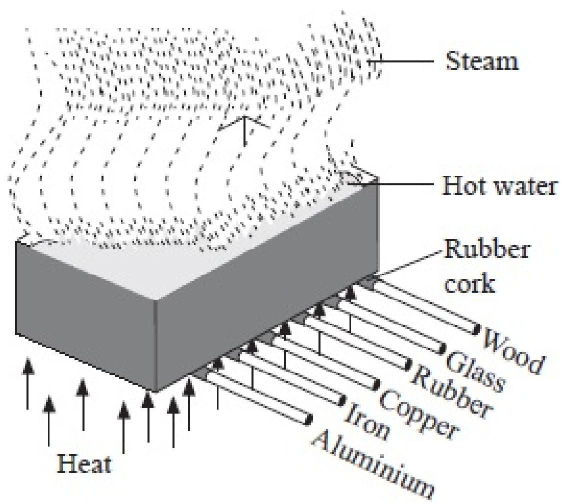


Fig. 7.2: Comparing thermal conductivities

Procedure

- Set the apparatus as shown. Ensure that the rods are held firmly. Pour boiling water into the container.
- The hot water bath is used for the uniform heating of the rods.
- Observe the order in which the wax (or vaseline) melts off the rods. The best conductor is one whose wax melts off first.
- List the rods in order of decreasing conductivity.

Observation

Different materials have different thermal conductivities. Metals are generally good conductors of heat. Non-metals are poor conductors of heat (insulators).

From the foregoing, solids that are good conductors of heat (metals) use both vibration of the atoms and free electrons to conduct heat. Solids that are poor conductors of heat like glass, wood and rubber make use of vibration of atoms as a mechanism to conduct heat because they have no free or mobile electrons.

Table 7.1 shows some of the good and poor conductors in decreasing order of thermal conductivity.

Table 7.1: Good and poor conductors of heat

Good conductors	**Poor conductors**
Silver	Concrete
Copper	Glass
Aluminium	Brick
Brass	Asbestos paper
Zinc	Rubber
Iron	Wood
Lead	Water
Mercury	Air

Note:

During thermal conduction, heat flows through the materials without the material shifting or flowing. Conduction is, therefore, the transfer of heat as a result of vibration of particles.

Experiment 7.2: Comparison of conductivities of wood and iron rods

Apparatus

Iron rod and wooden rod of the same diameter joined end to end, Bunsen burner, a piece of paper.

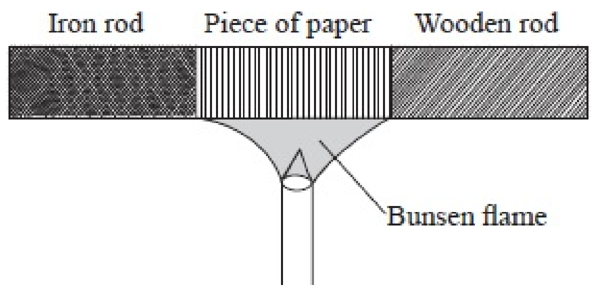


Fig. 7.3: Comparison of conductivities

Procedure

- The piece of paper is wrapped round the joint so that some of the paper is over the iron rod and some over the wooden rod.
- A flame is passed over the paper several times.

Observation and Explanation

The paper gets charred (blackened) on the region covering the wooden rod. This is because the wood does not conduct heat from the paper. Wood is said to be a bad conductor of heat while iron is a good conductor.

Factors Affecting Thermal Conductivity

Thermal conductivity in materials depends on the following factors:

(i) The temperature difference ($\Delta\theta$) between the ends of the conductor.

(ii) The length of the conductor.

(iii) The cross-section area (A) of the conductor.

(iv) The nature of the material (k).

The experiments below illustrate how these factors affect thermal conduction.

Experiment 7.3: To demonstrate how temperature difference (Aθ) affects thermal conduction

Apparatus

Two metal rods of same material, length and cross-section area, water bath, Bunsen burner.

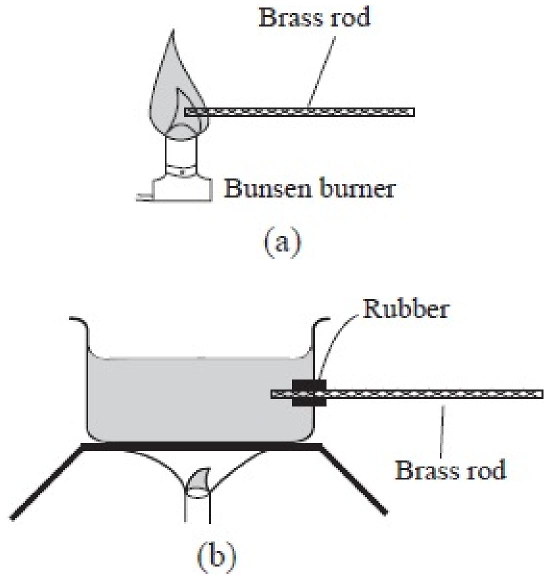


Fig. 7.4: Conduction depends on temperature differences

Procedure

- Hold one end of each rod in your hand.
- Put the other end of one of the rods in boiling water (about 100 °C) and the other rod in the bluish part of the Bunsen burner flame (about 500 °C) see figure 7.4. Note how long it takes before the rods are too hot to hold.

Observation

The rod placed in the flame becomes too hot earlier than the one placed in the boiling water.

Conclusion

The rate of heat flow (thermal conduction) increases with increase in temperature difference

Explanation

As stated earlier, thermal conduction in metals is by two mechanisms, namely, vibration of the atoms and by free (mobile) electrons. A high temperature difference ($\Delta\theta$) between the ends of the conductor sets the atoms into vibration more vigorously and since the atoms are joined by spring-like bonds, the vibrations are passed on more quickly to the cool end. The electrons in a similar way gain a lot of kinetic energy, causing them to spread the heat energy to cooler parts of the metal within a short time.

Experiment 7.4: To demonstrate how the length (*l*) of a conductor affects

thermal conduction

Apparatus

Two metal rods A and B of the same material and cross-sectional area, the length of rod A being twice that of rod B, Bunsen burner.

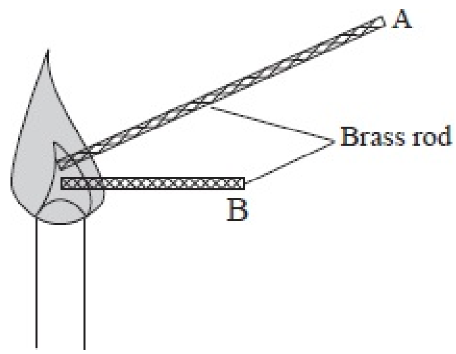


Fig. 7.5

Procedure

- Hold one end of rod A in one hand and rod B in the other hand.
- Put the other ends in the burner flame. Note how long it takes before each rod becomes too hot to hold.

Observation

The end of rod B held in the hand becomes too hot to hold earlier than A.

Conclusion

Thermal conductivity increases with decrease in length.

Explanation

Heat travels within a conductor along imaginary lines called **lines of heat flow**. These lines diverge from the hot end, as shown in figure 7.6

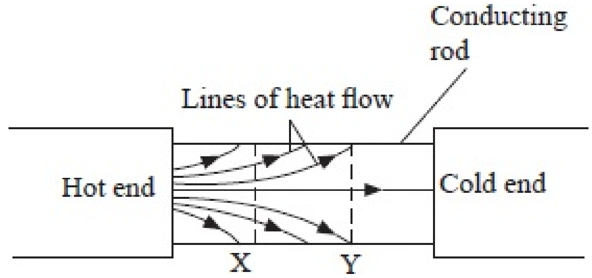


Fig.7.6

As can be seen from figure 7.6, the lines of heat flow passing through the cross sectional area of the metal rod at X are more than those passing through the same cross sectional area at Y which is a point farther away from the hot end.

This indicates that the shorter the length of material, the higher the amount of heat energy reaching the end. When the conductor is lagged, the lines of heat are uniform.

Lagging

This is the covering of good conductors of heat with insulating materials to reduce heat loss through the surface by conduction. Figure 7.7 shows lines of heat flow in a lagged metal rod.

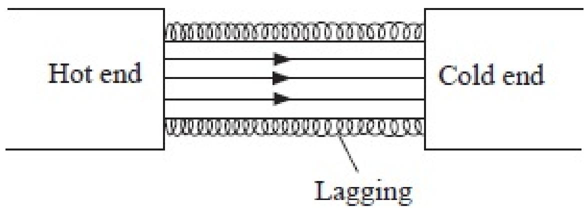


Fig. 7.7: Effects of lagging on heat flow

Experiment 7.5: To demonstrate how cross-section area of a material affects thermal conductivity

Apparatus

Two metal rods A and B of the same material and same length, the diameter of metal A being twice that of B, Bunsen burner.

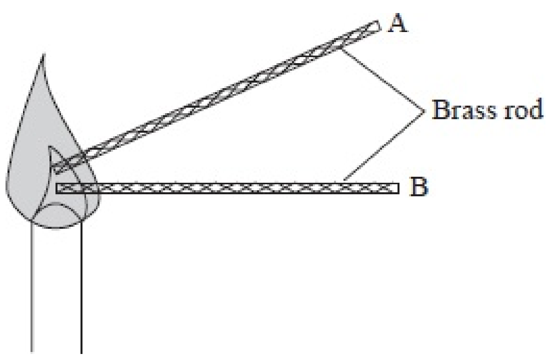


Fig. 7.8: Comparing rate of heat flow by cross-section area

Procedure

- Hold one end of rod A in one hand and one end of rod B in the other.

- Put the other ends in the Bunsen burner flame.
- Note how long it takes you to hold each of the metal flame.

Observation

The end of rod A held in the hand becomes too hot earlier than rod B.

Conclusion

Thermal conductivity increases with increase in area of cross-section of the conducting material.

Explanation

The number of free electrons per unit length of the thicker metal rod (A) is more than those in metal rod (B).

Experiment 7.6: To demonstrate how the type of material (k) affects thermal conductivity

Apparatus

Copper rod and iron rod of the same diameter and length, Bunsen burner.

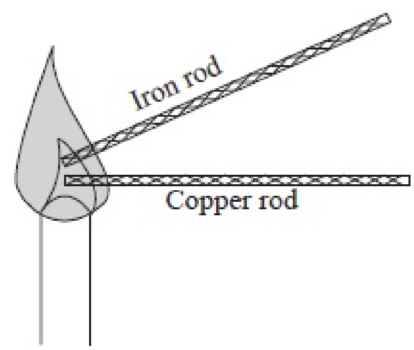


Fig. 7.9: Comparing rate of heat flow in different materials

Procedure

- Hold the two metal rods in the Bunsen burner.
- Note how long it takes you to hold each of the two metals in the flame.

Observation

The end of the copper rod held in the hand becomes too hot earlier that the iron rod.

Conclusion

Thermal conductivity depends on the nature of the material.

Explanation

Different materials have different strengths of force bonding the atoms within the material. The number of free electrons also differs from material to material. Materials with many free electrons are better conductors of heat. Copper has more free electrons than iron.

In summary, the rate of heat flow (thermal conductivity):

(i) increases with increase in temperature difference, i.e., **the rate of heat flow is directly proportional to the temperature difference**.

(ii) increases with decrease in length *l*, i.e., t**he rate of heat flow is inversely proportional to the length of a conductor**.

(iii) increases with increase in cross-sectional area (A) of the material, i.e., **the rate of heat flow is directly proportional to the area of cross-section of a material**.

(iv) increases with the thermal conductivity value (k) of the material.

Thermal Conductivity in Liquids

Experiment 7.7: To demonstrate that water is a poor conductor of heat

Apparatus

Boiling tube containing water, ice wrapped in a wire-gauze, Bunsen burner.

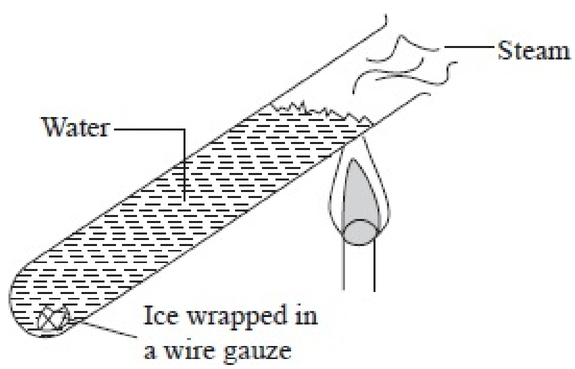


Fig. 7.10: Demonstrating thermal conductivity of water

Procedure

- Set up the apparatus as shown in figure 7.10.
- Heat the water at the top until it starts boiling.

• Note the changes, if any, in the ice.

Observation

Water at the top of the test tube boils while the ice remains unmelted.

Conclusion

Water is a poor conductor of heat.

Note:

(i) The test tube is made of glass (a poor conductor of heat), which limits possible conduction of heat down the tube.

(ii) The ice is wrapped in wire gauze to ensure that it does not float.

(iii) The fact that the wire gauze is a good conductor of heat and yet the ice remained unmelted shows that there is very little heat transfer in the water, unable to melt the ice.

(iv) Water is heated at the top to eliminate possibility of heat transfer to the ice by convection.

Although liquids are in general poor conductors of heat, the experimental set-up shown in figure 7.11 can be used to show that some liquids are better heat conductors than others.

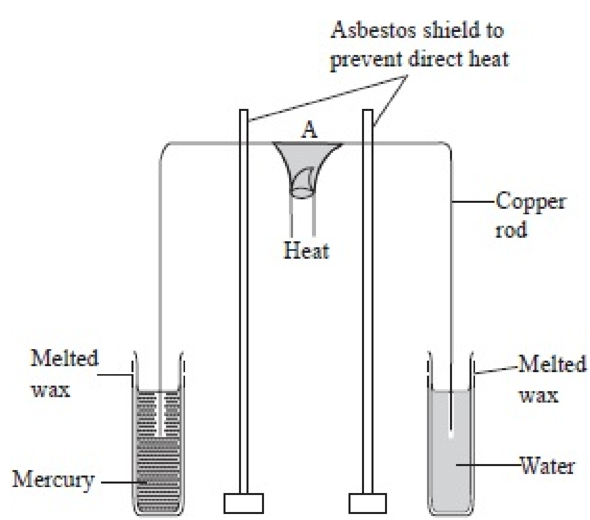


Fig. 7.11: Comparing thermal conductivities of mercury and water

The test-tubes are coated with a uniform layer of candle wax. When region A of the copper rod, which is midway from the centres of the test-tubes is heated for some time, the wax on the test-tube with mercury begins to melt. Later, the wax near the top of the test-tube with water melts while the wax lower down the test-tube does not melt. This shows that mercury is a better conductor of heat than water. It is important to note that mercury vapour is poisonous.

Why Liquids are Poor Conductors of Heat

Pure liquids have molecules further apart from each other. Although molecules move about within the liquid bulk, they are slow to pass heat to other regions compared to the free electrons in metals. This is because there are large inter-molecular distances between liquid molecules. There are also fewer collisions between the molecules. Electrolytes, e.g., salt solution, are better conductors of heat than pure liquids because of an increased compactness of the particles. Mercury is a metal existing as a liquid at room temperature. Bromine, the only non-metalic element existing as a liquid at room temperature, is a poor conductor of heat.

Thermal Conductivity in Gases

Since thermal conduction is by means of vibration of atoms and the presence of free electrons, gases are worst conductors of heat because of large inter-molecular distance between the atoms.

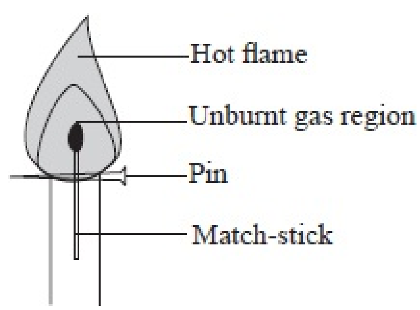


Fig. 7.12: Demonstrating poor thermal conductivity in gases

In figure 7.12, a match-stick held within the unburnt gas region of a Bunsen burner flame is not ignited by the heat from the hot part of the flame. This is because gas is a poor conductor of heat.

Some Applications of Good and Poor Conductors of Heat

1. Cooking utensils, soldering irons and boilers are made of metals which conduct heat rapidly. For cooking utensils, the handles are made of insulators such as wood or plastic. Metal pipes carrying water from boilers are lagged with cloth soaked in plaster of Paris to prevent heat losses.

2. Overheating of integrated circuits (ICs) and transistors in electronic devices can drastically affect their performance. Such components are fixed to a heat sink (a metal plate) to conduct away undesired heat, see figure 7.13.

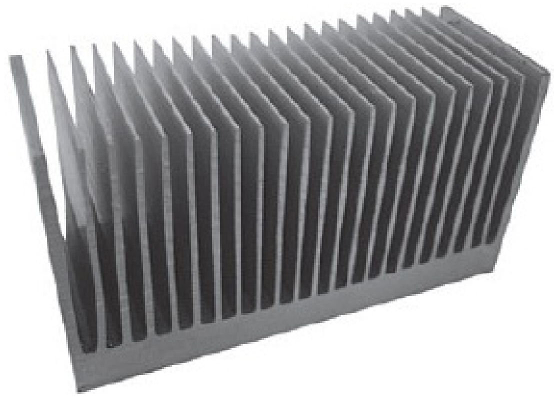


Fig. 7.13: Heat sink

The fins increase the surface area of the heat sink. This increases the rate of heat loss to the surroundings.

3. Fire-fighters put on suits made of asbestos material to keep safe while putting out fires. Film directors cloth their characters in similar suits as the latter act in stunts involving burning.
4. Birds flap their wings after getting wet as a means of introducing air pockets in their feathers. Air, being a poor conductor, reduces heat loss from their bodies. Wool, fur and thatch on roofs make use of the same concept. A soft-board ceiling is better than a concrete ceiling because it has many air pockets. Concrete is a better conductor of heat than air.
5. In modern buildings where the desired inside temperature is to be stabilised, double walls are constructed. Materials that are good insulators of heat and can trap air and are put between the walls. Examples of such materials are glass wool (fibre glass) and foam plastic, see figure 7.14.

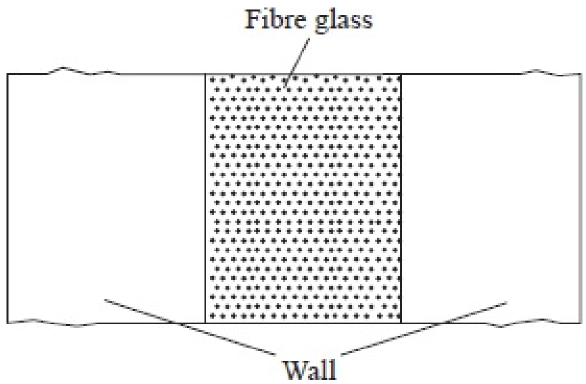


Fig. 7.14: Double wall insulation

Air on its own may not effectively give the desired insulation because it undergoes convection.

Double-glazed windows used for the same purpose have air trapped between two glass sheets.

8. In experiments involving heating water or liquid in a glass beaker, the beaker is placed on wire gauze. The gauze is heated and spreads the heat to a large area of the beaker. If a Bunsen burner flame is used to heat the beaker without the gauze, the heat from the flame may concentrate on a small area and this can make the beaker crack.

Convection

Convection is the process by which heat is transferred through fluids (liquids and gases). The heat transfer is by the actual movement of the fluid, called convection currents, which arise out of the following:

(i) *Natural convection*: Involves change in density of the fluid with temperature.

(ii) *Forced convection:* Mixing of hot and cold parts of the fluid through some external stirring, like a fan or pump.

Experiment 7.8: To demonstrate convection in liquids

There are various methods of demonstrating convection in liquids, depending on the kind of apparatus available. However, the basic principle of operation is the same.

Method 1

Apparatus

A beaker containing water, potassium permanganate crystals, Bunsen burner and tripod stand.

Procedure

- Half fill the beaker with water.
- Put some crystals of potassium permanganate in one corner of a large beaker, as shown in figure 7.15.
- Put the beaker on a stand and heat the corner of beaker containing potassium permanganate. Observe what happens.

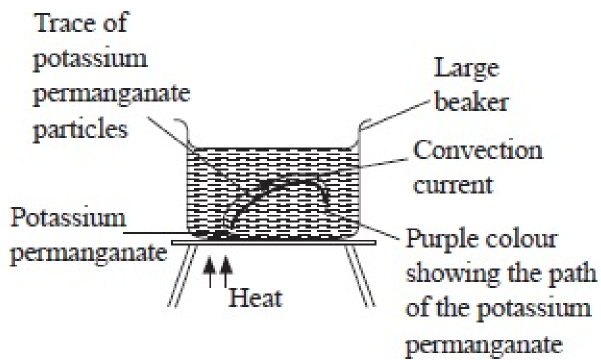


Fig. 7.15: Convection in water

Observation

A purple colouration rises up from the potassium permanganate, forming a loop.

Method 2

Apparatus

A rectangular tube filled with water up to the neck, potassium permanganate crystals in a porous material, Bunsen burner.

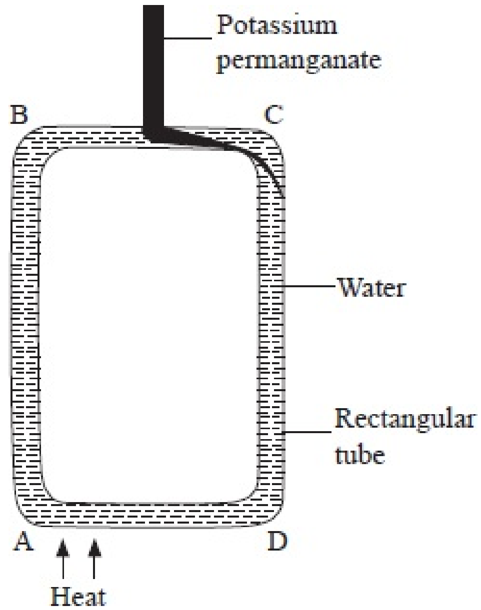


Fig. 7.16: Convection in water

Procedure

- Heat the water in the tube at point A, as shown in figure 7.16.
- Introduce potassium permanganate through the neck of the tube.
- Observe what happens to the potassium permanganate.

Observation

The colouration from the potassium permanganate flows in a clockwise direction.

Conclusion

From the two experiments, it is clear that when a liquid is heated, it rises while cooler liquid replaces it.

Explanation

Density is the mass per unit volume of a substance. When the volume of the substance increases with the mass remaining constant, its density decreases. When a liquid is heated, it expands and this lowers its density. The less dense liquid rises and its place is taken by more dense colder liquid. This movement of liquid forms **convection currents.**

Convection Currents in Gases

Experiment 7.9: To demonstrate convection currents in gases

Apparatus

A box with two chimneys and a transparent front, a candle, a smouldering straw, piece of cloth or paper.

Procedure

- Light the candle beneath chimney B, as shown in figure 7.17.

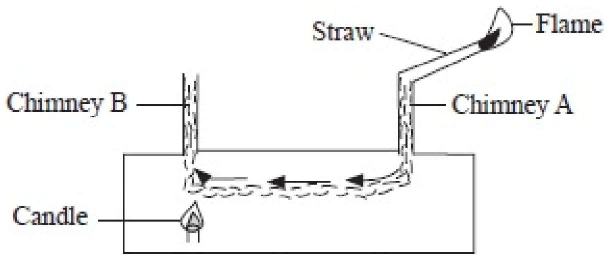


Fig. 7.17: Convection in gases

- Place a smouldering straw at the mouth of chimney A and leave it for some time. Observe what happens to the smoke that is produced by the burning straw.
- Put off the candle and repeat the experiment.

Observation

Smoke is sucked into the box through chimney A and exits through chimney B. When the candle is put off, the smoke is not drawn into the box.

Conclusion

Convection currents are set up when air or gas is heated.

Explanation

The candle heats up the air above it, which expands and rises up because of its lower density. Cold heavier air is drawn in through chimney A, carrying along the smoke which replaces the air that is escaping through chimney B.

Molecular Explanation of Convection in Fluids

Molecules in fluids are further apart and have negligible cohesive force. Heating a fluid increases the kinetic energy of the vibrating molecules and their random movement. As the fluid rises, these molecules pass energy to the molecules in the colder regions which have less energy. Because the molecules are further away from the heating source, their temperature is reduced. Meanwhile, the pressure near the heating source decreases because of depletion of molecules as they rise. Colder molecules move into the low pressure zone to fill the void being created.

Cumulatively, this movement of molecules constitutes the convection current. Convection currents are set up much faster in gases than in liquids because of the extremely low cohesive forces existing between the molecules of the gases.

Some Applications of Convection in Fluids

Domestic Hot Water System

Figure 7.18 is a model of domestic hot water system.

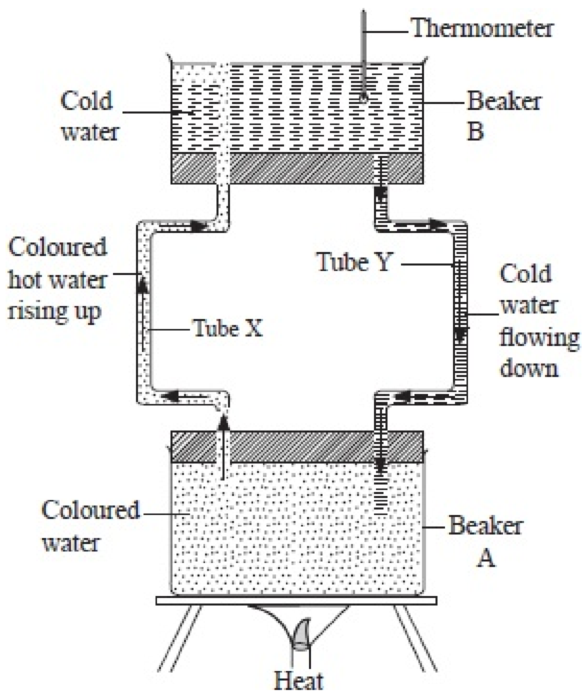


Fig. 7.18: Model of a domestic hot water supply

Initially, the two beakers A and B contain cold water. Water in beaker A is coloured to distinguish it from that in beaker B. When the water in beaker A is heated, it is observed to rise up through tube X and emerges on top of cold water in beaker B. The cold water flows down from beaker B to beaker A. As long as the heating continues, there will be movement of hot water into beaker B and cold water will flow down into beaker A. A thermometer in beaker B will show increase in temperature of the water contained in B.

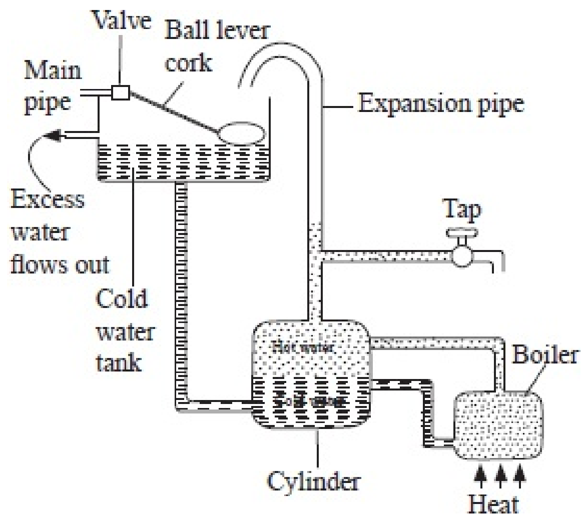


Fig. 7.19: Domestic hot water supply

The commercial domestic hot water system, shown in figure 7.19, utilises the same principle of operation. The hot water rises up because of the effective lowering of its density. The force of gravity helps the cold water to flow down from the cold water tank to the boiler. Notice that the top part of the cylinder contains hot water while the lower part contains cold water. The hot water tap and expansion pipe are connected to the upper region of the cylinder. The expansion pipe is an outlet for excess water that could have resulted from overheating. Once the cold water flows down the cylinder, the main pipe allows more cold water to flow into the cold water tank. When filled to capacity, the ball cock lever floating on the water closes a valve in the main pipe, stopping further inflow of cold water. An overflow pipe lets out water from the cold water tank if the valve fails.

The piping that conveys the hot water and the cylinder is lagged to minimise heat losses.

Ventilation

This is the supply of fresh air to a room. Figure 7.20 shows a room with large windows close to the floor and ventilation holes or openings high up in the walls.

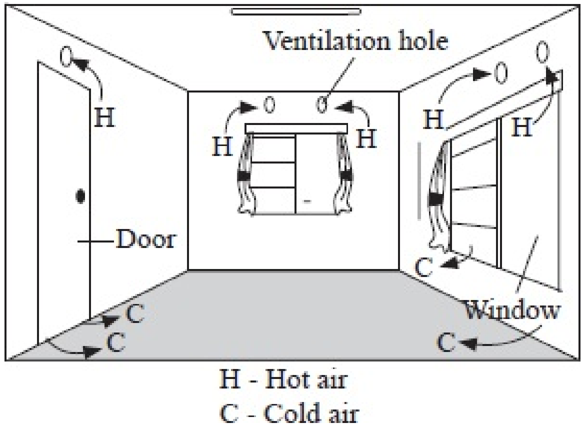


Fig. 7.20: Ventilation in a room

Air expelled by the room occupants is warm and less dense. It rises up and escapes through the ventilation holes. Cool fresh air flows into the room to replace the risen warm air. The room thus gets a continuous flow of fresh air. Some houses are fitted with air conditioning devices which cause forced convection of air, giving out cold dry air and absorbing warm moist air.

Car Engine Cooling System

Heat conduction and convection play a very crucial role of taking away heat from a car engine that would otherwise reduce its efficiency. In figure 7.21, the engine is surrounded by a metal water jacket that is connected to the radiator.

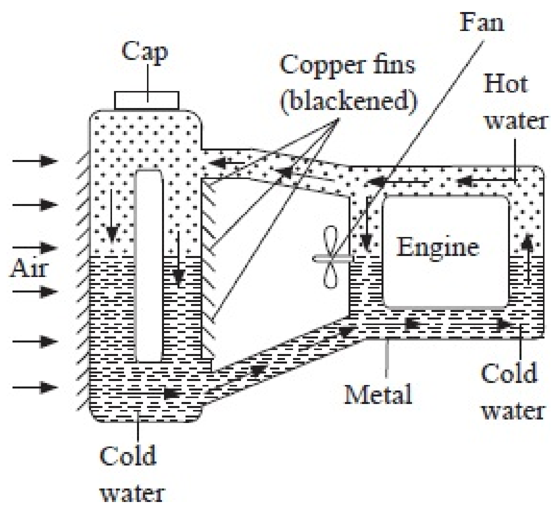


Fig. 7.21: Cooling system of a car engine

The metal surface conducts away heat from engine. This heats up the water, setting up convection currents. The hot water is pumped into the radiator which has thin copper fins that conduct away heat from the water. Air flowing past the fins speeds up the cooling process.

Land and Sea Breeze

This is a natural convection mechanism, and occurs especially at sea shores because of temperature differences between the mass of water and the land. The mass of water takes much longer time than the nearby land to be heated to the same temperature by the sun. Water also takes a longer time to cool than the land after being raised to the same temperature.

During the day, the land heats up much faster than the sea. The air just above the land gets heated up and rises because of reduced density. Cold air above the sea blows towards the land to replace the void being created by the warm rising air, see figure 7.22 (a). This is called **sea breeze**.

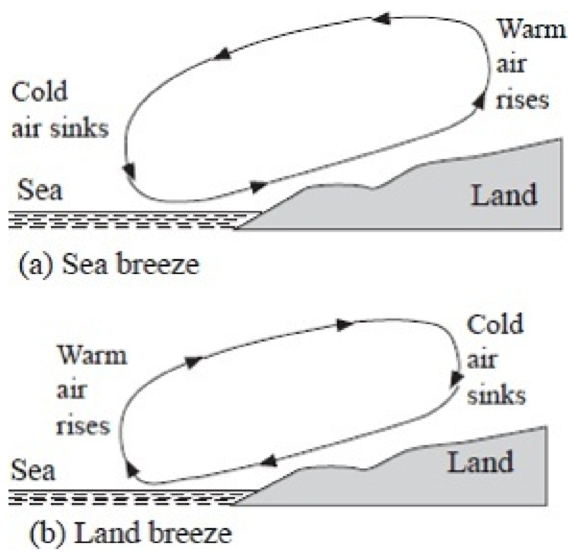


Fig. 7.22: Formation of land and sea breeze

In the evening, the temperature of the sea water is higher than that of the land. The air above the sea gets heated up and rises. Cold air from the land blows to the sea in what is called **land breeze**, see figure 7.22 (b).

Radiation

Heat from the sun to the earth is not transferred by either conduction or convection because of the vast expanse of the vacuum (absence of medium) that exists between the earth and the sun. Heat transfer through vacuum is called **thermal radiation**. All bodies absorb and emit radiation.

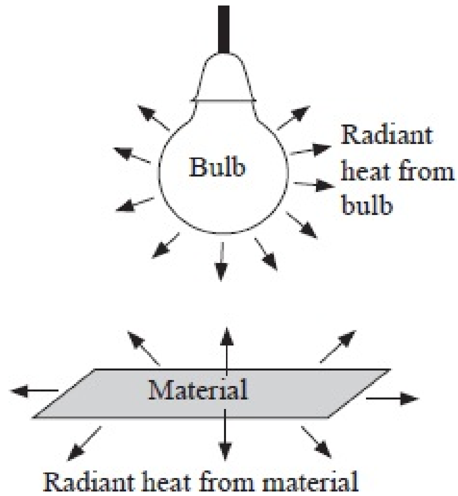


Fig. 7.23: Emission and absorption of radiant heat

The higher the temperature of an object, the greater the amount of radiation. A body emitting thermal radiation can also emit visible light when it is hot enough. An electric bulb in a room produces both light and radiant heat. The radiant heat is absorbed by the materials in the room, which in turn give out radiant heat of lower energy, see figure 7.23.

The material must have received the heat through radiation only. This is because air is a bad conductor of heat and if convection currents are set up, they will transfer heat upwards.

Nature of Radiant Heat

Experiment 7.8: To demonstrate the nature of radiant heat

Apparatus

Hand lens (convex), piece of paper.

Procedure

- Hold the hand lens above a piece of paper such that light from the sun is focused onto the paper. Note what happens to the paper.

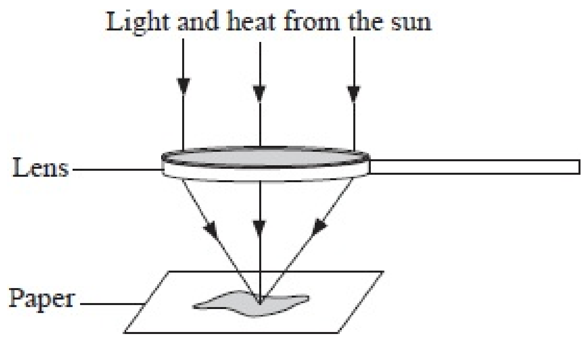


Fig. 7.24: Concentration of radiant heat

Observation

The paper catches fire.

Explanation

Radiant heat, like light, can be concentrated to a point using a lens. Thermal radiation is a wave, like light and can, therefore, be refracted. Because of the nature of its production, radiant heat is an electromagnetic wave that causes a heating effect in objects that absorb it.

Radiation is also described as the flow of heat from one place to another by means of electromagnetic waves.

Emission and Absorption of Radiation

Experiment 7.9: To compare the rate of absorption of radiation from different surfaces

Method 1

Apparatus

U-tube containing coloured water, two boiling tubes A and B painted black, a hollow cube painted black on one side and polished (shiny) on the opposite side, connecting tubes.

Procedure

- Set up the apparatus as shown in figure 7.25 and ensure that:

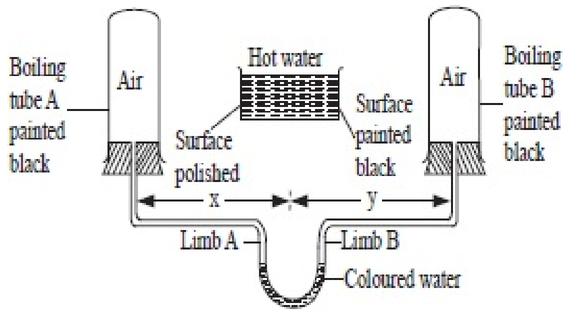


Fig. 7.25: Comparing emission of radiant heat

(i) The metal cube is centralized between the two boiling tubes, i.e ., distance x = distance y.

(ii) The level of coloured water in the U-tube is at the same height in both arms of the tube.

- Pour hot water into the metal cube. Observe what happens to the coloured water levels in the U-tube.
- Repeat the experiment with the sides of the metal cube exchanged.

Observation

The water level in limb A rises while the level in B falls.

Explanation

The boiling tube B receives more heat than boiling tube A, warming the air inside it. The air expands, increasing air pressure that pushes down the coloured water in limb B. When the sides of the metal cube are exchanged, the level of the water in limb A falls while the level in B rises. This experiment suggests that black surfaces are better heat emitters than polished (shiny) ones.

Method 2

Apparatus

Two similar tins with equal amounts of water, tin A blackened and tin B shiny, two thermometers, two lids and corks, two blocks of wood, source of heat.

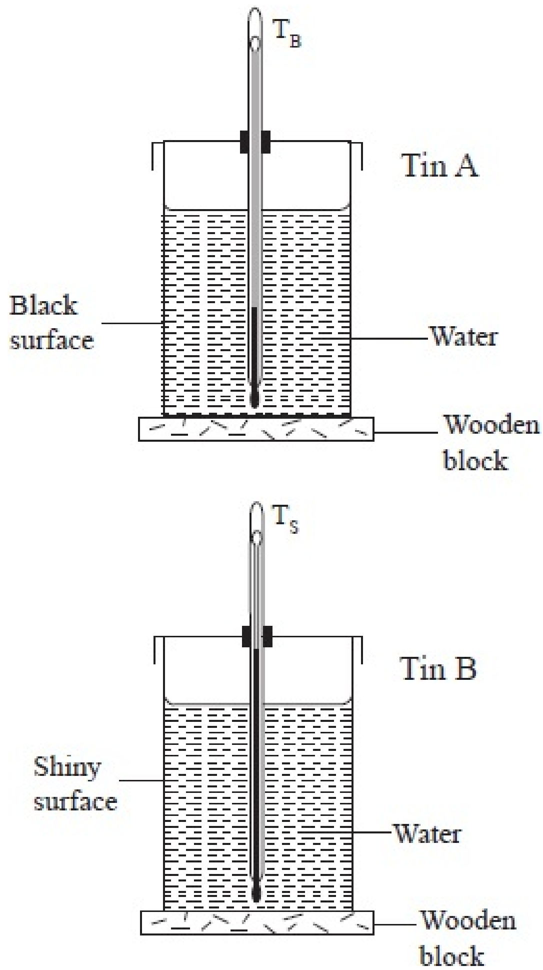


Fig.7.26: Emission of radiant heat from different surfaces

- On the same axis, draw two graphs of temperature against time for the temperature recorded by each thermometer.

Table 7.2

Time in minutes	0	2	4	6	8	10	12	14	16	18	20
Tempera-ture θ_1 from T_B											
Tempera-ture θ_2 from T_S											

Observation

After sometime, it is noted that the temperature recorded by T_B is lower than that recorded by T_S. The shape of the graph expected is shown in figure 7.27.

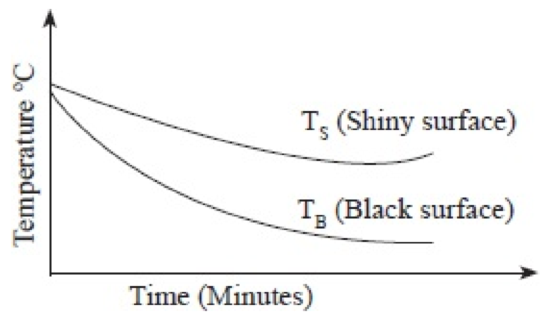


Fig.7.27: Rate of emission from different surfaces

The graph shows that water in a shiny (polished) tin lost heat less rapidly than the blackened tin.

Conclusion

From the experiments above, black surfaces are better emitters of heat than shiny surfaces.

Experiment 7.12: To compare absorption of radiant heat by different surfaces

Method 1

Apparatus

Two similar sheets of aluminium plates, one polished and the other painted black(dull), source of heat.

Procedure

- Using wax, fix a cork on the reverse side of each plate, as shown in figure 7.28.
- Set the plates vertically at a reasonable distance apart.

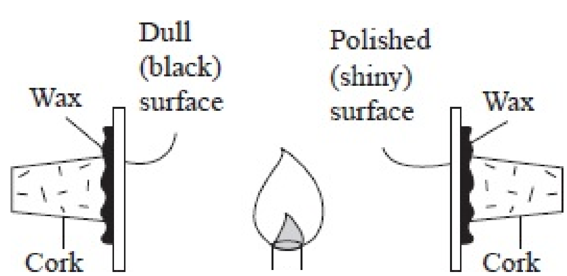


Fig. 7.28: Absorption of radiation

- Place the Bunsen burner midway between the plates and away from draught. Observe the corks fixed on the plates.

Observation

The cork fixed on the dull plate falls off after the wax melts, while the cork on the polished plate remains fixed for a longer time.

Method 2

Apparatus

Two tins A and B, each carrying the same amount of water, tin A blackened (dull), tin B shiny (polished), stop watch, two thermometers, two lids and corks.

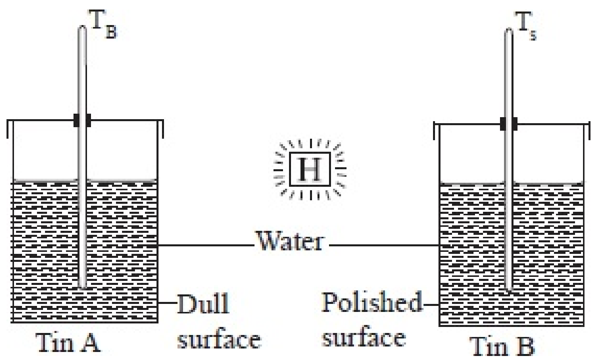


Fig. 7.29: Absorption of radiant heat

Procedure

- Set the apparatus as shown in figure 7.29.
- Place the heater midway between tin A and tin B.
- Read and record the temperatures of T_B and T_S at two minute intervals for about 20 minutes.
- Plot graphs of temperature (°C) against time (minutes) on the same axis.

Observation

The thermometer T_B immersed in water in the blackened tin records a higher reading than that of thermometer T_s.

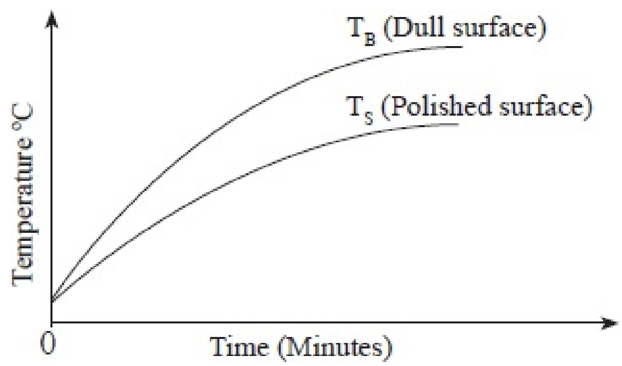


Fig. 7.30: Rates of absorption of radiant heat for different surfaces

From the sketch of graph in figure 7.30, the temperature of water in the polished tin does not increase as fast as the temperature of water in the blackened tin.

Conclusion

Black surfaces are better absorbers of radiant heat than polished surfaces.

Generally, good absorbers of radiant heat are also good emitters, while poor absorbers of radiant heat are also poor emitters. In addition, poor emitters of radiant heat are also good reflectors.

Applications of Thermal Radiation

1. Kettles, cooking pans and iron boxes have polished surfaces to reduce heat loss through thermal radiation.
2. Petrol tanks are painted silvery bright to reflect away as much heat as possible.
3. Houses in hot areas have their walls and roofs painted with bright colours to reflect away heat, while those in cold regions have walls and roofs painted with dull colours.
4. In solar concentrators, electromagnetic waves in the form of radiant heat are reflected to a common point (focus) by a concave reflector. The temperature at this point can be sufficiently high to boil water see figure 7.31.

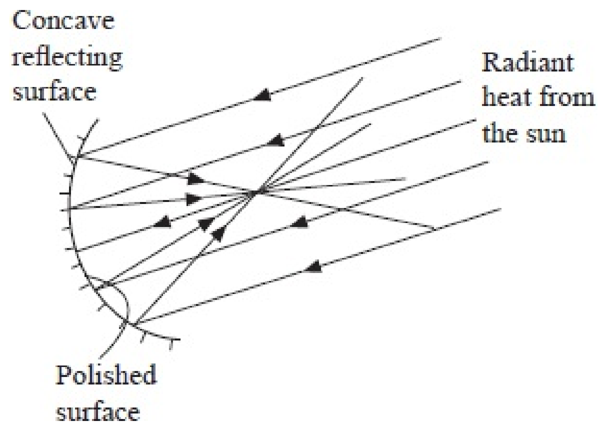


Fig. 7.31: Solar concentrator

5. *The Greenhouse Effect (Heat Trap)*

   A greenhouse has a transparent (glass or plastic) roof through which radiant heat energy from the sun passes, see figure 7.32. This heat is absorbed by objects in the green house, which then emit radiation of lower energy that cannot penetrate the glass. The cumulative effect is that the temperature of the houses increases substantially. Greenhouses are used in providing appropriate conditions for plants in cold regions.

   It is feared that carbon dioxide and other air pollutants in the lower layers of the atmosphere are having the same effects as glass, raising the temperature on earth to dangerous levels. This is known as The Greenhouse Effect.

Fig. 7.32: A greenhouse

6. *Solar Heater*

   The solar heater uses solar energy to heat water, see figure 7.33(a).

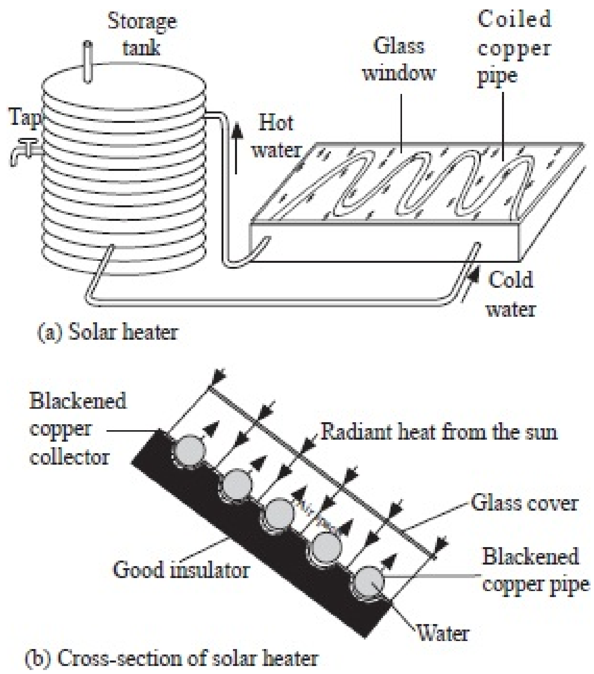


Fig 7.33: Solar water heater

It consists of coiled blackened copper pipe on a blackened insulating surface. Figure 7.33(b) shows the cross-section of the heater. Radiant heat from the sun passes through the glass and is absorbed by blackened copper pipes that contain water, which is heated up. Copper pipes and copper collectors are used because copper is a good conductor of heat. They are however painted black to increase their absorbing power.

Lower energy emitted after absorption of radiant energy does not escape because it cannot penetrate the glass. The temperature of the air above the pipe thus increases, boosting the heating of the water. A good insulating material is used as a base.

7. *Thermos Flask (Vacuum Flask)*

A thermos is designed to keep its contents at a fairly constant temperature by minimising transfer of heat between the contents of the flask and the surroundings. Figure 7.34 shows the main parts of a vacuum flask.

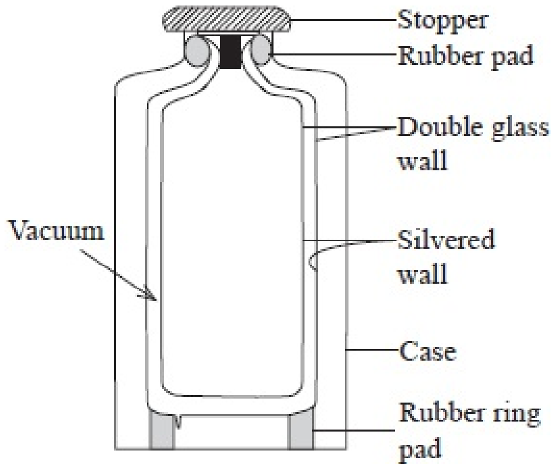


Fig. 7.34: A vacuum flask

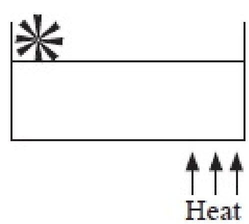
The flask is made of high quality glass, blown in such a way that it is double-walled. The air between the walls is pumped out to create a vacuum. This vacuum is an excellent insulator, minimising heat transfer by conduction and convection

Heat transfer by radiation, which might be relatively large, is reduced by a silver coating on the inside surfaces, so that each wall is a poor emitter and poor absorber of heat. Heat loss by evaporation from the liquid surface is prevented by a well-fitting cork. The metal or plastic case is necessary as a protection for the glass envelope. The soft padding holds the glass flask firmly in the case.

Revision Exercise 7

1. (a) Distinguish between natural and forced convection currents.

   (b) The paddle wheel in the figure below is made of a light material and is well-oiled. State the direction in which it will rotate.



2. (a) Explain why the feet feel colder when a person stands on a cemented floor than on a wooden floor.

   (b) While heating water in a beaker, a wire gauze is placed below the beaker. Explain.

3. (a) Explain why many houses in hot areas like Mombasa should be painted in white while those in colder places like Timboroa should be painted with dull colours.

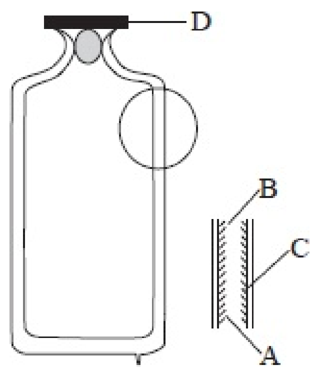
   (b) The ventilators for a room are put near the roof and not near the floor. Explain why.

4. Suggest:

   (a) how the thermal conductivity of a metal depends on its temperature.

   (b) why the rate of heat flow through a pane of glass is greater on a windy day.

5. The diagram below shows a vacuum flask with an enlarged view of the part circled:



   (a) State the material parts A and C are made of.

   (b) State what types of heat energy are reduced by or prevented by the parts marked B, C and D.

   (c) Explain how A is effective in reducing heat transfer.

6. (a) Draw the cross-section of a basic solar heating panel that uses heat from the sun to warm water which flows through pipes.

   (b) Explain the following as regards the solar heater:

      (i) Why the pipe is fixed to a dark-coloured collector plate.

      (ii) Why the pipe is made of copper.

      (iii) Why the pipe is coiled several times.

      (iv) Why the collector plate is fixed to an insulator.

      (v) Why the panel front is covered with glass.

7. Explain the following:

   (a) Two thin blankets are warmer than a single thick one.

(b) Flames go upwards.

(c) A person should crawl close to the floor in a smoke-filled room.

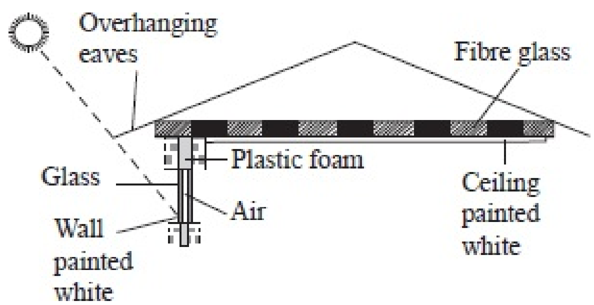
(d) A chimney and a fire help to ventilate a room.

8. Explain the greenhouse effect and how it affects the earth.

9. (a) Explain how you would use a concave reflector to heat some water in a black container on a sunny day. State the difference expected when the container is made shiny?

(b) Explain why a swimmer would prefer to put on wet clothes before diving into cold water?

10. The diagram below shows a cross-section through a house:



(a) Explain why houses in tropical areas should have overhanging eaves.

(b) Explain why the walls and ceiling boards are painted white.

(c) Explain how heat loss through the three modes of heat transfer is minimised.

(d) Explain the use of fibre glass and foam plastic.

(e) If the air between two glasses is replaced by plastic foam, the rate of heat transfer across the window would be reduced. Explain.

(f) It is not advisable to have a vacuum between the glasses, though the vacuum is an even poorer conductor of heat than air. Explain.

Chapter 8

Rectilinear Propagation and Reflection at Plane Surfaces

Light is a form of energy that makes visual perception possible. For a person to see an object, light energy from the object must enter the eye. This energy is converted into a 'picture' and interpreted in the mind.

Besides helping us to see our surroundings, light is also very essential as a source of energy for the process by which plants manufacture their food (photosynthesis).

Sources of Light

Some objects produce their own light and are known as **luminous** sources. Examples of such objects are the sun, stars, burning candles, a wood or charcoal fire, a red-hot heating element, electric light bulbs, television screens and glow worms, to mention a few.

Most objects do not, however, produce light of their own. They are seen when light falling on them from luminous sources is reflected (bounces off their surfaces). Examples of such objects include the moon, planets, plants, people, books, walls, clothes and wall charts. Such objects are referred to as **non-luminous**.

Rays and Beams of Light

A source of light produces pulses of energy which spread out in all directions.

The path along which light energy travels is referred to as a **ray of light**. In diagrams, rays are represented by lines with arrows on them to show the direction of travel. A **beam** is a stream of light energy which is considered to be a bundle of rays of light, as shown in figure 8.1. Beams of light are readily seen:

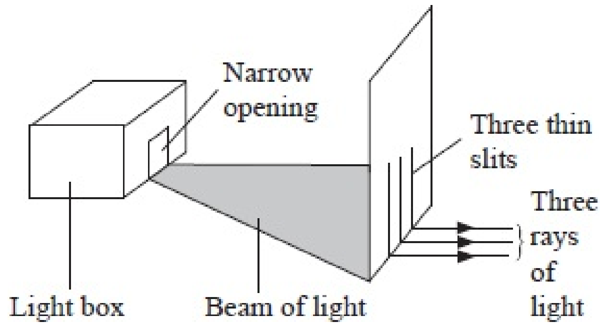


Fig. 8.1: Obtaining beams and rays of light

(i) in the morning as the sunlight breaks through the clouds.

(ii) when a spotlight is shone in a smoky room or a car drives along a dusty road at night with its headlamps on.

(iii) when sunlight streams into a smoky dark room through a small opening.

Types of Light Beams

A source of light may give rise to an infinite number of rays, all spreading out from the source as shown in figure 8.2.

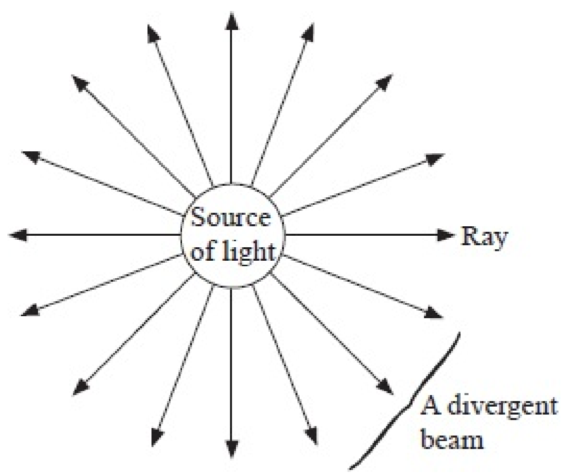


Fig. 8.2

Beams of light that appear to spread out (diverge) are referred to as **divergent beams**, for example, beam of light from a spotlight. Parallel beams are those that appear to be perfectly parallel to each other, e.g., beam of light from the sun reaching the earth's surface.

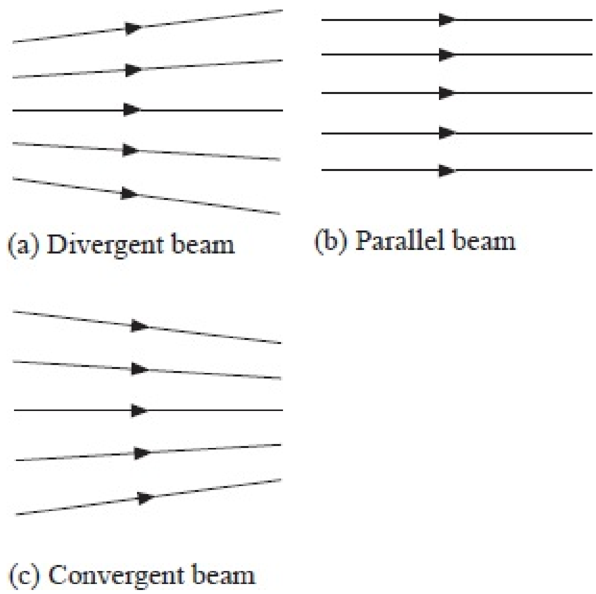


Fig. 8.3: Types of beams

Beams may also appear to collect (converge) to a point, in which case they are referred to as **convergent beam**. These are shown in figure 8.3 (a), (b) and (c).

Opaque, Translucent and Transparent Objects

Some objects do not allow light to pass through them at all, e.g., brick walls, metals, wood and stone. Such objects are said to be **opaque**. Other objects allow light to pass through, but we cannot see through them, e.g., some glass panes used in toilet and bathroom windows (frosted glass) and greased paper. Such materials are said to be **translucent**.

There are still other types of objects which allow light to pass through and we see clearly through them, e.g., car windscreens and ordinary window panes. These objects are said to be **transparent**.

Rectilinear Propagation of Light

Unlike some other forms of energy, light does not need a material medium to carry it. In a vacuum, the speed of light is 3×10^8 ms^{-1} (300 000 000m/s). Light from the sun reaches the earth having travelled mostly through the vacuum of space.

When light from a source falls on an opaque object, it casts a shadow of the object with sharp edges on a screen placed behind it. This suggests that light travels in straight lines in a uniform transparent medium.

Experiment 8.1: To investigate how light travels

Apparatus

Three identical cardboard sheets, source of light, piece of thread.

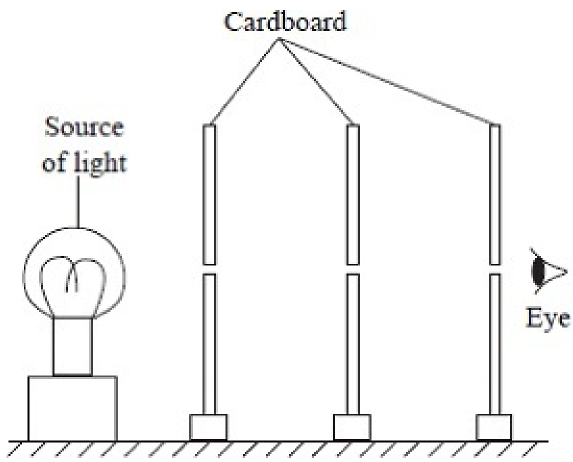


Fig. 8.4: Light travels in a straight line

Procedure

- Take the three cardboard screens and bore a pinhole through the middle of each.
- Arrange the sheets such that the holes are exactly in line. This is done by pulling a piece of cotton thread through the holes tightly.
- Place a lamp behind the first cardboard and view through the hole in the last cardboard sheet at the other side, as shown in figure 8.4. Observe what happens.
- Displace the middle cardboard sheet to the side and look through again. Observe what happens.

Observation

When the holes in the three cardboard sheet are in line, the eye sees the lamp. However, when the middle cardboard is displaced, the eye can no longer see the lamp.

Explanation

When the holes in the cardboards are in a straight line, light travels through the holes and the lamp is seen from the other side. When one of the cardboards is displaced, the beam of light is cut and since light cannot bend to follow the displaced hole, the lamp cannot be seen.

Conclusion

Light travels in a straight line. This property of light is known as the **rectilinear propagation of light**.

Shadows

Shadows are formed when an opaque object is in the path of a beam of light. The type of shadow formed depends on:

(i) the size of source of light.

(ii) the size of opaque object.

(iii) the distance between the object and the light source.

Experiment 8.2: To study the formation of shadows by a point source of light

Apparatus

Bulb (source of light), pin, screen, wooden or tin box.

Procedure

- Place a light bulb inside a ray box with a small hole in it.
- Place an obstacle (pin) in the path of light coming from the small hole. The hole acts as a point source.
- Place a white screen behind the obstacle as in figure 8.5. Observe what happens.

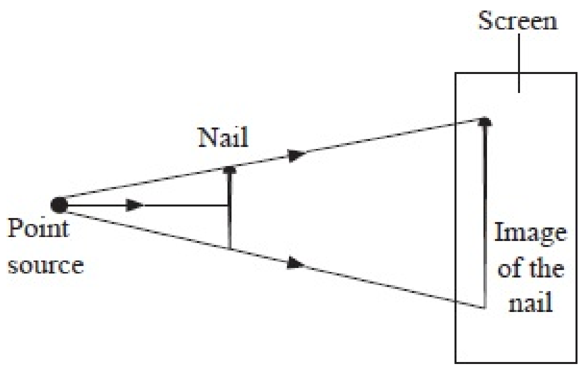


Fig. 8.5: Shadow formation by a point source

Observation

A uniformly and totally dark shadow is seen on the screen. This shadow is called the **umbra** (Latin for shade).

The shadow has a sharp edge, supporting the idea that light travels in straight lines.

Experiment 8.3: To study the formation of shadows by extended sources of light

Apparatus

Bulb, raybox, pin, screen.

Procedure

- Using a raybox with a large hole to act as an extended source of light, repeat experiment 8.2, as shown in figure 8.6.

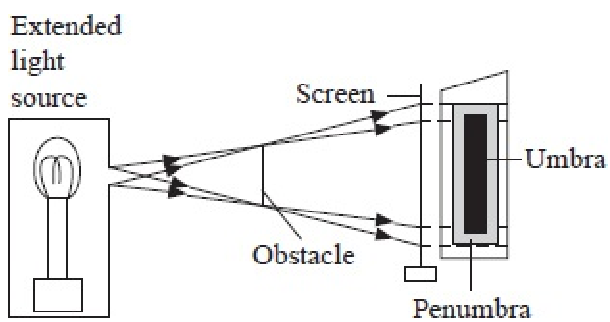


Fig. 8.6: Shadow formation by an extended light source

Observation

The centre of the shadow remains uniformly dark as before, but smaller in size. The shadow is edged with a border of a partial shadow called **penumbra**.

Explanation

The centre of the shadow still receives no light at all from the light source. Light from some parts of the extended source of light reaches the centre parts of the shadow on the screen, but light from other parts is cut off by the opaque object, resulting in a partial shadow at the edges.

Conclusion

Extended light sources produce shadows that is much softer and without sharp edges.

An application of this is the use of frosted light bulbs and lamp shades to provide a more pleasant lighting with less sharp shadows. Fluorescent tubes are usually surrounded by a frosted diffuser to scatter the light and reduce the sharpness of shadows.

Experiment 8.4: To study the formation of shadows by extended sources of light when the object distance is changed

Apparatus

Extended source, small obstacle (ball), screen.

Procedure

- Using a raybox with large hole and a small obstacle moved closer to the source, repeat experiment 8.2 as shown in figure 8.7 (a).

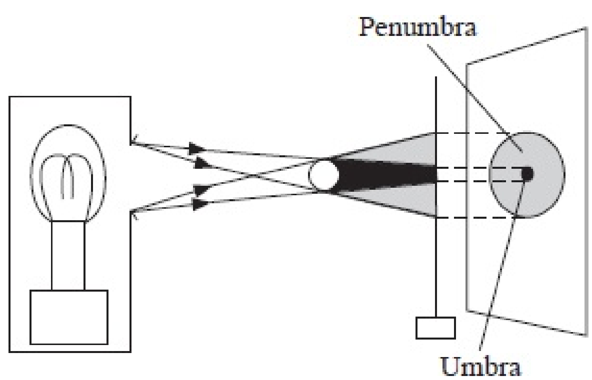


Fig. 8.7 (a): Shadow formation by an extended light source when the object is moved closer

- Move the obstacle away and repeat the experiment as shown in figure 8.7 (b).

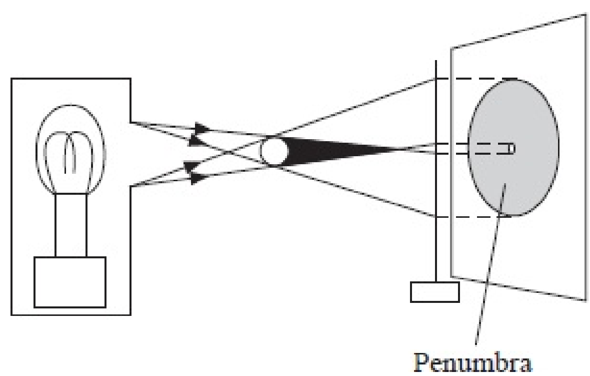


Fig. 8.7 (b): Shadow formation by an extended light source when the object is moved away

Observations

When the ball is moved closer to the source, a ring of penumbra is formed. No umbra is seen.

When the ball is far away, there is umbra surrounded by penumbra as in experiment 8.3.

Explanation

The centre of the shadow now receives light from the extended source. Since the ball is smaller than the source of light, its umbra does not reach the screen because of the distance.

However, when the ball is moved closer to the screen, the tip of the umbra reaches the screen.

Eclipse

An eclipse is a phenomenon of shadow formation which occurs once in a while. It is the total or partial disappearance of the sun or moon as seen from the earth. Eclipses are explained in terms of the relative positions of the earth, the moon and the sun.

Solar Eclipse

The sun is eclipsed when the moon passes between the sun and the earth. When this happens, the moon intercepts light from the sun, thereby casting a shadow on the earth and causing darkness during the day.

When a solar eclipse does occur, the path of the moon's umbra across the surface of the earth is very narrow (never wider than 272 km), so that most people on the earth see mainly a partial eclipse. In the umbra, the sun is completely covered, giving rise to a total eclipse (point Y in figure 8.9). In the penumbra, the sun is only partially covered, giving rise to partial eclipse of the sun (points X and Z).

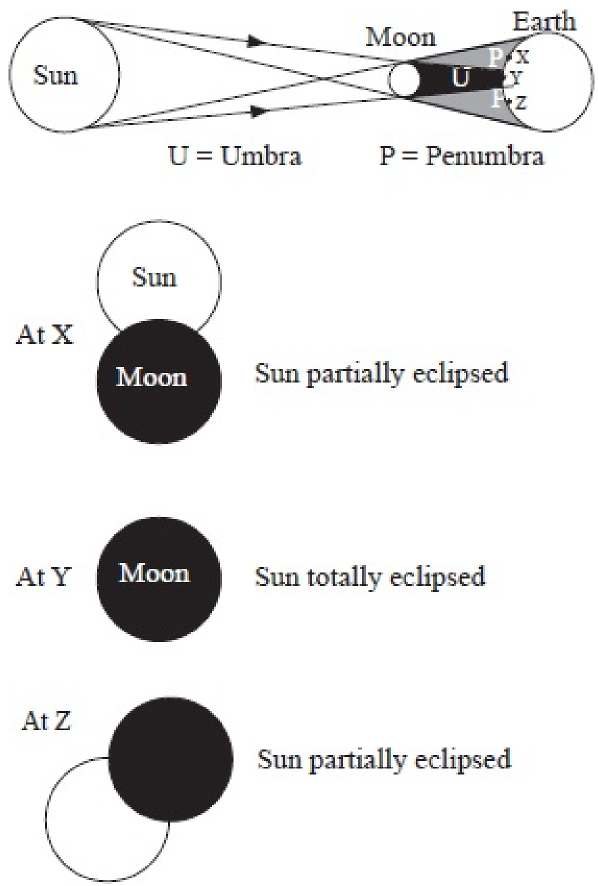


Fig. 8.9: Total and partial eclipses of the sun

The total eclipse, which never lasts more than about 8 minutes, allows us to see the sun's atmosphere which is normally not visible because of the brightness of the sun's disc itself. Red prominences and the rim of the sun's disc called the **corona**, which now surrounds the circumference of the moon, can be seen at the same time as the stars in the sky.

Annular Eclipse

Sometimes the umbra of the moon is not long enough to reach the earth because the distance between the moon and the earth varies (the moon's orbit is elliptical). When the moon is farther away from the earth, its disc is slightly smaller than the sun's disc. So, when a solar eclipse occurs, the moon is not large enough to cover the sun totally. A bright ring of sunlight can be seen round the edge of the dark disc of the moon as shown in figure 8.10. This is an **annular** or **ring eclipse**.

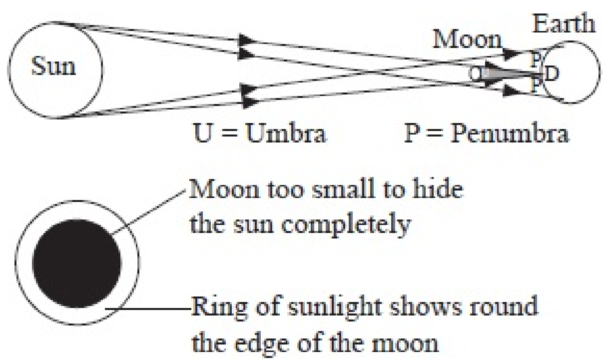


Fig. 8.10: Annular eclipse of the sun

Lunar Eclipse or Eclipse of the Moon

The moon does not emit light, but only reflects light from the sun. Thus, when it passes into the earth's shadow from direct sunlight, it is obscured.

A lunar eclipse occurs when the moon passes through the earth's umbra, as shown in figure 8.11.

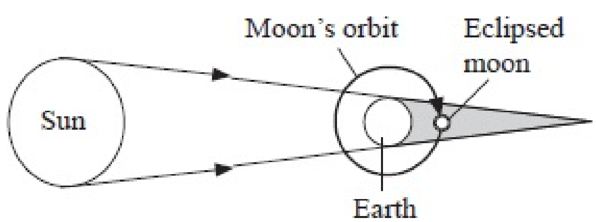


Fig. 8.11: Eclipse of the moon

A lunar eclipse only happens occasionally when the moon is full. It can last for as long as 1 hour 45 minutes, because the moon is much smaller than the earth and takes sometime to pass through the earth's umbra.

During a total lunar eclipse, it is still possible to see the moon because a small amount of sunlight reaches it. The sunlight is bent or refracted by the earth's atmosphere giving the moon a dim a coppery colour.

The Pinhole Camera

This is a simple camera with a small aperture but no lens. It is a light proof box with a small hole on one side.

How to make a pinhole camera

Make a small box (about 15 cm × 10 cm) of cardboard and paint its inside black. Cut out a square hole (about 6 cm × 6 cm) at the back.

Cover this hole with a translucent tracing paper (or greased white paper). The paper should be fixed tightly with glue or cellotape. This makes the screen onto which the camera projects the picture, see figure 8.12.

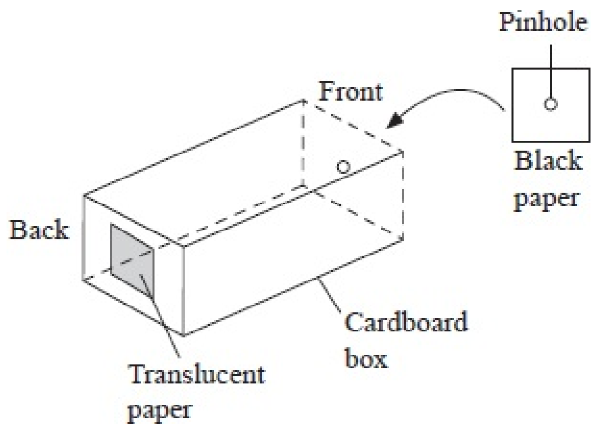


Fig. 8.12: The pinhole camera

Make a hole with a nail at the front end of the box and cover it with a black paper. Make a small pinhole with a pin or a needle on the black paper directly in front of the hole made with the nail.

Images in a pinhole camera

Experiment 8.5: To form an image in a pinhole camera

Apparatus

Pinhole camera, an object.

Procedure

- Set up the camera in a darkened or dimly-lit room with the pinhole facing a brightly-lit object. The object may be outdoors and viewed through an open window or may be an electric lamp, a candle or an illuminated pin, as in figure 8.13.

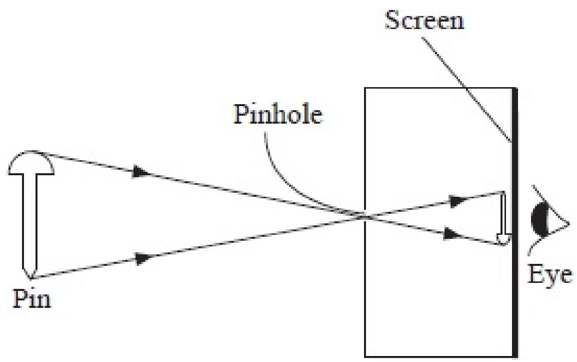


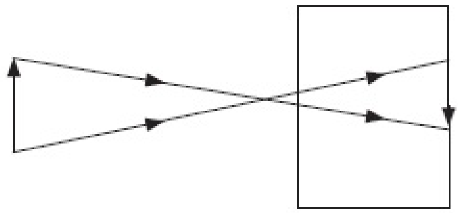
Fig. 8.13: Formation of an image in a pinhole camera

- Observe the image formed on the translucent paper.
- Move the camera closer to the object and observe the effect on the screen.
- Move the camera away from the object. Observe the effect on the image formed on the screen.
- Make a second pinhole beside the one in the black paper. What do you observe?
- Make more pinholes around the original pinhole in the black paper. What do you observe on the screen?
- Increase the size of the pinhole (by joining the many adjacent pinholes to form one large hole). Observe the effect on the image once again.

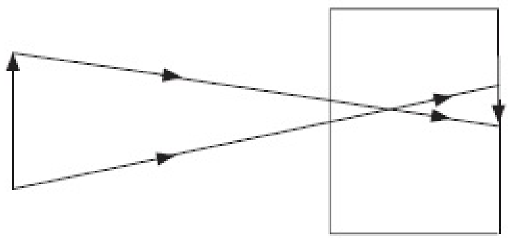
Observation

When the camera is set up with the pinhole facing the brightly-lit object pin, a sharp inverted image of the illuminated pin is seen on the screen, as in figure 8.13.

When the camera is moved near to the object, the size (height) of the image formed on the screen increases, i.e, the image becomes larger, as shown in figure 8.14 (a). Conversely, when the camera is moved farther away from the object, the image becomes smaller as shown in figure 8.14 (b).



(a) Object near the pinhole; larger image.



(b) Object distance greater; smaller image.

Fig. 8.14: Effect of changing the distance of the object from the pinhole

When more holes are added close to the first main pinhole, images of each point are seen overlapping on the screen, see figure 8.15.

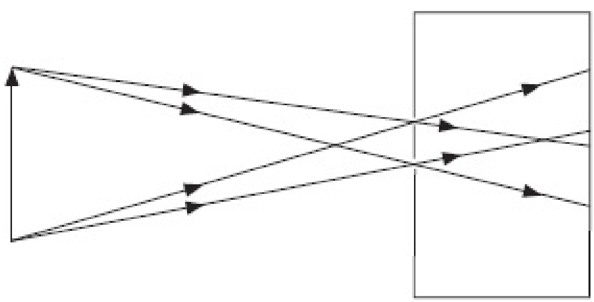


Fig. 8.15

When the pinhole is enlarged, a brighter but very blurred image is seen on the screen.

Explanation

Each point on the object acts as a source of light, emitting rays in all directions. The pinhole admits narrow cones of light from all points of the object facing the hole. When these cones of light fall on the screen they produce bright spots on every part of the object, hence the formation of the image.

The image is real as it is formed on a screen. The image is inverted (upside down) because light from the top of the object forms the lower portion of the image while light from the bottom of the object forms the upper section of the image. This further confirms the rectilinear propagation of light.

If the camera was made in such a way that it could be elongated by moving the screen farther away from the pinhole but keeping the distance between the object and the pinhole fixed, it would be observed that the image enlarges when the length of the camera is increased and diminishes when the length of the camera is reduced, see figure 8.16.

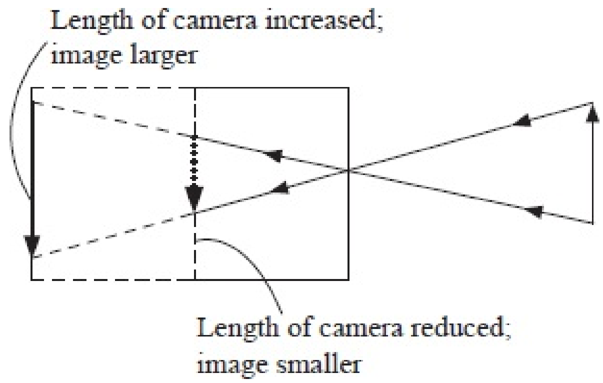


Fig. 8.16: Effect of changing the length of camera

Enlarging the pinhole is equivalent to adding an infinite number of other small holes close to the original pinhole. Each of the imaginary pinhole allows a narrow cone of light to reach the screen from each point on the object. Hence, several images of each point are formed overlapping on the screen. The additional brightness of the resultant image is due to more light which now gets into the camera through the enlarged hole. The image appears blurred due to the overlapping of different images falling on the same area of the screen.

Magnification

The change in the size of an image relative to that of the object is called the **magnification**, m.

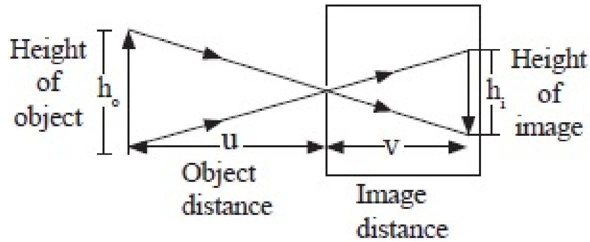


Fig. 8.17: Object and image distances in a pinhole camera

Thus, magnification, m

$$= \frac{\text{height of image } h_i}{\text{height of object } h_o}$$

It can be proved from the geometry of similar triangles that:

Magnification, m

$$= \frac{\text{distance of image from pinhole (v)}}{\text{distance of object from pinhole (u)}}$$

$$\text{Hence, } \frac{\text{height of image } h_i}{\text{height of object } h_o}$$

$$= \frac{\text{distance of image from pinhole (v)}}{\text{distance of object from pinhole (u)}}$$

Example 1

The distance between the pinhole and screen of a pinhole camera is 10 cm. The height of the screen is 20 cm. At what minimum distance from the pinhole must a man 1.6 m tall stand if a full length image is required?

Solution

The information can be represented as in figure 8.18.

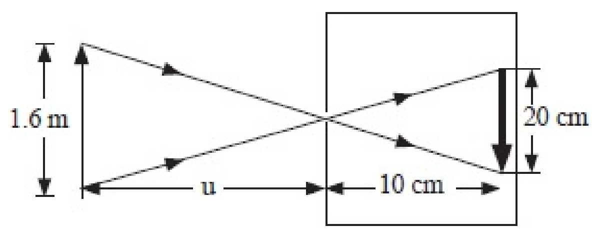


Fig. 8.18

$$\text{Magnification } m = \frac{h_i}{h_o} = \frac{v}{u}$$

But h_i	=	20 cm
	=	0.2 m
h_o	=	1.6 m
And v	=	10 cm
	=	0.1 m

m

$$\text{Therefore, } u = \frac{h_o \times v}{h_i}$$

$$= \frac{1.6 \times 0.1}{0.2}$$

$$= 0.8 \text{ m}$$

Example 2

An object of height 5 m is placed 10 m away from a pinhole camera.

Calculate:

(a) the size of the image if its magnification is 0.01.

(b) the length of the pinhole camera.

Solution

(a) $\text{Magnification} = \dfrac{\text{height of image } (h_i)}{\text{height of object } (h_o)}$

$$0.01 = \frac{h_i}{5}$$

$$h_i = 0.01 \times 5$$

$$= 0.05 \text{ m}$$

The image is 5 cm high.

(b) $\text{Magnification} = \dfrac{\text{image distance } (v)}{\text{object distance } (u)}$

$$0.01 = \frac{v}{10}$$

$$V = 0.01 \times 10$$

$$= 0.1 \text{ m}$$

The length of the pinhole camera is 10 cm.

Taking Photographs with a Pinhole Camera

The pinhole camera can be used to take still photographs if it is modified as follows:

(a) The box should be painted black on the inside to eliminate reflection of light.

(b) The translucent screen should be replaced by a light-tight lid with a photographic film fitted on the inside. The film should be fitted in a dark room.

(c) The pinhole should be covered with a thin black card which acts as a **shutter**, see figure 8.19.

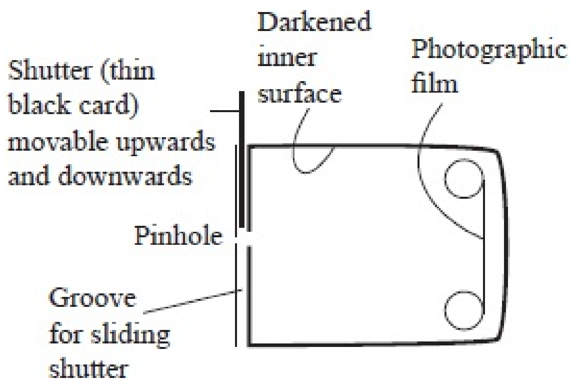


Fig. 8.19: Pinhole camera modified to take photographs

A photograph may be taken by facing the camera towards the scene to be photographed, which should be well lit. The camera is then supported firmly and the shutter pulled up for a suitable duration to expose the film to the light from the scene. Since the pinhole is very small, it allows very little light to reach the film. The exposure time, therefore, needs to be long enough to allow sufficient light to pass through.

There is no standard exposure time for the camera, as this depends on several factors, including size of the pinhole, lighting conditions, sensitivity of the film and length of the camera. The suitable time can only be determined by trial and error.

When the best time is found and photograph taken, the film is removed and the negative developed and printed.

The pinhole camera has one main advantage. It is able to form focused images on the film of objects both far and near the camera. The camera is said to possess a large depth of field because of the small aperture.

However, this small aperture is also the source of its major weakness as a camera. The exposure time has to be long in order to get clearer pictures. During this long exposure, there is every likelihood of movement which would produce blurred pictures. The exposure time could be reduced by enlarging the pinhole, but as observed, this will also produce blurred photographs. Although the small hole produces sharp photographs due to rectilinear propagation of light, there is a size limit below which photographs are not sharp. It is found that pinholes of diameter about 1.0 mm produce the sharpest images. Holes with smaller diameters produce blurred photographs due to an effect known as **diffraction**.

Example 3

The photographic film of a pinhole camera is 20 cm away from the pinhole. A student of height 1.6 m stands 8 m from the opening of the pinhole. Find the height of the student's image.

Solution

$$\text{Magnification, m} = \frac{\text{height of image } h_i}{\text{height of object } h_o}$$

$$= \frac{\text{image distance from pinhole (v)}}{\text{object distance from pinhole (u)}}$$

But $h_o = 1.6$ m

$v = 20$ cm

$= 0.2$ m

$u = 8$ m

$$M = \frac{v}{u} = \frac{h_i}{h_o}$$

$$\frac{0.2}{8} = \frac{h_i}{1.6}$$

Therefore $h_i = 0.04$ m

The student's image height is 4 cm.

Reflection of Light

Bodies like the sun, stars, lamps and fires can be seen because they are luminous. Non-luminous objects are seen when light from one of these sources, like the sun, bounces off their surface into our eyes. This bouncing off of light is called **reflection**.

The amount of light energy reflected by a body depends on the nature of the surface of the body (smooth or rough). The smoother the surface, the greater the fraction of light reflected from the body and the brighter the body appears to our eyes.

Regular and Diffuse Reflection

A white sheet of paper, a highly polished silvery metal surface and a mirror reflect all the light that falls on them. The effect is however different due to the nature of the surfaces of the materials. The surface of a polished sheet of metal or a mirror is very smooth and reflects all the parallel rays of light from a particular source in one direction only, see figure 8.20.

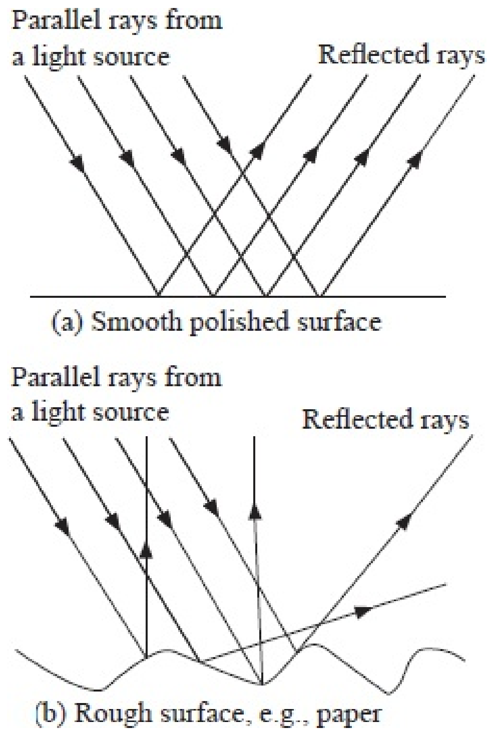


Fig. 8.20: Regular and irregular (diffuse) reflection

This is called **regular** or **specular reflection**. The irregular reflection of the light rays in different directions by a rough surface is called **diffuse reflection**.

Reflection by Plane Mirrors

A plane mirror is a flat smooth reflecting surface which forms images by regular reflection. It is often made by bonding a thin polished metal surface to the back of a flat sheet of glass or silvering the back side of the flat sheet of glass. The silvered side is normally coated with some paint to protect the silver coating.

The silvered side of the mirror is shown by the shading behind the reflecting surface. When using a glass plane mirror in an experiment, the silvered surface should be placed on the reflecting line drawn for the experiment, as shown in figure 8.21.

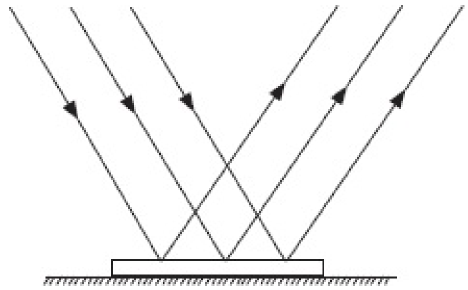


Fig. 8.21: Reflection by a plane mirror

Definition of Terms used in the Reflection of Light

Figure 8.22 shows the incident ray, reflected ray, the normal, the angle of incidence and the angle of reflection.

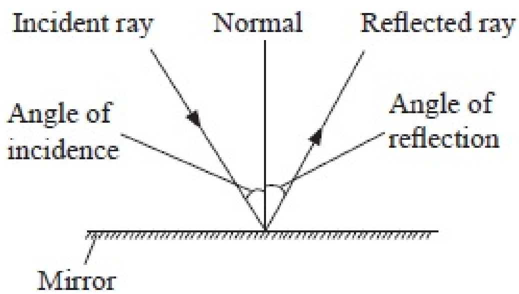


Fig. 8.22: Terms used

The **incident ray** is the ray that travels from the source to the reflecting surface.

The **angle of incidence** is the angle between the incident ray and the normal.

The **normal** is the line drawn perpendicularly at the point where the incident ray strikes the reflecting surface.

The **reflected ray** is the ray that bounces from the reflecting surface.

The **angle of reflection** is the angle between the reflected ray and the normal.

Laws of Reflection

Experiment 8.6: To investigate the relationship between the angle of incidence and the angle of reflection

Apparatus

Soft board, drawing pins, mounted plane mirror, sheet of paper (plain).

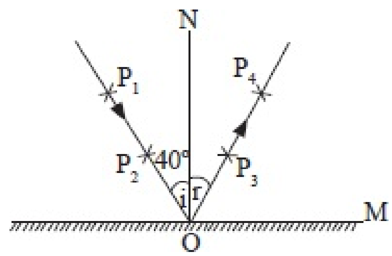


Fig. 8.23: Relationship between the angle of incidence and the angle of reflection.

Procedure

- Fix a sheet of paper on softboard using drawing pins.
- Draw a straight line, M, on which the mirror is placed.
- Mark a point O on M and draw a normal ON from O.
- Measure an angle of 40° from the normal and draw a line at that angle.
- Fix two pins P_1 and P_2 on this line, see figure 8.23.
- Observe the pins from the opposite side of the normal and place two searching pins P_3 and P_4 such that they appear to be in line with the images of P_1 and P_2 in the mirror.
- Fix these pins and mark their positions with a cross (x).
- Remove the searching pins and draw the line joining them to point O.
- Measure the angle r.
- Repeat for other angles of incidence 20°, 30°, 60°, 70° and 80°.
- Record your results in the table below:

Angle *i*	20°	30°	40°	50°	60°	70°	80°
Angle *r*							

The experiment may also be done using the raybox in place of the pins P_1 and P_2, see figure 8.24.

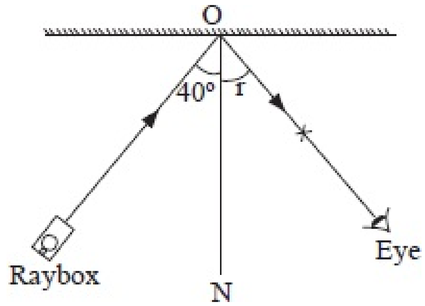


Fig. 8.24: Investigating the laws of reflection

- The ray from the raybox is directed along the line 40° to the normal. Mark a point X on the reflected ray. The line OX represents the reflected ray.
- The angle r is then measured and recorded.

Observation

(i) The angle of incidence, i, equals the angle of reflection, r.

(ii) The incident ray, the reflected ray and the normal at the point of incidence all lie on the same plane.

The above observations are referred to as the **laws of reflection** and they hold true for all reflecting surfaces.

Rotation of a Mirror Through an Angle

Experiment 8.7: To investigate the relationship between angle of rotation of a mirror and the angle of rotation of the reflected ray

Apparatus

Soft board, drawing pins, sheet of paper (plain), raybox, mounted mirror.

Procedure

- Fix a plain sheet of paper on soft board using drawing pins.
- Draw a straight line XY on the paper.
- Draw another line X’Y’ at an angle of 10° to XY such that the two lines intersect point O, see figure 8.25 (b).

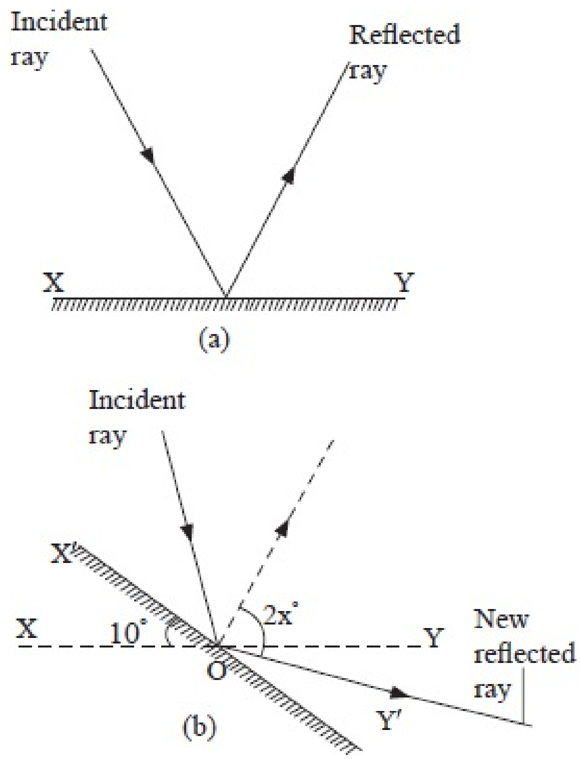


Fig. 8.25: Rotating the mirror

- Place the plane mirror with its reflecting surface vertical to the plane of the paper along XY, such that O is approximately at the middle of the mirror line.
- Direct a ray from a raybox (along the plane of the paper) to the mirror at an angle of 40° to the mirror line at O.
- Mark the paths of the incident and the reflected rays.
- Keeping the direction of the incident ray constant, rotate the mirror to lie along the line X'Y'. Mark the path of the reflected ray again.
- Withdraw raybox and the mirror and draw the incident ray and the two positions of reflected rays, producing them to meet at O.
- Measure the angle between the two mirror positions and the angle between the two positions of the reflected rays.
- Repeat the experiment for different angles of the mirror, e.g., 10°, 15°, 20°, 25°, 30° and 50° for a fixed direction of the incident ray.
- Record your results in the table shown below.

Angle of rotation of mirror	10°	20°	30°	40°	50°
Angle of rotation of reflected ray					

Observation

If the direction of the incident ray remains constant, the angle of rotation of the reflected ray is twice the angle of rotation of the mirror, see figure 8.25 (b).

This property is used in instruments where a beam of light is used as a pointer. For example, it is used in the mirror galvanometer (used for measuring very small electric currents) and the sextant (used in navigation for measuring the angle of elevation of the sun or stars).

Example 4

A plane mirror lying with its face up makes an angle of 10° with the horizontal. A ray of light shines down vertically on the mirror as shown in figure 8.26.

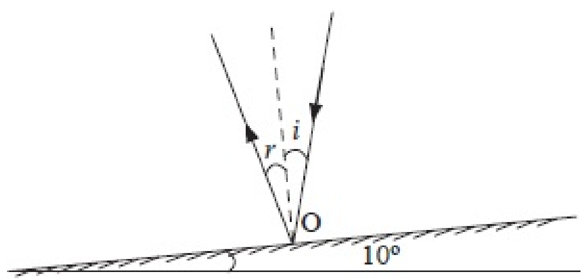


Fig. 8.26

(a) What is the angle of incidence?

(b) What angle will the reflected ray make with:

(i) the vertical?

(ii) the horizontal?

Solution

(a) The incident ray is perpendicular to the horizontal. A normal drawn to the inclined mirror through the point of incidence makes an angle i with the incident ray. Using the property of vertically opposite angles, the angle i is 10°.

(b) Since i = r, angle of reflection is also 10°.

Therefore, the reflected ray makes:

(i) angle of 20° with the vertical.

(ii) angle of (90 – 20) = 70° with the horizontal.

Example 5

Figure 8.27 shows a ray incident at an angle of 25° at position 1. The mirror is turned through 6° to position 2. Through what angle is the reflected ray rotated.

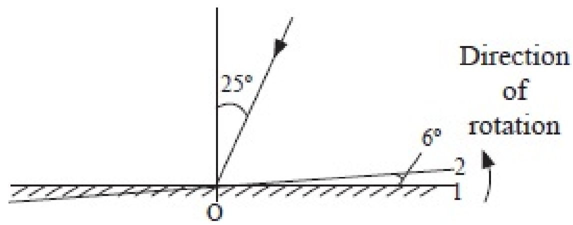


Fig. 8.27

Solution

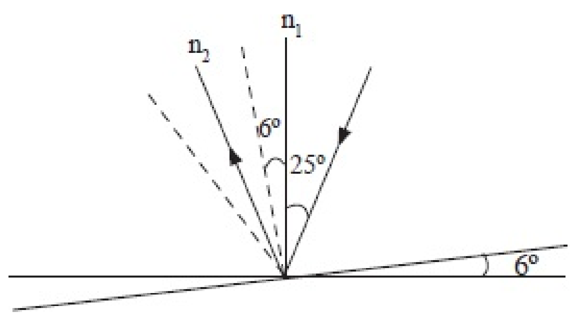


Fig. 8.28

The incoming ray is fixed.

Rotation changes the angle of incidence from 25° to (25 + 6) = 31°. Hence, the angle of reflection is 31° from the new normal. Since this angle is measured off the normal to the mirror which itself has rotated through 6°, the total change in the angle of reflected ray is 12°.

Example 6

A suspended plane mirror makes an angle of 20° with a wall. Light from a window strikes the mirror horizontally. Find:

(a) the angle of incidence.

(b) the angle between the horizontal and reflected ray.

Solution

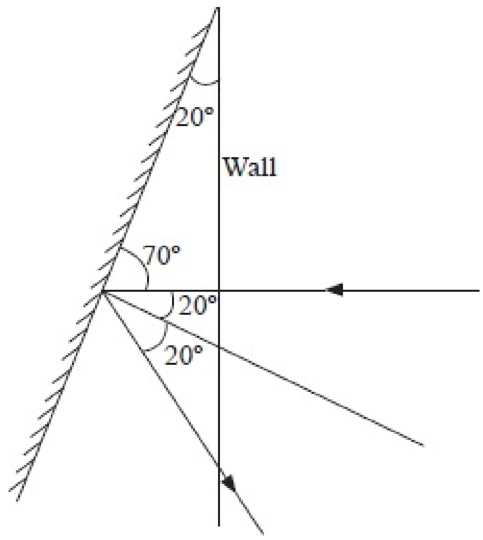


Fig. 8.29

(a) From figure 8.29, the light makes an angle 70° with the mirror. Hence, the angle of incidence equals 20°.

(b) Since i = r = 20°, the reflected ray makes an angle of 40° with the horizontal.

Formation of Images by Plane Mirrors

Experiment 8.8: To locate the image in a plane mirror

Apparatus

Softboard, plain sheet of paper, pins, mounted mirror.

Procedure

- Arrange the mirror on softboard, as in figure 8.30.
- Fix an object pin, O, in front of the mirror.
- View the image of the object pin, O, in the mirror by placing the eye on one side of the normal.
- Fix a search pin P_1 into the soft board in front of the eye such that it covers the image I of the object pin.

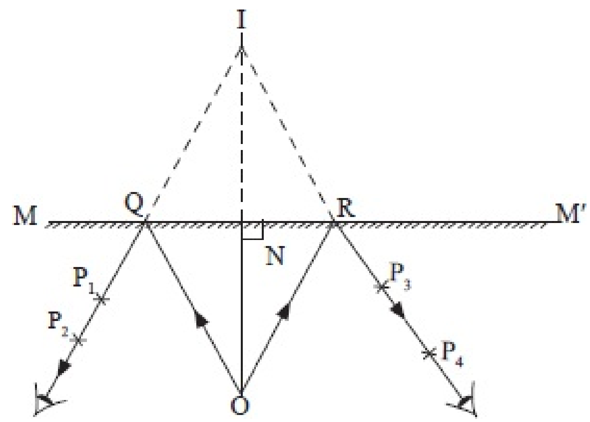


Fig. 8.30: Locating an image in a plane mirror

- Fix another search pin P_2 behind P_1 such that P_2, P_1 and the image I are in a straight line.
- Shift the eye to another position on the other side of the normal ON and repeat the steps above with pins P_3 and P_4, as shown in the diagram.
- Remove the mirror and pins.
- Draw a line through P_1 and P_2 to cut the mirror line at Q.
- Draw another line through P_3 and P_4 to cut the mirror line at R. Extend the two lines to meet at I as shown in figure 8.30.
- Join O to I and mark the intersection of OI with MM′ as N.
- Measure the line segments ON and NI.

Repeat the experiment with different distances of O from the mirror line.

Observation

ON = NI.

Conclusion

The image is formed as far behind the mirror as the object is in front of the mirror.

Characteristics of Images Formed by Plane Mirrors

Experiment 8.9: To investigate the size of image in a plane mirror

Apparatus

Soft board, plain sheet of paper, mounted mirror, extended object.

Procedure

Repeat experiment 8.8 using an extended object as shown in figure 8.31. Measure TS and T'S'.

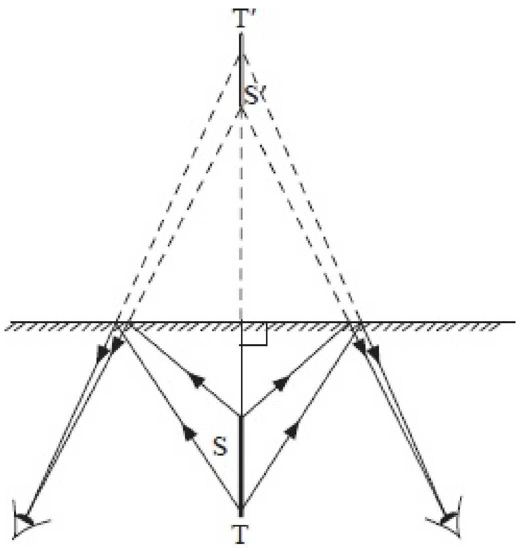


Fig. 8.31: Size of image formed in a plane mirror

Observation

The image formed is the same size as the object.

Experiment 8.10: To investigate the nature of the image formed in a plane mirror

Apparatus

Mirror, softboard, plain sheet of paper. *Procedure*

- Stand in front of a mirror and view your image in the mirror.
- Raise your right hand and observe the behaviour of the image.
- Obtain a piece of white paper and draw a vertical line through its centre.
- To the left of the line, write a word, e.g., ‘BET’, see figure 8.32.

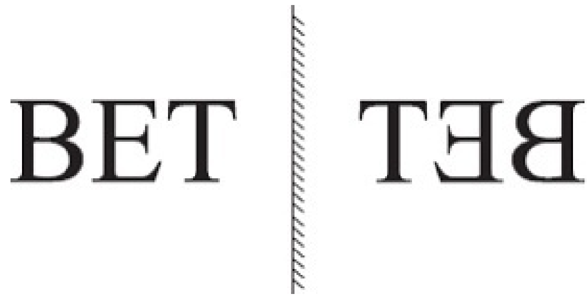


Fig. 8.32: Lateral inversion

- Place a plane mirror along the line with the reflecting surface facing the word and vertical to the plane of the paper.
- View the image of the word in the plane mirror and note the appearance.

Observation

(i) When you raise your right hand, the image in the mirror raises its left hand.

(ii) The word appears inverted left to right (laterally inverted).

From figures 8.30 and 8.31, it is clear that no rays come from the image. The rays (represented by dotted lines) only appear to come from there.

Images from rays which only appear to come from them, but are not real rays, are called **virtual images**. Such images cannot be formed on the screen as they are only imaginary (as seen by the observers eye).

Parallax

Imagine viewing two trees positioned in a line, one behind the other, as shown in figure 8.33. With the eye at position E_1, tree 2 appears to right of tree 1 and with the eye at position E_2, tree 2 appears to the left of tree 1.

This apparent relative motion of two objects due to the movement of the observer is called **parallax**.

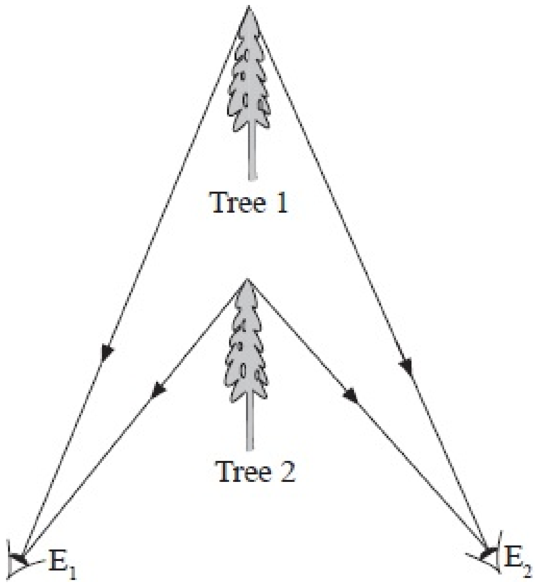


Fig. 8.33: Parallax

If the two trees were being viewed at the same position, i.e., tree 1 on top of tree 2, the apparent relative change in their positions would not have occurred. The two trees would have appeared to move as one unit.

This means that parallax occurs only when objects are some distance apart. When the objects are at the same position, there is no parallax. In measurements using a metre rule, it is found that when the eye is not positioned vertically above the point to be measured, there is an error due to parallax.

Other instruments that have moving pointers above a scale, e.g., electrical meters, may suffer errors of parallax if the line of sight is not placed perpendicular to the pointer.

Experiment 8.11: To locate the position of the image in a plane mirror by method of no parallax

Apparatus

Softboard, plain sheet of paper, mirror, pins.

Procedure

- Secure a plain sheet of paper on a soft board using drawing pins. Draw a mirror line. Place the mirror on the paper as in earlier experiments.
- With the mirror on the mirror line, position an object pin, O, about 10 cm in front of the mirror, see figure 8.34.

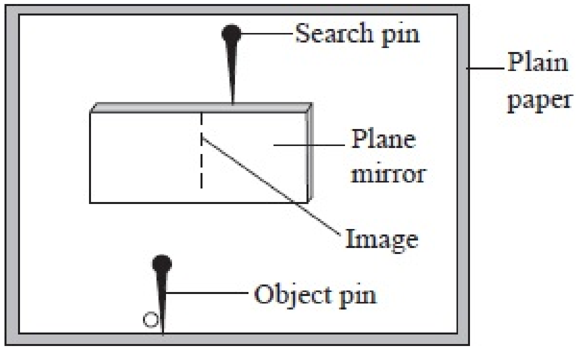


Fig. 8.34: Finding image position by non-parallax

- Obtain another pin (a search pin) whose height is greater than the height of the mirror. Hold this search pin behind the mirror such that its top can be seen when the eye is placed in front of the mirror and directly in front of the object pin. The eye sees the image of the object pin and the top of the search pin.
- Shifting the eye position sideways, you will observe parallax between the image of the object pin and the top of the search pin. Keep moving the search pin until there is no parallax between the image of the object pin and the top of the search pin. This position of the search pin is the position of the image of the object pin.
- Fix the search pin into the softboard and measure the image and object distances.
- Repeat for different positions of object pin to confirm the results.

Observation

The object distance is always equal to the image distance.

The characteristics of the images formed by a plane mirror can thus be summarised as follows:

(i) The image is as far behind the mirror as the object is in front of the mirror.

(ii) The image is the same size as the object.

(iii) The image is virtual, erect and laterally inverted.

Example 7

A girl stands 2.0 m in front of a plane mirror.

(a) Calculate the distance between the girl and her image.

(b) If the mirror is moved 0.6 m away from the girl, what will be the distance between her and the image?

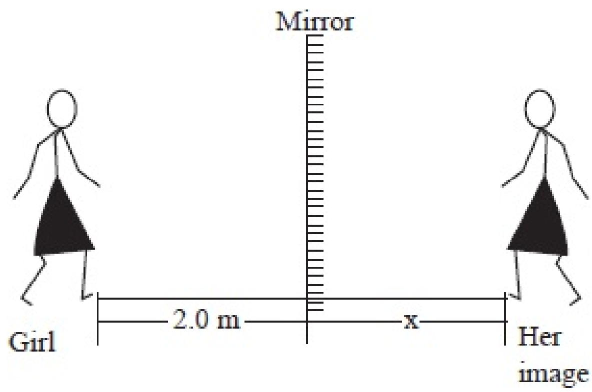


Fig. 8.35

(a) Since object distance equals image distance, the image is 2.0 m behind the mirror. Thus;

Distance between object and image

= object distance + image distance

= 2.0 + 2.0

= 4.0 m

(b) When the mirror is moved 0.6 m away; object distance becomes 2.0 + 0.6 = 2.6 m. The image distance is also 2.6 m.

Hence, distance between them

= 2.6 + 2.6 m

= 5.2 m

Images Formed by Mirrors at an Angle

Mirrors inclined at 90°

Experiment 8.12: To investigate formation of images by mirrors inclined at an angle of 90°.

Apparatus

Two mirrors, object.

Procedure

- Arrange two plane mirrors M_1 and M_2 at right angles to each other on a level bench, as shown in figure 8.36.
- View the images as shown.

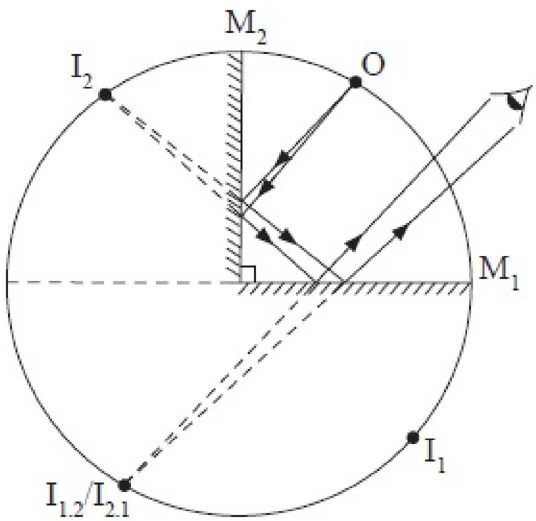


Fig. 8.36: Images formed by two plane mirrors inclined at 90° to each other

Observation

Three images will be seen. Rays of light by which the eye sees one of these images $1_{1.2}$, are shown in the figure.

Explanation

When two mirrors are inclined at right angles to each other as in figure 8.36, two images I_1 and I_2 are formed by a single reflection by mirrors M_1 and M_2 respectively. Two extra images $1_{1.2}$ and $I_{2.1}$ are produced by double reflections. The subscripts in the symbols $I_{1.2}$ and $I_{2.1}$ signify the order in which reflections take place. Thus, $I_{1.2}$ implies reflection by mirror 1 then mirror 2.

The image I_1 is seen by looking into mirror 1 and image I_2 by looking into mirror 2. The two images $I_{1.2}$ and $I_{2.1}$ are actually superimposed on one another so that we only see a total of three images as in figure 8.36.

Mirrors inclined at 60°

When the angle is made 60°, we see five images, as shown in figure 8.37.

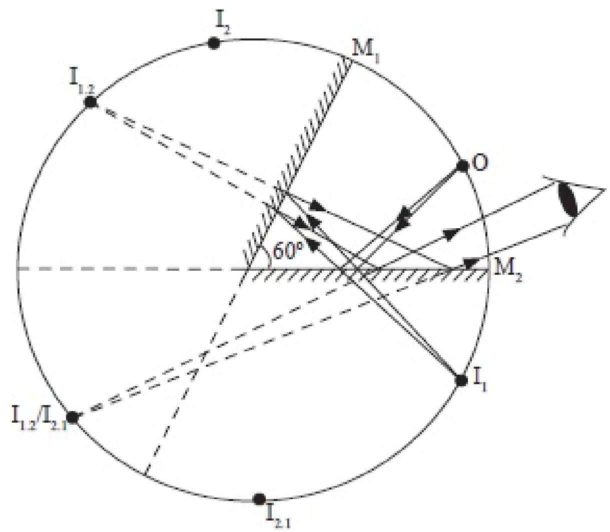


Fig. 8.37: Images formed by two plane mirrors inclined at 60° to each other

Mirrors inclined at 45°

When the angle is further reduced to 45°, the number of images seen increases to seven as in figure 8.38.

Repeat the experiment with the mirrors inclined at 120°, 72°, 40° and 30°.

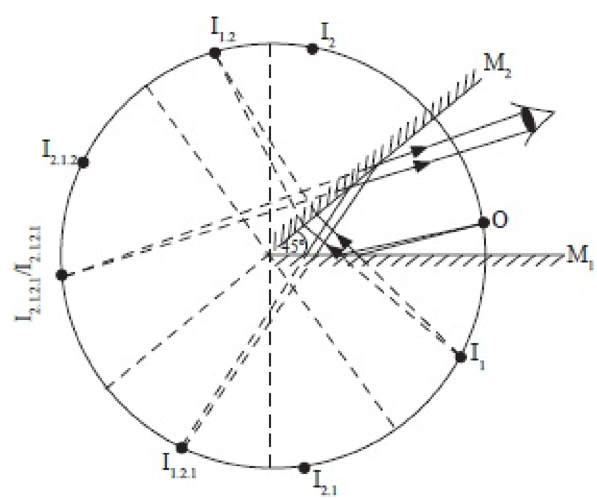


Fig. 8.38: Images formed by two plane mirrors inclined at an angle of 45° to each other

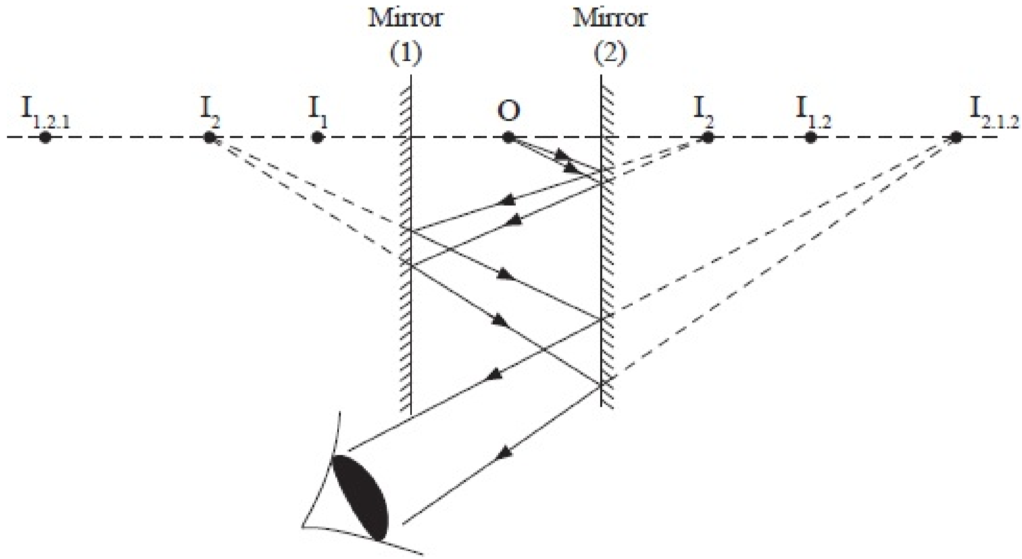


Fig. 8.39: Images formed by two parallel mirrors

By recording the results in the table below, try to find the relationship between the number of images, n, and θ, the angle between the mirrors.

Angle between mirrors (θ)	*Number of images (n)*	$\frac{360°}{\theta}$	$\frac{360°}{\theta} - 1$
90°	3	$\frac{360°}{90°} = 4$	4 – 1 = 3

Conclusion

The number of images increases as the angle is reduced. The actual number (n) of images when the mirrors are inclined at an angle is given by the formula;

$$n = \frac{360°}{\theta} - 1$$

Mirrors parallel to each other

When the mirrors are parallel, i.e., θ = 0°, number of images formed is given by;

$$n = \frac{360°}{\theta} - 1 = \infty \text{ (n is infinite)}$$

This is evident as one walks between parallel mirrors, as in some wash rooms or a barbers shops. The farther images are fainter due to absorption of light on reflection.

Example 8

Two parallel plane mirrors are placed 30 cm apart. An object placed between them is 10 cm from one mirror. Determine the image distance of two nearest images formed by each mirror.

Solution

Figure 8.40 illustrates the set-up. Since image distance equals object distance;

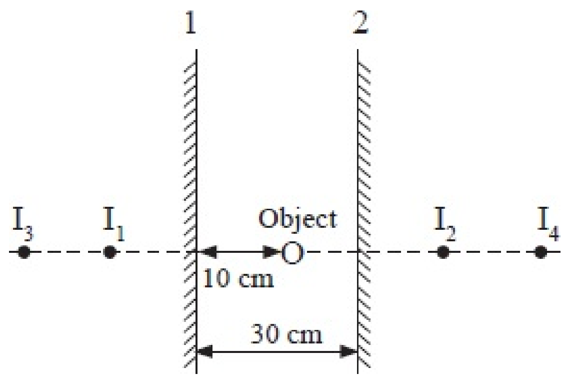


Fig. 8.40

The image of the object on mirror 1 is I_1. Image distance is 10 cm.

The image of object on mirror 2 is I_2. Image distance is 20 cm.

The image distance of I_2 on mirror 1 is 50 cm.

The image distance of I_1 on mirror 2 is 40 cm.

Example 9

Two plane mirrors are inclined at angle 60° to each other. A ray of light makes an angle of 40° with mirror M_1 and goes on to strike mirror M_2. Find the angle of reflection on the second mirror M_2.

Solution

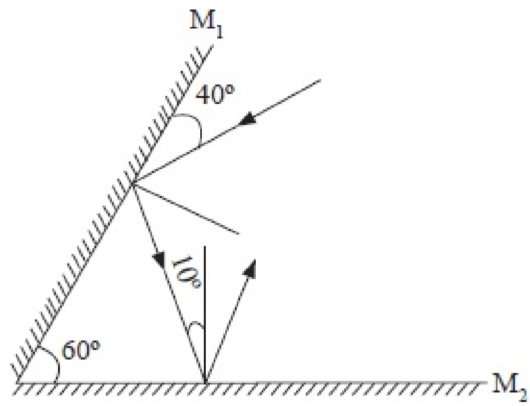


Fig. 8.41

The angle of incidence on mirror 1 is 50°.

Since I = r, the angle of reflection is also 50°.

Hence, the incident ray makes an angle of 10° with the normal of mirror 2.

Therefore, the angle of reflection on mirror 2 is 10°.

Applications of Plane Mirrors

The Kaleidoscope

The kaleidoscope applies the principle of mirrors at an angle. Initially, it was produced as a toy under the name 'mirrorscope'.

It consists of two mirrors M_1 and M_2 placed at an angle of 60° to each other inside a tube.

The bottom of the tube is a ground glass plate for admitting light. On this plate is scattered small pieces of brightly coloured glass, which act as objects.

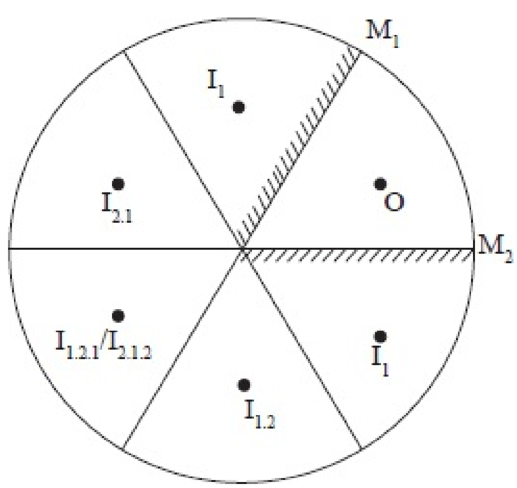


Fig. 8.42: The kaleidoscope

When one looks down the tube, five images of the object are seen which together with the object form a symmetrical pattern in six sectors, as shown in the figure. The instrument is used by designers to obtain ideas on symetrical patterns.

The Periscope

This is an instrument used to view objects over obstacles. It is used in submarines and also to watch over the heads of crowds. The images seen with aid of the instrument are erect and virtual.

A simple periscope may be constructed by arranging two plane mirrors inclined at 45° to the horizontal, as shown in figure 8.43. The rays from the object are reflected by the top mirror and then reflected again by the bottom mirror into the observer's eye.

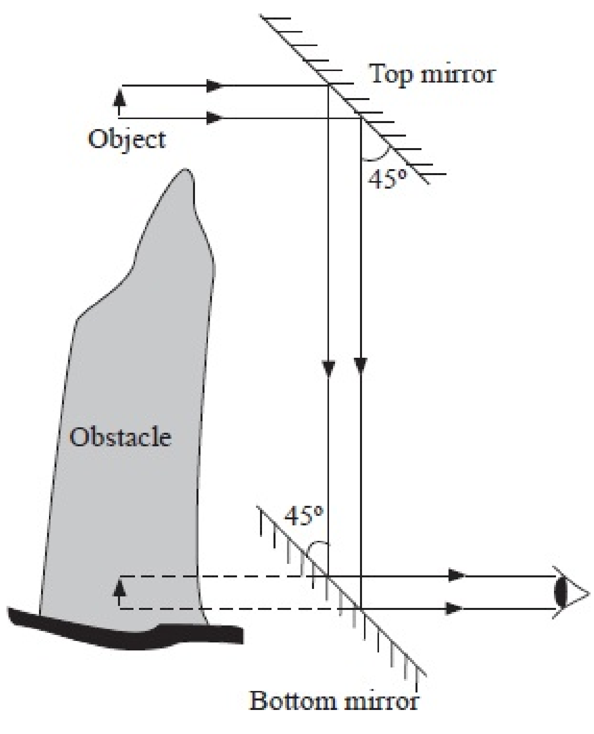


Fig. 8.43: Simple periscope

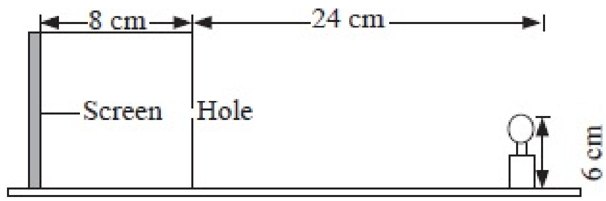
More elaborate periscopes are used in submarines. Here, prisms are used instead of mirrors and the tube supporting them incorporates a telescope to extend the range of vision.

Revision Exercise 8

1. How does a person see an object?
2. Distinguish between luminous and non-luminous objects, giving five examples of each.
3. Light travels in a straight line. Describe a laboratory experiment to verify this fact.
4. (a) Distinguish between a lunar and a solar eclipse. Describe the events leading to the occurrence of each.
   (b) State the conditions necessary for the occurrence of an annular eclipse.
5. (a) Outline the steps required to make a pinhole camera.
   (b) A pinhole camera forms on its screen an image which appears upside down. With the aid of ray diagrams, explain how this happens.
   (c) The pinhole camera has advantages and disadvantages when used to take photographs. Discuss these.
   (d) Briefly describe the effects of the following on the size of the image formed on the screen of a pinhole camera.
      (i) Increasing the distance of object from the pinhole.
      (ii) Decreasing the distance of the object from the pinhole.
6. (a) State the laws of reflection.
   (b) Name three applications of the reflection of light in everyday life.
   (c) Explain the construction and the working of an instrument that could be used to view a football match from outside the field which has a high concrete wall.
7. (a) How many images would be seen from two mirrors when the reflecting surfaces make an angle of 60° with each other?
   (b) What is the practical application of this arrangement?
   (c) At what angle would the two mirrors be inclined to form.
      (i) 17 images.
      (ii) 29 images
8. (a) Define the term magnification as applied to the formation of images by a pinhole camera.
   (b) A pinhole camera of length 15 cm forms an image 3 cm high of a man standing 9 m in front of the camera. What is the height of the man? Give your answer to the nearest centimetre.

9. (a) What is the purpose of a translucent screen on the pinhole camera?

(b) A lamp of height 6 cm stands in front of a pinhole camera at a distance of 24 cm. The camera screen is 8 cm from the pinhole as in the figure below. What is the height of the image on the screen?



10. (a) Two mounted mirrors are inclined at an angle of 120° with their faces inwards. A pin is placed between them. Draw ray diagrams to show how many images will be observed.

(b) Complete the ray diagram below to show how the eye views the tip of the lighted candle as the object.

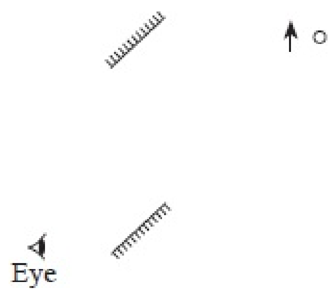
11. (a) Describe an experiment to verify the laws of reflection.

(b) A man stands 300 cm from a large wall-mirror. He then walks slowly towards the mirror at a speed of 50 cm per second. What is the distance between him and his image after 4 seconds?

12. (a) Differentiate between a real image and a virtual image.

(b) Although a plane mirror forms a virtual image, it is possible to take your own picture when standing in front of a plane mirror. Explain.

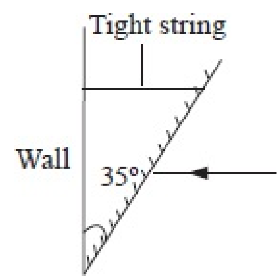
13. The figure below shows part of an incomplete device:



(a) Draw the ray diagram to show the true position of the image.

(b) Describe fully the image formed.

14. In a hair salon, a plane mirror is suspended using a string and makes an angle of 35° with the wall, as shown below:



A ray of light strikes the mirror horizontally. Calculate the angle between the horizontal and the reflected ray.

Chapter 9

Electrostatics (I)

When a plastic comb, a plastic pen or rubber balloon is rubbed on one's sleeve or hair and brought near small pieces of paper, it attracts them.

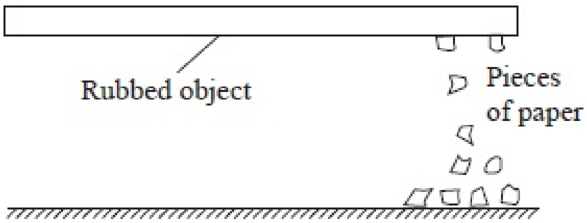


Fig. 9.1: A rubbed plastic object attracting pieces of paper

Household mirrors and windows attract dust and other small particles when wiped with a dry duster. A crackling sound is sometimes heard when nylon cloth are taken off the body.

These observations are as a result of the formation of static charges. The charges found on the surfaces of the materials are caused by friction between the rubbed surfaces. The materials are said to be charged and the study of these static charges is called **electrostatics**.

There are two types of charges **negative** and **positive charges**. The SI unit of charge is the **coulomb**(C). Subunits of the coulomb, millicoulombs (mC) and microcoulombs (μC) are also used.

1000 mC = 1C

1 000 μC = 1 mC

1 000 000 μC = 1C

Origin of Charge

Matter is made up of atoms. An atom consists of particles known as **protons**, **neutrons** and **electrons**. The protons and neutrons are concentrated in a small space at the centre of the atom and form the nucleus of the atom.

Protons are positively charged while neutrons have no charge. The electrons move in orbits around the nucleus and are negatively charged.

The nucleus has positive charge due to the charge on the protons. The total number of the positive charges in the nucleus is equal to the total number of negative charges on the electrons. Therefore, the whole atom is neutral, see figure 9.2.

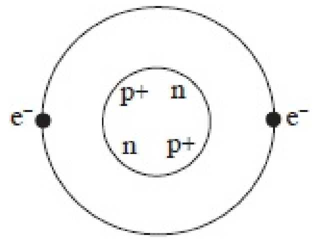


Fig. 9.2: The particles in an atom

Electrons in the outermost orbit are weakly held by the nucleus and can be transferred easily from the atoms of one material to another by rubbing.

The material that gains electrons becomes negatively charged and the one which loses electrons becomes positively charged. It is worth noting here that charge is neither created nor destroyed during rubbing or charging, but simply transferred from one body to another. A negatively or positively charged atom is called an **ion**.

When a polythene rod is rubbed with a piece of cloth, the cloth loses negative charges to the rod, making the latter negatively charged. Consequently, the cloth becomes electron deficient and it acquires positive charge, see figure 9.3 (a) and (b).

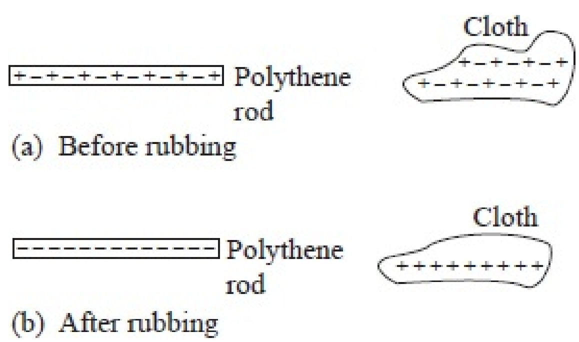


Fig. 9.3: Charging by rubbing

Materials such as polythene and most plastics acquire extra electrons on their surface and hence become negatively charged when rubbed. The rubbing material (cloth or duster) loses an equal number of negative charges and becomes positively charged. On the other hand, materials such as acetate, perspex and glass have electrons removed from their surface when rubbed. They thus become positively charged while the rubbing material (duster) gains an equal number of negative charges.

Experiment 9.1: To investigate the law of charges

Apparatus

Two glass rods, silk cloth, silk thread, a stand, a Bunsen burner, polythene and duster.

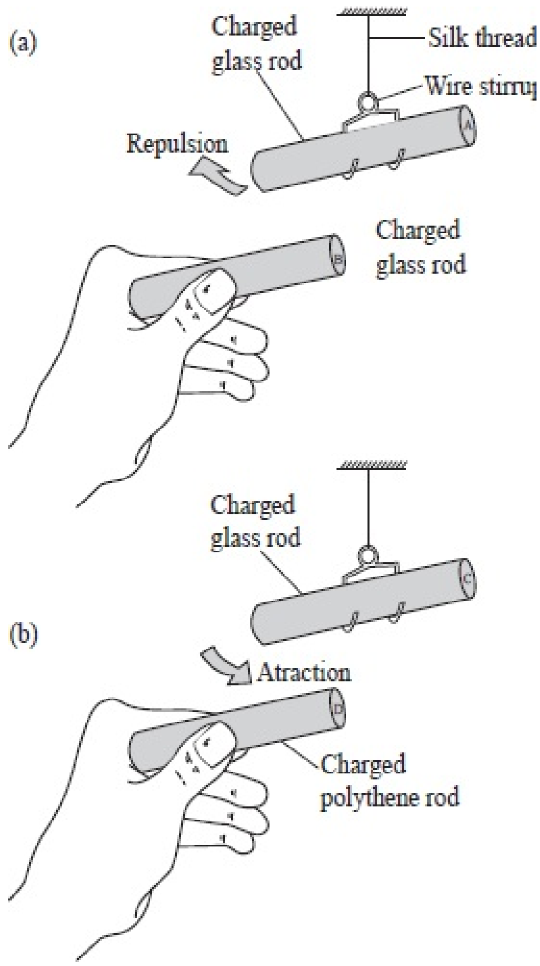


Fig. 9.4: Law of charges

Procedure

- Dry the glass rod by running it over a Bunsen flame a few times.
- Rub the dry rod with a silk cloth.
- Suspend the rubbed glass rod by a thread from the stand.
- Dry a second glass rod and rub it with silk cloth.

- Hold this second glass rod close to the suspended glass rod, as shown in figure 9.4 (a) and observe what happens.
- With the glass rod still suspended, bring a polythene rod rubbed with fur close, to it as shown in figure 9.4 (b). Note what happens.

Observation

When a charged glass rod is moved close to a suspended charged glass rod, they repel each other. When a charged polythene rod is moved close to a suspended charged glass rod, they attract each other.

Explanation

Since the glass rods were rubbed with the same material, both acquired a positive charge. The repulsion between them implies that like charges repel each other. The polythene rod (negatively charged) attracted the glass rod (positively charged), showing that unlike charges attract each other.

Therefore, like charges repel and unlike charges attract each other. This is called the **basic law of electrostatic charges**.

Charging by Induction

Experiment 9.2: To charge a conductor by the induction method

Apparatus

A polystyrene ball coated with aluminium point, silk thread, glass rod, silk cloth, stand, polythene rod.

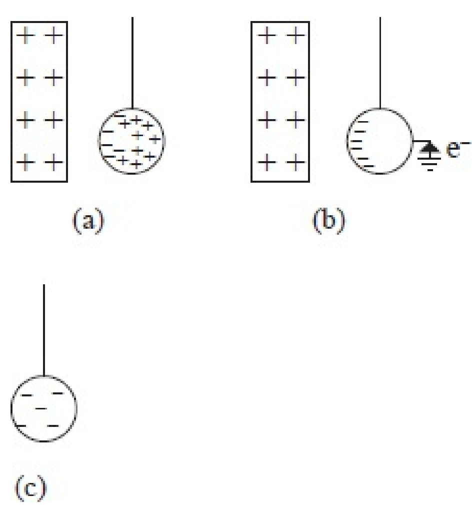


Fig. 9.5: Charging by induction

Procedure

- Suspend the polystyrene ball coated with aluminium using dry silk thread.
- Bring a charged glass rod close to, but not touching the suspended ball, as shown in figure 9.5 (a).
- Touch the side of the ball away from the glass rod with a finger, as shown in figure 9.5 (b).
- While holding the glass rod near the ball, withdraw the finger and then the glass rod, see figure 9.5 (c).
- Bring a charged polythene rod (negatively charged) close to, but not touching the polystyrene ball.

Observation

When a charged polythene rod is moved close to the charged ball, they repel.

Explanation

Initially, the positive glass rod attracts negative charges on the ball at the side close to it, leaving positive charges to the farther right side of the ball (9.5 a).

Touching the ball with fingers makes negative charges flow from the earth through the body to the sphere. The electrons neutralise the positive charges on the right part of the ball.

When the rod is withdrawn, negative charges on the ball spread all over the ball. Hence, the ball becomes negatively charged (9.5 c) as confirmed by the repulsion from the negatively charged polythene rod.

When a body is charged by induction, it acquires charges that are opposite to the inducing charge.

Charging by Contact

Experiment 9.3: To charge a conductor by the contact method

Apparatus

Polystyrene ball coated with aluminium paint, silk thread, glass rod, silk cloth, polythene rod, woollen cloth.

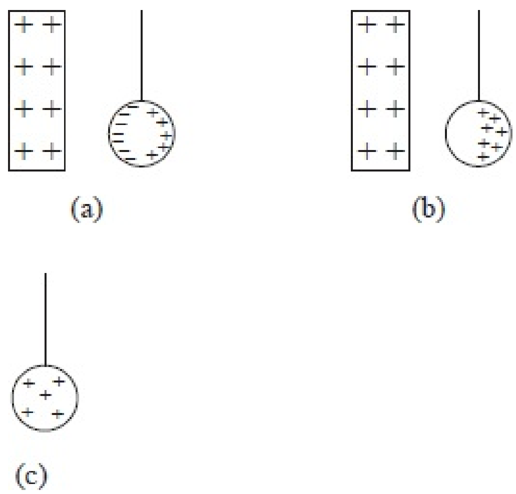


Fig. 9.6: Charging by contact

Procedure

- Suspend the polystyrene ball coated with aluminium with a dry silk thread.
- Bring a charged glass rod close to, but not touching the ball, see figure 9.6 (a).
- Bring the charged glass rod in contact with the ball, rolling it over the surface, as shown in figure 9.6 (b).
- Withdraw the charged rod.
- Bring a charged polythene rod close to, but not touching the suspended ball and observe what happens.

Observation

The suspended ball is attracted by the polythene rod. If the charged ball is tested with a positively charged glass rod, they repel.

Explanation

When the positive rod is rolled on the ball, some of the negative charges induced in the ball are neutralised by some positive charges on the rod.

When the rod is withdrawn, the positive charges redistribute themselves all over the surface of the ball (9.6 c).

Conclusion

When a body is charged by contact method, it acquires charges that are similar to the ones on the charging rod.

Charging by Separation

Experiment 9.4: To charge a conductor by the separation method

Apparatus

Two metal spheres A and B with insulating stands, a polythene rod, woollen cloth, stand, thread.

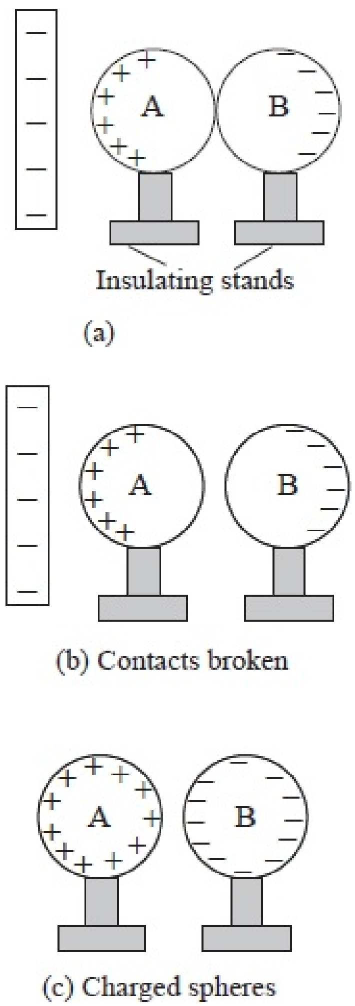


Fig. 9.7: Charging by separation

Procedure

- Place the two spheres A and B together so that they form a single conductor.
- Charge a polythene rod and place it close to, but not touching sphere A.
- Move sphere B away so as to break contact, while holding the charged polythene rod in position.
- Withdraw the polythene rod.

- Test the two spheres A and B using a suspended negatively charged polythene rod for the presence and type of charge in each sphere.

Observation

When the two spheres in turn are brought close to the suspended charged polythene rod, sphere A attracts the rod while sphere B repels it.

Explanation

Sphere A attracts the negative rod because it has acquired positive charges which are opposite to the charges on the rod.

Sphere B repels the rod because it has acquired negative charges which are similar to the charges on the rod.

The Electroscope

This is an instrument which works on the principle of electrostatic charges. It is used for investigating the effects of electric charges. Figure 9.8 shows a common type of electroscope.

The gold-leaf electroscope consists of a thin gold or aluminium leaf on a plate connected to a metal rod that has a brass cap at the top.

The cap acquires a charge through induction or contact and spreads it down the rod to the plate and leaf. The cap is circular to ensure uniform distribution of charges on it.

Both the plate and the leaf show the presence of charges by repelling each other, making the leaf diverge. The absence of charges is also shown when the leaf divergence decreases.

The metal casing is for protecting the leaf from the effects of draught. The casing has a glass window through which observations are made.

The rod is supported by passing it through a plug of good insulating material such as rubber. The insulator stops charge given to the cap from spreading onto the case and leaking away. The casing may have a terminal for connection to the earth. This is labelled E, see figure 9.9 (b).

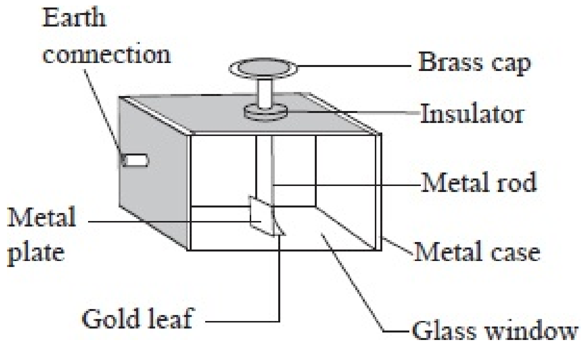


Fig. 9.8: Gold-leaf electroscope

When the electroscope is touched by a finger or connected to the earth by a wire, electrons either flow to the earth or from the earth, depending on the charge on the electroscope.

This process of losing charges to or gaining charges from the earth through a conductor is called **earthing**.

Charging an Electroscope by the Contact Method

Charge a polythene rod by rubbing it with a clean, dry duster. Roll the charged rod over the brass cap of the electroscope and subsequently withdraw it.

The negatively charged polythene rod repels the negative charges which spreads on the plate and the leaf. Repulsion between the plate and the leaf occurs and the leaf divergence increases, as shown in figure 9.9 (a).

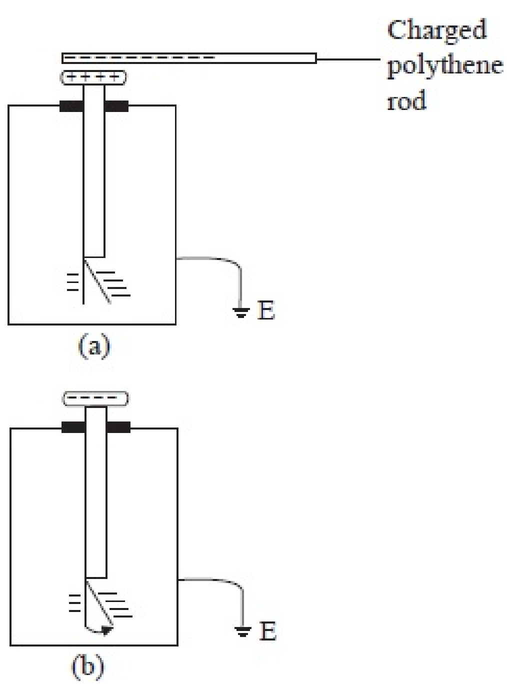


Fig. 9.9: Charging an electroscope negatively by contact

When the process is repeated several times with the negatively charged polythene rod, the leaf divergence increases to a maximum point. The electroscope is said to be charged negatively by contact method.

The electroscope can be discharged by touching the brass cap with a finger.

The electroscope can be charged positively through the same process by using a different charging material, e.g., glass rubbed with a clean dry silk cloth. In this case, electrons are attracted from the cap to the rod. They neutralise the rod and the electroscope becomes positively charged.

In the contact method, the charged material coming into contact with the cap of the electroscope is an insulator. Only the charges on the rod's surface coming into contact with the cap are used in neutralising the charges induced on the cap.

Charging an Electroscope by Induction

The most effective way of charging an electroscope is by the induction method.

Experiment 9.5: To charge an electroscope by induction

Apparatus

A gold leaf electroscope, polythene rod, woollen cloth.

Procedure

- Touch the cap of a gold-leaf electroscope with your finger to ensure that it is fully discharged.
- Bring a charged polythene rod close to the cap of the uncharged electroscope, see figure 9.10 (a). Note what happens to the leaf of the electroscope.
- While the rod remains in its position, touch the cap and note again what happens to the leaf.
- Withdraw your finger and subsequently remove the polythene rod. Note what happens.

Observation

When the charged polythene rod is brought close to the cap, the leaf rises. When the cap is touched while the rod is still in position, the leaf divergence decreases, see figure 9.10 (b).

When the earth connection is removed by removing the finger and the polythene rod subsequently withdrawn, the leaf diverges, see figure 9.10 (c).

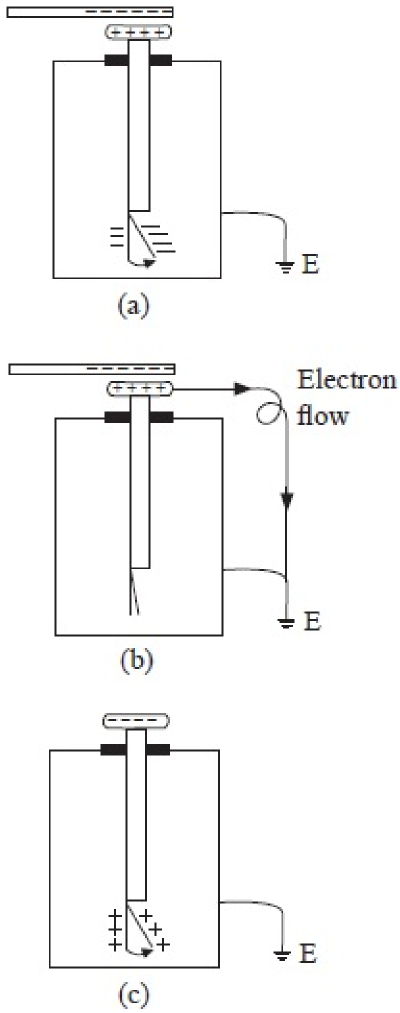


Fig. 9.10: Charging an electroscope by induction

Explanation

When the charged polythene rod is brought close to the cap, electrons are repelled to the plate and the leaf, making the leaf diverge. When the cap is touched, the negative charge (electrons) flow to earth through the body.

When the earth connection is broken by removing the finger and the polythene rod withdrawn, the positive charge which was attracted to the cap redistributes onto the plate and the leaf. The leaf as a result diverges and the electroscope becomes positively charged, see figure 9.10 (c). The electroscope can be charged negatively in the same way by using a positively charged rod.

Uses of the Electroscope

An electroscope has a number of uses, some of which are described below.

1. *To detect the presence of charge on a body*

The material to be tested is placed on or brought close to the cap of the electroscope. If it is not charged, the leaf does not diverge.

2. *To test the sign of charge on a charged body*

Charge an electroscope negatively by contact method. Slowly bring a negative rod to be tested close to the cap of the electroscope. The leaf diverges more. It does so because the negative charges on the rod repel more charges from the cap to the plate and the leaf. Similar charges in the plate and the leaf are repelled.

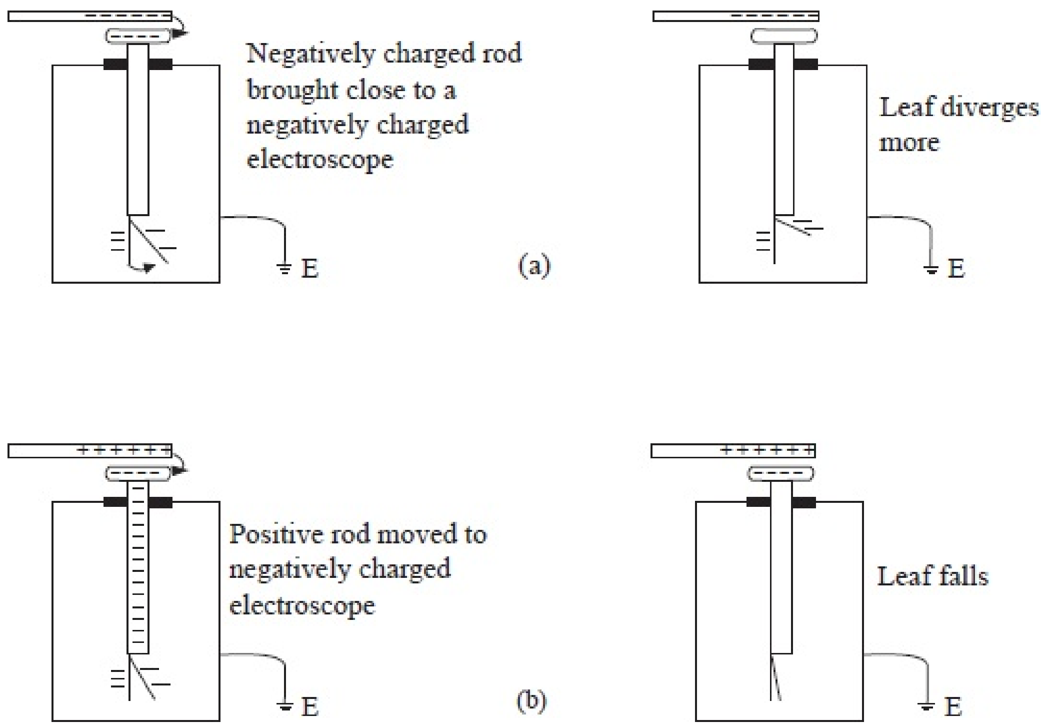


Fig. 9.11: To test the sign on a body

When a strong positively rod is brought from high position towards the negatively electroscope, the leaf divergence first decreases then increases as the rod approaches the cap. The leaf divergence reduces slightly first because the positive charges on the rod attract negative charges on the leaf and the plate, making the electroscope neutral. On moving the rod much lower, the leaf divergence increases again to higher position. This is because the strong positive rod attracts more electrons from the plate and the leaf, making them more positive. Hence, they repel further. The same observations are made when a negatively charged rod is brought towards a positively charged electroscope.

On moving a neutral conductor close to a charged electroscope. Leaf divergence decreases. Charges on the electroscope induce opposite charges on the conductor. The table below shows a summary of the results obtained when we test the sign on a charged object using differently charged electroscopes.

Charge on electroscope	**Charge brought near cap**	**Effect on leaf divergence**
+	+	Increase
–	–	Increase
+	–	Decrease
–	+	Decrease
+ or –	Uncharged body	Decrease

An increase in the divergence of the leaf is therefore the only sure way of confirming the kind of charge on a body.

3. To test the quantity of charge on a charged body

Two pith balls coated with aluminium and having different radii are placed on insulating handles.

They are charged by rubbing with a duster. The charged balls are brought close to the cap of a charged electroscope.

The ball with a smaller radius causes a slight increase in divergence while the larger ball causes a greater increase in divergence.

4. To test for insulation properties of a material

Materials like copper, iron, aluminium, zinc and graphite make the leaf divergence decrease. Materials like plastic, glass, wood, do not affect the divergence of the leaf.

For metals and graphite, the leaf decreases in divergence because they allow electrons to flow between the electroscope and the earth. Such materials are called **conductors**. In conductors, electrons freely move from one atom to another. Such electrons are called **free electrons**.

For materials like plastic, glass and wood, there is no change in leaf divergence because they do not allow electrons to flow between the electroscope and the earth. In these materials, the electrons are not free to move and they are strongly bound to their nuclei. Such materials are called **insulators**.

There are other materials like silicon and germanium which are conductors under special conditions. Their conductivity is between the conductivity of insulators and conductors. Such materials are called **semiconductors**.

Charges in Air

Air can also be charged. The presence of charges in air can be shown by heating air above a charged electroscope. It observed that the leaf divergence decreases.

When a fuel burns, chemical reactions yield ionised products. The ions move and collide with air molecules, causing air to become ionised. Ionisation produces both positive and negative charges. The ions carrying opposite the charge to the electroscope are attracted to the cap of the electroscope, resulting in the discharge of the electroscope. Charges on insulators can be removed by ionised air.

Other than heating, air can also be ionised by radiations.

Applications of Electrostatic Charges

Some of the applications of electrostatics include electrostatic precipitators, spray painting and photocopiers.

Electrostatic Precipitator

Air pollution is a serious environmental problem of global concern. Heavy industrialisation has contributed most to this phenomenon. In an attempt to reduce the pollutants, some industries have installed electrostatic precipitators. Figure 9.12 shows a common precipitator used in chimneys.

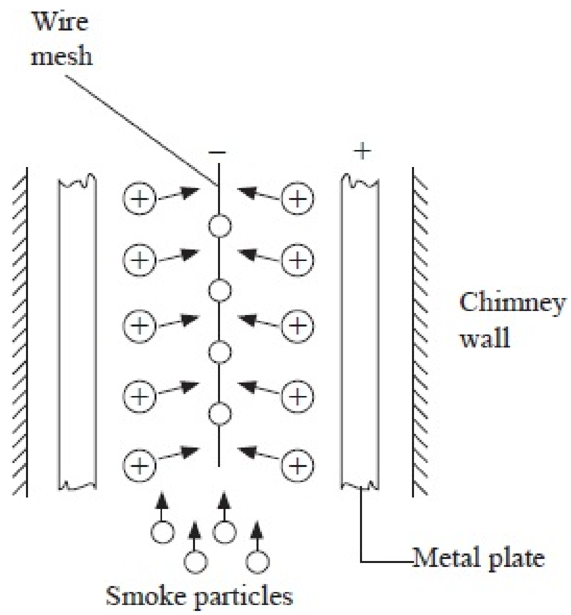


Fig. 9.12: Electrostatic precipitator

The precipitator consists of cylindrical metal plate fixed along the walls of the chimney and a wire mesh suspended through the middle. The plate is charged positively at a potential of about 50 000 V while the mesh is negatively charged. A strong electric field is set up between the plates, which ionises the particles of the pollutants. These are then attracted to the plate. The resulting deposits are then removed from the plates occasionally.

Spray Painting

The spray gun can is filled with the paint and its nozzle charged. During spraying, the paint droplets acquire similar charges and, therefore, spread out finely due to repulsion. As they approach the metallic body, they induce opposite charges which in turn attracts them to the surface. Little paint is therefore used.

Photocopier

A photocopier produces paper copies of documents using heat and electrostatic charges. Inside a photocopier is a cylindrical drum that is charged negatively.

Fig. 9.13: A photocopier

The bright light is used to illuminate the original document. The unprinted areas reflect light and become negatively charged while the toner is positively charged and, therefore, sticks on the negatively charged areas. The toner image is transferred to the paper which is negatively charged. The hot drum melts the toner to the paper and pressure rollers help to ensure complete and dry bonding to the paper. A copy of the original document is, therefore, produced.

Dangers of Electrostatics

Some dangers associated with electrostatics include:

(i) Sparks and fires

- Fuel rubbing the inside of a pipe becomes charged and can cause a spark which ignites the fuel.
- Fuel in plastic cans generates charges as it rubs with inner walls of the can.
- Fast moving water jets become charged and may cause fuel tanks in shops to explode while cleaning them out.

(ii) Electric shock

- A person walking on a nylon carpet can experience shock by touching metallic door handles in the building.
- A car radiator generates charges that can cause shock if touched.

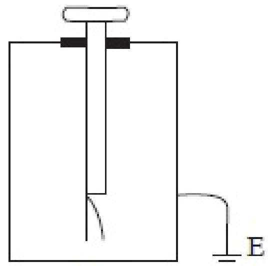
(iii) Lightning

- Electrostatic charges from lightning cause shock leading to death.

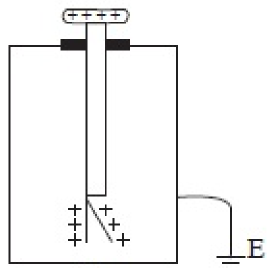
Revision Exercise 9

1. (a) Explain the following:
   - (i) A nylon dress sticks on the body and crackles when removed.
   - (ii) Fuel tankers have a loose chain under them to touch the ground as they move.
   - (iii) A glass window when wiped with a dry cloth on a dry day soon becomes dusty.

   (b) Explain what happens when a charged glass rod is brought close to a neutral pithball placed on a flat table.
2. Explain why it is not possible to charge an electroscope by following the steps below:
   - (i) Bring a charged rod near to, but not touching the cap.
   - (ii) Touch the cap with a finger.
   - (iii) Remove the charged rod.
   - (iv) Remove the finger.
3. Describe how to charge an electroscope positively using a positive rod. Name the other apparatus needed.
4. State two applications of electrostatics.
5. Describe the construction of a gold-leaf electroscope. Given a gold-leaf electroscope, an ebonite rod and fur, explain how you would use them:
   - (a) to detect presence of electrostatic charge on another body.
   - (b) to find the sign of the charge on the body.
6. A polythene rod may be charged negatively by rubbing it with a cloth, but a brass rod held in the hand cannot be charged this way.
   - (a) State clearly what happens when the polythene is being charged.
   - (b) Explain why brass cannot be charged by rubbing.
7. The two electroscopes below are identical. One is charged while the other is not. Copy the diagram and show the divergence of the leaves after connecting the caps of the two electroscopes with a thin copper wire.



(a)



(b)

8. A positively charged rod is brought near the cap of a lightly charged electroscope. The leaf first decreases in divergence but as the rod is brought nearer, it diverges. State the charge on the electroscope and explain the behaviour of the leaf.

9. Explain why a gold-leaf electroscope casing is made of metal. Why is the casing earthed?

10. An uncharged metal rod brought close to, but not touching the cap of a charged electroscope causes a decrease in the divergence of the leaf. Explain.

11. (a) Explain what happens when a plastic pen is touched by a charged polythene rod and then moved close to snall pieces of paper.

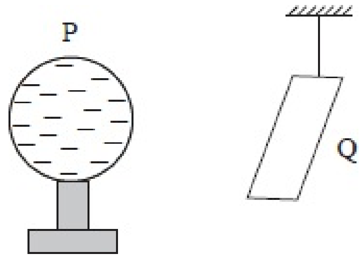
 (b) Why do some motor tyres contain graphite?

12. In the diagram below, a negatively charged metal sphere P is placed a short distance away from a suspended light neutral metal plate Q.

 (a) What will happen to Q?

 (b) Show the resulting charge distribution on both P and Q.

 (c) What do you observe when you introduce:



(i) a neutral light conductor C between P and Q.

(ii) a negative conductor between P and Q.

Cells and Simple Circuits

Electricity is one of the most common forms of energy.

It is used, among other things, for lighting, heating and powering devices like television, radio, mobile phones, computers and high speed trains.

A Simple Electric Circuit

Experiment 10.1: To set up a simple electric circuit

Apparatus

One dry cell, a torch bulb, a switch, connecting wires.

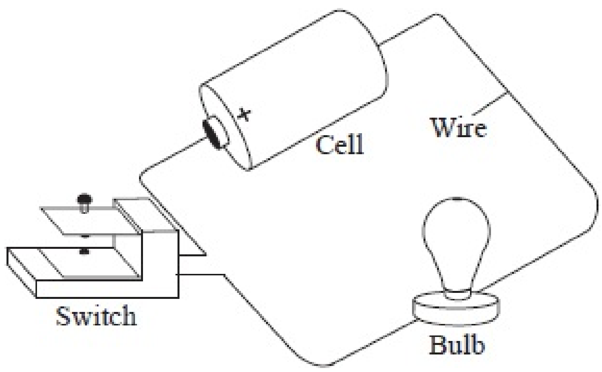


Fig. 10.1: A simple electric circuit

Procedure

- Connect the apparatus as shown in figure 10.1.
- Close the switch and observe what happens.

Observation

The bulb lights.

Explanation

The bulb lights because charges are flowing through it. The rate of flow of charge (charge per unit time) is called an **electric current** and is measured using an ammeter, see figure 10.2. The SI unit of current is the Ampere (A).

Fig. 10.2 : Ammeter

From the definition of current;

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

Where I is current flow in Amperes, Q the charge in coulombs and the t time in seconds.

Example 1

Calculate the amount of current flowing through a bulb if 300 coulombs of charge flows through it in 2.5 minutes.

Solution

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

$$= \frac{300}{2.5 \times 60}$$

$$= 2A$$

Conventional Circuit Diagram

An electric circuit like the one shown in figure10.3(a) allows charges to move in a complete path when the switch is closed, see figure 10.3(b). The circuit is then said to be **closed**. Copper wire readily allows electric charges (mainly electrons) to flow. The wires may be covered by an insulating material like rubber to prevent the user from electric shock if the current is too high. The cell is the source of electrical energy in the circuit and maintains the flow of charges round the circuit. When a gap is introduced in the circuit, for instance by opening the switch, the charges stop flowing. The circuit is then to be **open (broken circuit)**. Loose connection of wires or components in the circuit may open the circuit.

For clarity and neatness, symbols are used in representing components of an electrical circuit. Figure 10.3 shows the conventional ways of drawing the circuit in figure 10.1.

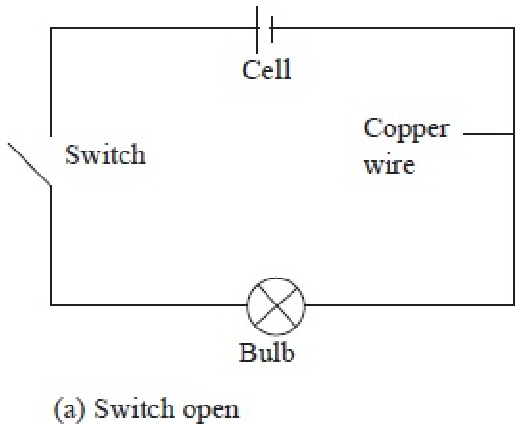


Fig. 10.3 (a): Circuit diagram

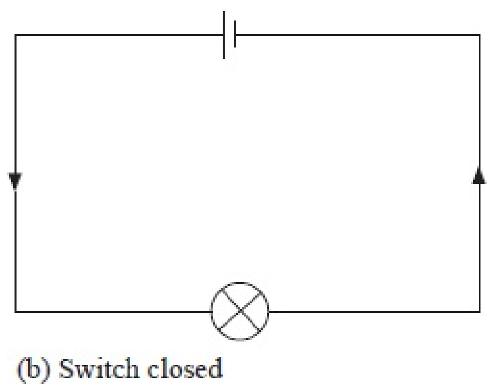


Fig. 10.3 (b): Circuit diagram

Connecting wires are drawn as straight lines with right angle corners, although the actual wires are flexible and bent. The arrow-heads drawn on the lines indicate the direction of flow of electric current.

A condition can cause an electric current to accidentally flow through a path of extremely low resistance and avoid the path of the load. This condition is referred to as short circuit.

In figure 10.4 (a), the cell and bulb are short circuited by the wire AB while in figure 10.4 (b), only the bulb is shorted.

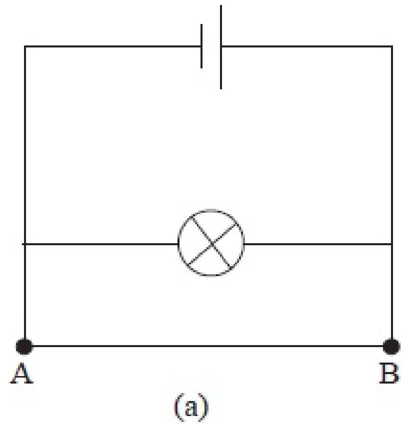


Fig. 10.4 (a)

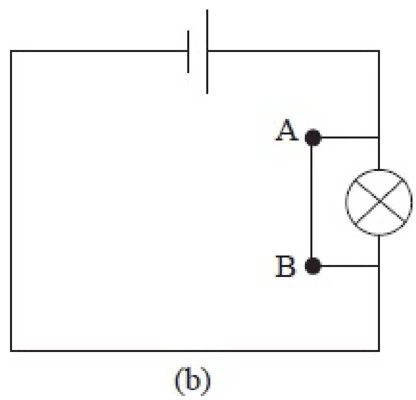
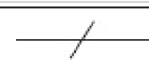
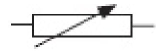
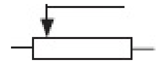
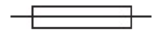
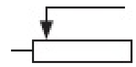
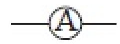
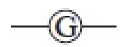


Fig. 10.4 (b)

Table 10.1 shows some of the electrical symbols used in drawing circuits.

Table 10.1

Device	**Symbol**
Cell	
Battery	
Switch	
Bulb/Filament lamp	
Wires crossing with no connection	
Wires crossing with connection	
Fixed resistor	

Fixed resistor	
Variable resistor	
Potential divider	
Fuse	
Capacitor	
Rheostat	
Ammeter	
Voltmeter	
Galvanometer	

Electromotive Force and Potential Difference Potential Difference

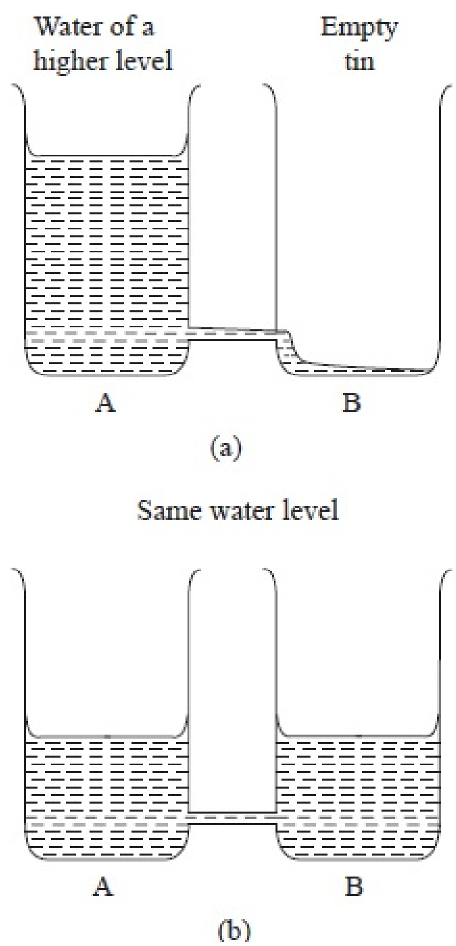


Fig. 10.5: Water level and potential difference analogy

We have seen that a cell moves charge round a circuit. To explain this, consider a tin containing water connected to another empty tin, as shown in figure 10.5(a).

Water flows from tin A to tin B because the water in the two tins is at different levels. When the two levels are the same, as shown in figure 10.5(b), the water stops flowing. Hence, there must be a difference in the water levels if it is to flow.

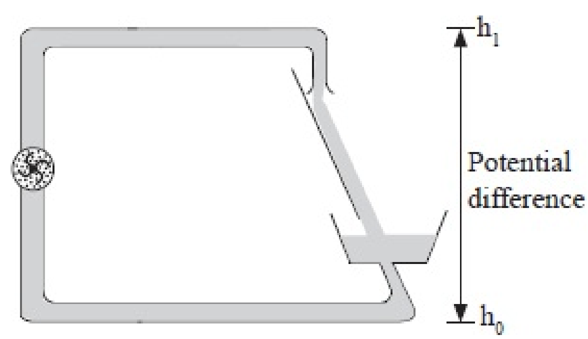


Fig. 10.6: Water and electric circuit analogy

Let us study the flow of water in figure.10.6, which can be referred to as water circuit because water flows round a complete ring. Water at a height h_1, from the ground level has potential energy because of its position. The greater the height, the higher the potential energy. The rate of flow will depend on the height, to which the water had initially been raised. A higher water level results in a faster rate of flow. At a height h_0, the water has no potential energy. If the water is to be raised to h_1, a pump has to be used. So long as the pump in the water circuit is working, the water will move round the complete path, from a point of higher potential energy to a point of lower potential energy. The pump creates a difference in potential.

Now replace the water at height h_1 with positive charges, pipes with copper wires and the pump with a battery, see figure 10.7.

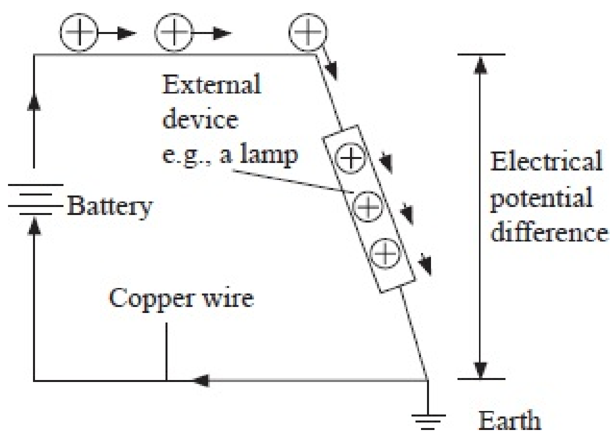


Fig. 10.7

For the charges to move through the conductor, there must be a battery which produces an electrical potential difference at the ends of the conductor. The battery does the work of pumping charges to a high potential so that they can flow. The higher the potential difference (pd), the stronger the current in the circuit, if the other factors like opposition to flow of current (resistance) are kept constant. The model of the circuit shown in figure 10.7 can help suggest that the function of a battery is to cause a potential difference across a conductor.

Not all the energy supplied by the pump is used to drive the water round the circuit. Some of the energy is lost in moving or raising parts of the pump. Similarly, for the battery, some energy is lost in moving charges through the battery itself. The total energy supplied by the battery is called its **electromotive**

force (emf).

Potential difference is measured in volts, by an instrument called **voltmeter**.

Fig. 10.8: Voltmeters commonly used in laboratories

Although both emf and pd are measured in volts, the potential difference of a cell is different from its emf. The emf of a cell is the **voltage** across its terminals when it is supplying no current in the circuit (an open circuit), while the pd of a cell is the voltage across the cell in a closed circuit. Figure 10.9 (a) and (b) respectively show the emf of the cell as 1.5 V and the pd as 1.45 V.

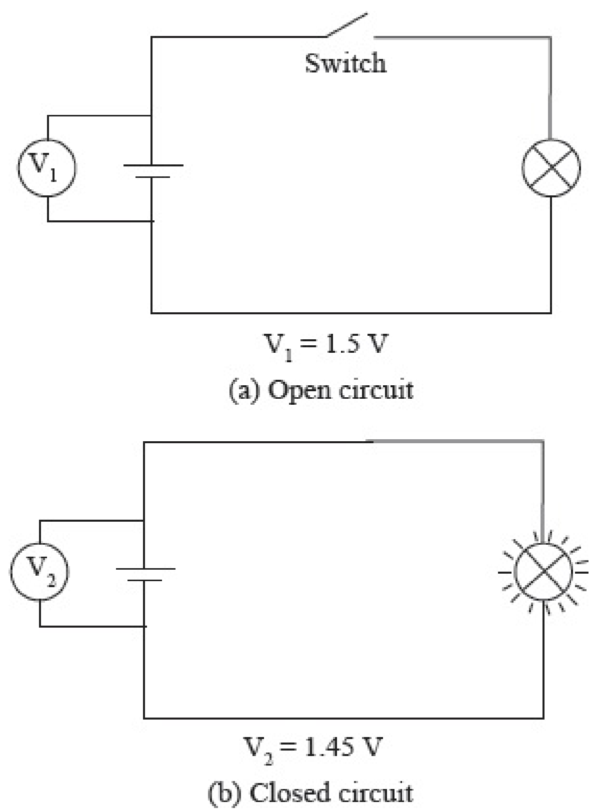


Fig. 10.9: Pd and emf of a cell

The difference between the readings is known as the **lost volts**, in this case 0.05V. This voltage is lost because of the opposition to the flow of charges within the cell (internal resistance).

Connecting Cells in Series and Parallel

Cells in Series

When two or more cells are connected such that the positive terminal of one is joined to the negative of another one, then they are said to be in **series**, see figure 10.10. Two or more cells connected in series make a **battery**.

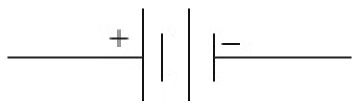
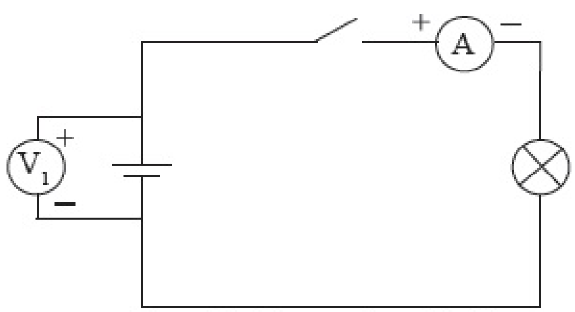


Fig. 10.10: Cells in series

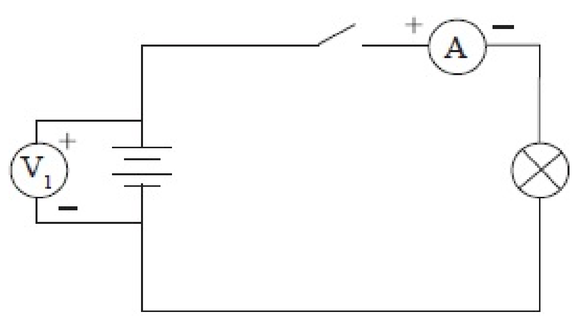
Experiment 10.2: To investigate the effect of series connection on current and emf

Apparatus

Two cells, a 2.5 V torch bulb, connecting wires, switch, ammeter (0 – 5A), voltmeter (0 – 5 V).



(a) Emf and current in a circuit



(b) Emf and current when cells are in series

Fig. 10.11: Emf and current

Procedure

- Set up the circuit shown in figure 10.11 (a). Note the way the ammeter and voltmeter are connected.
- Read and record the voltmeter and ammeter readings.
- Switch on the circuit.
- Read and record the voltmeter and ammeter readings. Note the brightness of the bulb.
- Repeat the experiment with two cells in series, as shown in figure 10.11 (b).

Observation and explanation

Connecting cells in series increases the emf and the current in the circuit (the rate of flow of charge) is higher. If the emf of each cell is 1.5V, then the total emf is 3 V (emf's are added). Note that an ammeter is always connected in series while the voltmeter is connected across the cells in parallel.

Cells in parallel

Cells are said to be in parallel when placed side by side, the positive terminals joined together and the negative terminals also connected together.

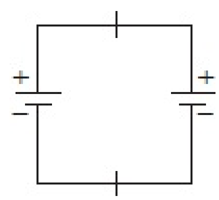


Fig. 10.12: Cells in parallel

Experiment 10.3: To investigate the effect of parallel connection on current and emf

Apparatus

Two cells, voltmeter (0 – 5 V), ammeter (0 – 5A), switch, 2.5 Vbulb, connecting wires.

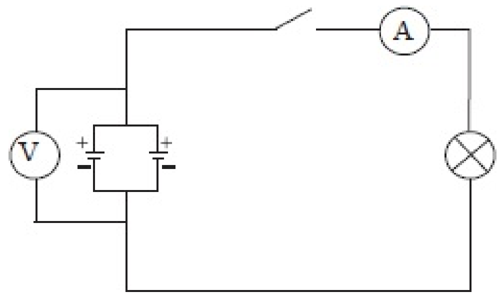


Fig. 10.13: Emf and current with cells in parallel

Procedure

- Connect the circuit as shown in figure 10.13.
- Read and record the voltmeter reading.
- Put on the switch.
- Read and record the voltmeter and ammeter readings.
- Compare the results to when only one cell was used.

Observation

The emf of the cells is the same as that for a single cell. There is no significant increase in the brightness of the bulb and the current flowing in the circuit.

Conclusion

The effective emf for identical cells in parallel is the same as the emf of a single cell.

Note:

(i) Cells should be arranged in parallel when they have identical emfs, otherwise one will drain the other.

(ii) The advantage of connecting cells in parallel is that the current is supplied for a longer time.

Experiment 10.4: To investigate the current flowing in a circuit when devices are arranged in series and parallel

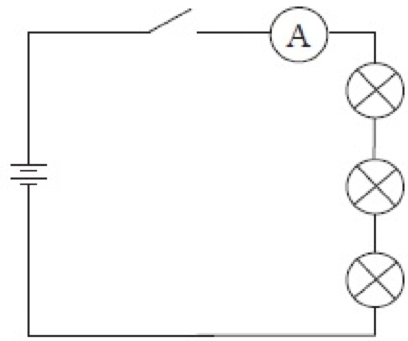
Apparatus

Two cells, three identical bulbs, ammeter, a switch.

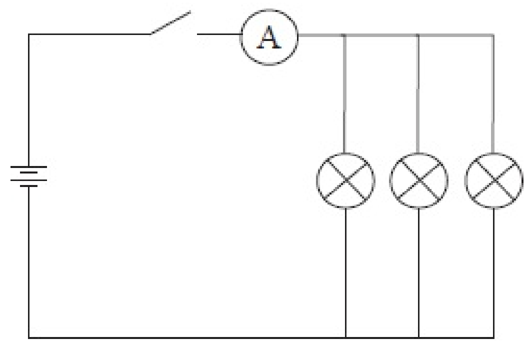
Procedure

- Set up the circuit shown in figure 10.14 (a).

- Close the switch.
- Observe the brightness of the bulbs and record the ammeter reading.
- Disconnect one of the bulbs and observe what happens to the other bulbs.
- Connect the circuit as shown in figure 10.14 (b).
- Close the switch and observe the brightness of the bulbs.



(a) Series arrangement of bulbs



(b) Parallel arrangement of bulbs

Fig 10.14: Arrangement of bulbs

- Read and record the ammeter reading.
- Disconnect one of the bulbs and observe what happens to the other bulbs and the reading of the ammeter.
- Disconnect two of the bulbs and observe the brightness of the remaining bulb.

Observation

The bulbs connected in series give out light of the same brightness and when one is disconnected, the others go off too. In the parallel circuit, the three bulbs give out light of the same brightness, but brighter than the ones connected in series. When some of the bulbs are disconnected, the rest continue with the same brightness.

Conclusion

The same current flows through devices connected in series. If one of the devices is disconnected, it introduces an open circuit. Electrical devices connected in series offer greater opposition (resistance) to the flow of current.

For devices connected in parallel, the current flowing in one does not affect the current flowing in the other devices. If one of the devices causes an open circuit, current will still flow in the other devices.

In domestic electrical wiring (lighting circuit), bulbs are connected in parallel, as shown in figure 10.15.

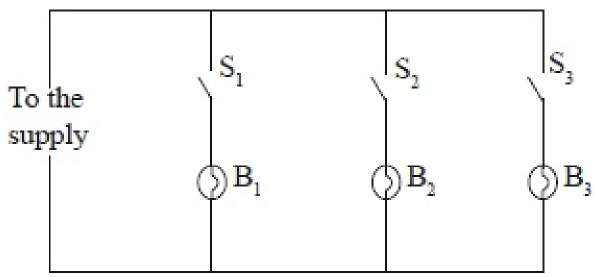


Fig. 10.15: Bulbs wired in parallel

The three bulbs can be switched on or off independently, and one bulb blowing out does not affect the working of the remaining bulbs.

Example 2

Three cells have an emf of 1.5 V each. What is the total emf when the cells are in parallel and when in series?

Solution

When in parallel;

Effective emf = the emf of one cell = 1.5 V

When in series;

Effective emf = 1.5 + 1.5 + 1.5 = 4.5 V

Example 3

Diana connected three identical bulbs, as shown in figure 10.16.

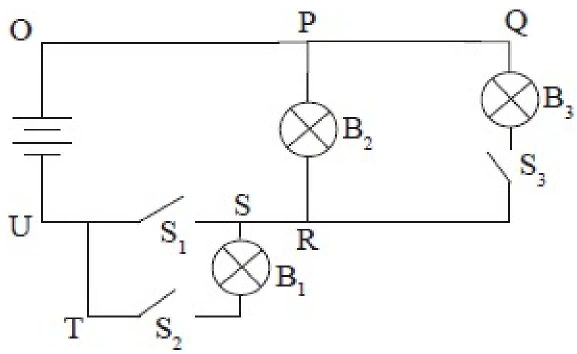


Fig. 10.16

Explain what happens, indicating the path of current when:

(a) S_1 is closed while S_2 and S_3 are open.

(b) S_2 is closed while S_1 and S_3 are open

(c) S_1 and S_2 are closed while S_3 is open.

(d) S_1 and S_3 are closed while S_2 is open.

(e) S_2 and S_3 are closed while S_1 is open.

Solution

(a) Bulb B_2 lights because it is in a closed circuit, while B_1 and B_2 do not light because they are in open circuits. Path of current;

O → P → R → S → U

(b) Bulbs B_1 and B_2 light because they are in a closed circuit. The bulbs are less bright, since they are in series. Path of current is;

O → P → R → S → T → U

(c) Bulbs B_2 lights brightly. B_1 does not light since it is short-circuited. B_3 is in an open circuit. Path of the current is;

O → P → R → S → U

(d) B_1 does not light (open circuit). B_2 and B_3 are in a closed parallel circuit. They light with the same brightness. Path of the current;

O → P → R→ S → U and

O → P → Q → R → S → U

Current through B_2 is the same as current through B_3.

(e) The three bulbs light. B_1 is brighter than B_2 and B_3. B_2 and B_3 share the current flowing through B_1.

Path of the current is;

O → P → R → S → T → U

and

O → P → Q → R → S → T → U

Conductors and Insulators

Experiment 10.5. To investigate electrical conductivity

Apparatus

Bulb, a cell and cell holder, connecting wires, switch, two crocodile clips, sampled materials.

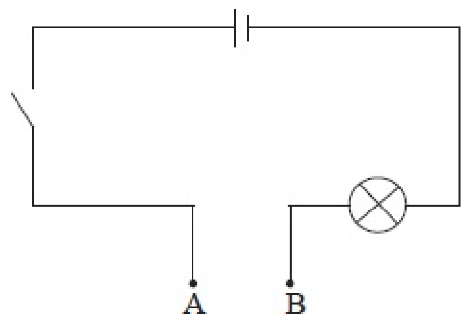


Fig. 10.17: Electrical conductivity

Procedure

- Set up the apparatus as shown in figure 10.17.
- Connect the crocodile clips to the ends A and B.
- Bring ends A and B of the crocodile clips together and switch on the circuit. The bulb should light, indicating that the circuit is ready for use.
- Fix the material under test between the two clips and switch on. Note the brightness of the bulb.
- Repeat for other materials.

Observation

The bulb lights in some cases although with different amount of brightness. In other cases, the bulb does not light at all.

The materials which, when connected, the bulb lights are known as

conductors. Examples are copper, silver and aluminium. Those materials which, when connected, the bulb does not light (they do not allow electric charges to pass through them) are called **insulators**. Examples of insulators are plastic, rubber and dry wood.

Conductors can either be good or poor. Examples of good conductors are copper, silver and aluminium. An example of a poor conductor is graphite. Metals are in general good conductors of electricity. They have a large number of free electrons moving randomly within them, as shown in figure 10.18 (a). When a cell is connected across the ends of the conductor, the free electrons move in the direction, as indicated in figure 10.18 (b).

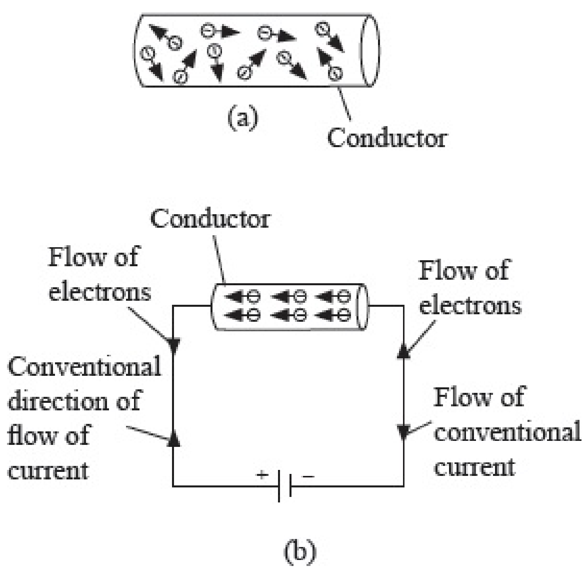


Fig. 10.18: Flow of electrons in a conductor

When electrons are made to drift in a given direction, current is said to be flowing through the conductor. Conventionally, current is taken to flow in the direction opposite to that of electron flow.

Poor conductors like graphite have fewer free electrons. Insulators have their electrons tightly bound to the nuclei of their atoms. Because they cannot conduct electric current, insulators are used as cover materials for good conductors.

There exists another group of materials whose electrical properties fall between those of conductors and insulators. Such materials are called **semiconductors**. Examples of semiconductors are silicon and germanium. It is these elements that form the basis of diodes, transistors and integrated circuits which have wide applications. Some liquids like dilute sulphuric acid, sodium chloride solution and potassium hydroxide are good conductors of electric charge. These liquids are called **electrolytes**. Others like paraffin and cooking oil are poor conductors.

Sources of Electricity

The main sources of electricity present are chemical cells and generators driven by water (hydro) steam (geothermal) and fuel oil. The alternative sources gaining prominence are wind-driven generators and solar cells. Apart from cells, batteries and generators, other sources of electricity include solar cells or panels, thermocouples and some crystals when under pressure (piezo electric effect). The main sources of electricity presently are chemical cells, generators and solar cells. Figure 10.19 shows some of these sources.

Fig. 10.19: Some sources of electricity

Chemical Cells

Chemical cells produce an electromotive force as a result of a chemical reaction.

There are two types of chemical cells, namely, primary and secondary cells.

(a) Primary Cells

Primary cells cannot be renewed once the chemicals are exhausted while secondary cells can be renewed by recharging.

Experiment 10.6: To make a simple primary cell

Apparatus

Zinc and copper plates, a beaker containing dilute sulphuric acid, a bulb, connecting wires, a switch, an ammeter (0 – 100 mA).

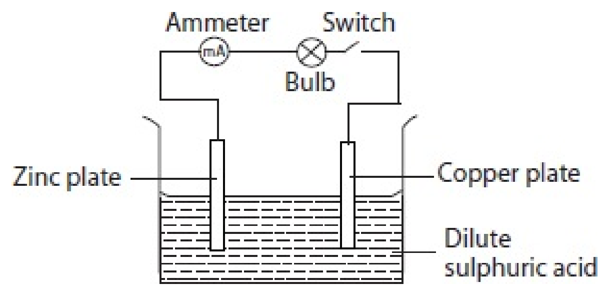


Fig. 10.20: Simple cell

Procedure

- Clean the surfaces of the metal plates using a wirebrush.
- Connect the circuit as shown in figure 10.20.
- Dip the plates in the acid.
- With the switch open, observe bubble formation on the plates.
- Close the switch and observe the brightness of the bulb.
- Record the ammeter reading. Observe if it remains constant over a period of time. Observe also gas bubble formation on the plates.
- Add potassium dichromate to the acid and observe what happens.

Observation

Bubbles of gas form around the zinc plate when the switch is open, while no bubbles are formed around the copper plate. This indicates that zinc is reacting with the acid faster than copper. When the switch is closed, current flows through the circuit as indicated by the ammeter. This current may not be sufficiently large to light the bulb brightly lit. Bigger bubbles of gas form around the copper plate and on testing, the gas is found to be hydrogen.

The zinc metal is ‘eaten’ away as it reacts with acid. The strength of current supplied decreases because of cell defects and the bulb soon goes off. Addition of potassium dichromate to the acid makes the bulb relight.

Explanation

The two metal plates (electrodes) when dipped in the dilute sulphuric acid (electrolyte) carry electric charges (current) into and out of the electrolyte. Dilute sulphuric acid exist as hydrogen ions (H^+) and sulphate ions (SO_4^{2-}), as seen in the chemical equation below;

$$H_2SO_4(aq) \rightleftharpoons 2H^+ (aq) + SO_4^{2-} (aq)$$

The chemical action between zinc and dilute sulphuric acid liberates electrons, which flow through the connecting wire and the bulb to the copper plate.

$$Zn (s) \rightarrow Zn^{2+} + 2e^-$$

The hydrogen ions (H^+) move to the copper plate, where they are neutralised by the electrons that had come from the zinc and acid reaction. This produces hydrogen gas bubbles around the copper plate.

$$2H^+ (aq) + 2e^- \rightarrow H_2(g)$$

Copper receives more electrons from the reaction of the zinc and the acid. This makes the zinc plate negative and copper plate positive. Conventionally, the direction of current is from the positive plate to the negative plate.

Accumulation of bubbles around the copper plate is called **polarisation**. This effect produces a resistance to the flow of current and also sets up some 'local' cells with in the copper whose electron flow tends to oppose the flow of electrons from the zinc plate. The overall effect is increase in the **internal resistance** of the cell, which reduces the flow of current. When potassium dichromate (depolariser) is added, some of its oxygen atoms combine with the hydrogen atoms to produce water. This boosts the current flow once more, but the electrolyte gets more diluted by the water.

The zinc plate on the other hand is 'eaten' away as it reacts with dilute sulphuric acid. This defect is called **local action**. Impurities in zinc promote local action. The use of pure zinc or coating the zinc with mercury (amalgamation) reduces this effect.

Polarisation and local action are the main short coming of a simple cell.

The Leclanché cell

Figure 10.21 shows a Leclanche' cell, which is an improvement of the simple cell. Defects of polarisation and local action have been minimised.

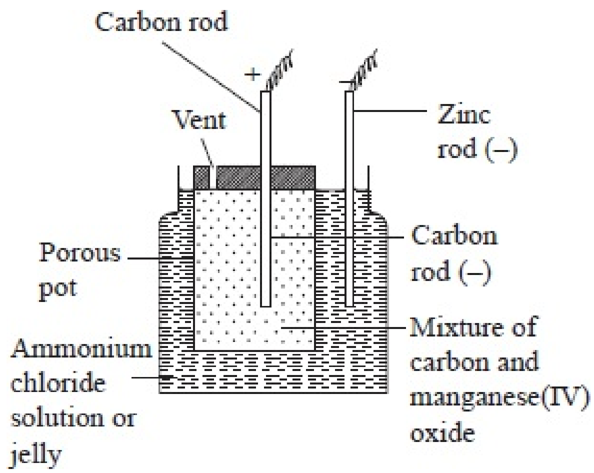


Fig. 10 21: Leclanché cell

The carbon rod (positive terminal) is surrounded with manganese (IV) oxide mixed with carbon powder.

The manganese (IV) oxide acts as a depolariser, reacting with the hydrogen gas formed on the carbon rod to produce water. This process is however slow and hence large currents cannot be drawn out of this cell steadily for a long time. The carbon powder increases the effective area of plate, which in effect reduces the opposition to flow of current.

The zinc plate is immersed in ammonium chloride solution, which converts zinc to zinc chloride when the cell is working. Local action is still a problem in this cell.

The cell is used for purposes where current is not drawn from it for a very long time, like operating bells and telephone boxes. It has a longer life span than the simple cell.

The Dry cell

This type of cell is referred to as dry cell because it has no liquid. The ammonium chloride solution in the Leclanché cell is replaced with the ammonium chloride jelly or paste. Manganese (IV) oxide [or (II) dioxide] and carbon powder act as the depolariser. The hydrogen gas produced is oxidised to water, making the cell become wetter as it is used.

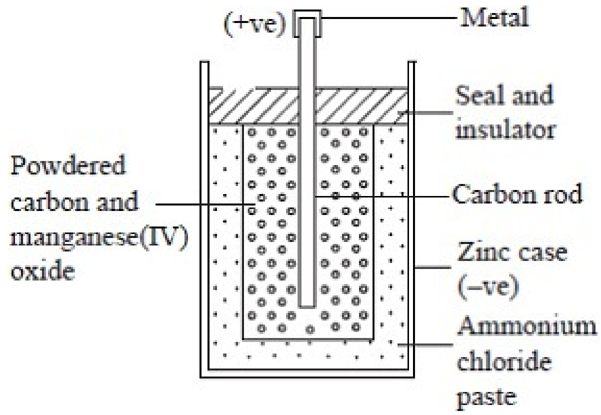


Fig. 10. 22: The dry cell

The zinc case acting as the negative electrode gets eaten away by the ammonium chloride and changes to zinc chloride. Local action is still problem in this cell.

The cell cannot be renewed once the chemical action stops. A new dry cell has an emf of about 1.5 V.

Large currents should not be drawn from the dry cell within a short time. Shorting its terminals can also ruin it. The cells must be stored in dry places.

Dry cells are used in torches, calculators and radios.

(b) Secondary Cells

The chemical process which occurs in secondary cells when delivering current can be reversed by applying a direct current to the terminals. Examples of such cells are the lead-acid accumulator and nickel alkaline cell. Secondary cells are also called **storage cells** because they can store electrical energy as chemical energy.

Experiment 10.7: To charge and discharge a simple secondary cell

Apparatus

Two clean lead plates, beaker containing dilute sulphuric acid, charging battery, zero-centred ammeter, connecting wires, a variable resistor and two switches.

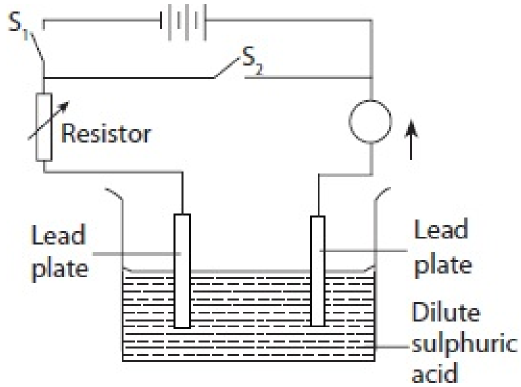


Fig. 10.23: Charging and discharging secondary, cells

Procedure

- Set up the apparatus as shown in figure 10.23.
- Close the switch S_1 and observe the changes on the plates, if any.
- Note how the ammeter reading varies with time and the direction of the pointer with respect to the zero mark.

Observation

When S_1 is closed and S_2 is open, the cell is **charging**. The positive plate (anode) turns chocolate brown while the negative (cathode) plate remains metallic grey (lead). Gas bubbles form on the two plates. The ammeter deflects away from the zero mark. This deflection decreases with time.

When the switch S_1 is open and S_2 is closed, the cell is being embolden (passing current to an external circuit). The ammeter deflects in the opposite direction from charging. The dark brown colour on the positive plate turns to grey and gas bubbles are seen on the plates.

Explanation

During charging, sulphuric acid is electrolysed, giving off oxygen at the anode and hydrogen at the cathode. The oxygen reacts with the lead to give lead (IV) oxide, which is deposited at the anode. Hydrogen gas formed at the cathode has no effect. The flow of current through the ammeter decreases with time because the cell starts supplying current in the opposite direction to the charging current. In discharging, the current flows in the direction opposite to that when charging. Oxygen gas bubbles form at the cathode while hydrogen gas forms at the anode. The dark brown colour on the positive plate changes to grey.

Lead-acid Accumulator

This is the most reliable, long lasting and cost effective of the secondary cells. Figure 10.24 shows a lead-acid accumulator.

Fig. 10.24: Lead-acid accumulator

A 12 V lead-acid accumulator has six cells connected in series. Each cell has several plates made in the form of a lattice grid, the positive plates carrying lead (IV) oxide and the negative plates having spongy lead.

The plates are very close to one another and are prevented from getting into contact (short circuiting) by having insulating sheets separating them.

The **surface area** and the **number of plates** in a given cell determine the current-carrying capacity of the cell. The charge (electrical energy) stored is directly proportional to the surface area of the plates, see figure 10.25.

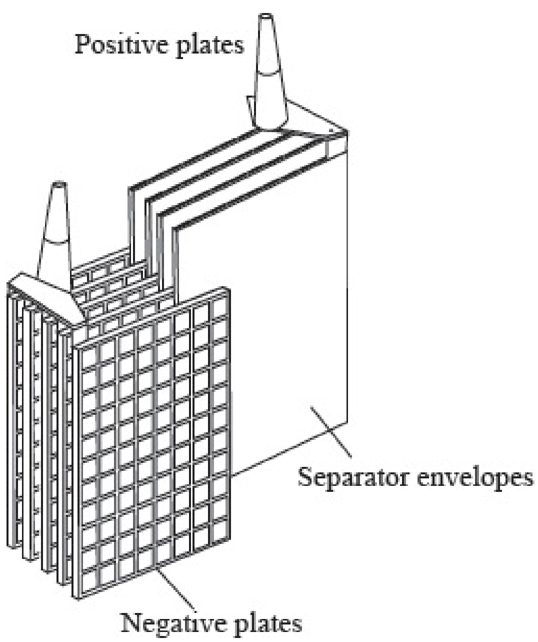


Fig. 10.25: Plates inside a lead-acid accumulator

The container used in the construction of the lead-acid accumulator must be mechanically strong, acid-proof and with insulating properties. The electrolyte is a solution of about 64 per cent water with relative density of 1.00 and about 36 per cent sulphuric acid with relative density of 1.84. When the accumulator is discharging (giving out electrical energy), the sulphuric acid dissociates into hydrogen ions (H^+) and sulphate (SO_4^{2-}) ions.

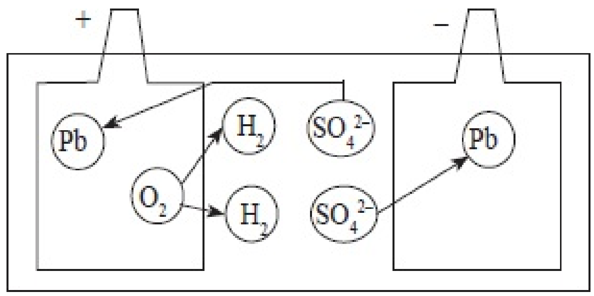


Fig. 10.26: Chemical reaction in a lead-acid accumulator

At the positive plate, a sulphate ion reacts with the lead to form lead sulphate, while the hydrogen ions react with the oxygen in the lead (IV) oxide to form water, as below;

$2PbO_2\ (s) + 2H_2SO_4\ (aq) \rightarrow 2PbSO_4\ (s) + 4H_2O\ (l)$

At the cathode, lead reacts with sulphuric acid to form lead sulphate and hydrogen gas;

$Pb\ (s) + 2H_2SO_2\ (aq) \rightarrow PbSO_4\ (s) + H_2\ (g)$

During these processes, electrons are amassed at the negative plate while positive charges develop at the anode because of the deficiency of electrons. This generates an electromotive force between the anode and the cathode. A single cell has an emf of 2.2V when fully charged but this drops to 2.0 V when it is working. As the battery continues working, lead sulphate (white deposit) forms on the plates and the relative density of the electrolyte drops because of the formation of water.

In recharging, a direct current is passed through the cell in the opposite direction to that during discharging, see figure 10.27.

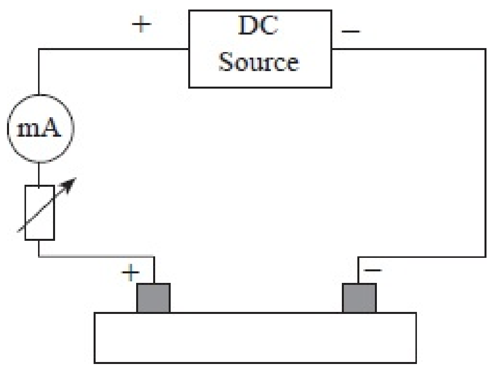


Fig. 10.27: Charging a lead-acid accumulator

The process that takes place during discharging is reversed during recharging.

Capacity of Lead-acid Accumulator

The capacity of the lead-acid accumulator is the amount of current that can be drawn in a given time from the battery. This is the total amount of charge, Q = It, and is expressed in ampere-hours (Ah).

Lead-acid accumulators give strong current over a long time compared to other cells because of an effective low internal resistance. The internal resistance of a cell is inversely proportional to the linear dimensions of the plates.

Example 4

A battery is rated at 30 Ah. Find how long it will work if it steadily supplies a current of 3 A.

Solution

$Q = It$

But $I = 3$ A and $Q = 30$ Ah

$30 = 3 \times t$

Therefore, $t = 10$ hours

Example 5

The charge stored by a cell A of plate dimensions 0.2 m × 0.2 m is 108 000 C.

(a) Calculate the charge is stored by cell B of plate dimensions 0.4 m × 0.4 m?

(b) Find the ratio of internal resistance of cell A to that of cell B.

Solution

(a) $\frac{\text{Charge stored by cell A}}{\text{Charge stored by cell B}}$

$= \frac{\text{area of A}}{\text{area of B}}$

$\frac{108\ 000}{\text{Charge stored by B}} = \frac{0.2 \times 0.2}{0.4 \times 0.4}$

$\therefore$ charge stored by B = 432 000C

(b) $\frac{\text{Resistance of cell A}}{\text{Resistance of cell B}}$

$= \frac{\text{length of plate B}}{\text{length of plate A}}$

$= \frac{0.4}{0.2}$

$= \frac{2}{1}$

The ratio is 2:1

Maintenance of Accumulators

1. The level of the electrolyte should be checked regularly and maintained above the plates. Topping up should be done using distilled water not acid. Acid can only be used in cases where there has been spillage.
2. The accumulator should be charged when the emf of the cell drops below 1.8 V and when the relative density of the acid falls below 1.12. The relative density of the acid is measured using a hydrometer.
3. Large currents should not be drawn from the battery for a long time. This loosens the lead (IV) oxide and the lead in the mesh framework of the plates, causing them to fall off. The plates then buckle.
4. The accumulator should not be left in a discharged condition for a long period. The lead (II) sulphate deposits on the plates harden up and cannot be converted back to lead (II) oxide and lead. This is called **sulphation**.
5. Shorting or overcharging the accumulator should be avoided.
6. The terminals should always be kept clean and greased.
7. The accumulator should not be directly placed on the ground during storage. It should be rested on some insulator like a wooden block.

Alkaline Accumulators

The electrolyte in this case is an alkaline solution, such as potassium hydroxide. The common types are nickel-cadnium and nickel-iron accumulators. Figure 10.28 shows a nickel-iron accumulator with iron as the negative terminal and nickel hydroxide as the positive terminal.

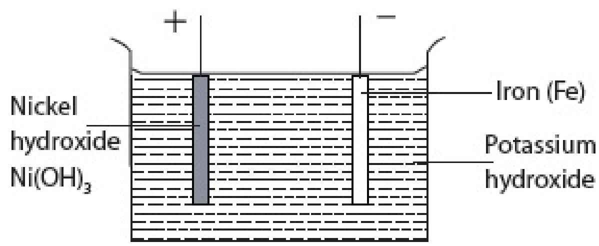


Fig. 10.28: Nickel-iron cell

Advantages of Alkaline Accumulators over Lead-acid Accumulators

1. Large currents can be drawn from them.
2. They can be kept in a discharged condition for a very long time before the cells are damaged.
3. They require very little attention to maintain.
4. They are lighter (more portable) than the lead-acid accumulators.

Disadvantages

1. They are very expensive.
2. They have a lower emf per cell.

Uses of Alkaline Accumulators

They are used in ships, hospitals and buildings where large currents might be needed for emergencies.

Solar Electrical Energy

Solar electrical energy is gaining prominence as a substitute for hydro-electrical and diesel generated power energies which are increasingly becoming limited as the global climate change takes toll. Solar energy is preferable since it is clean and renewable.

The main component of a solar electrical system is the solar panel consisting of solar cells, see fig. 10.29. Solar cells convert energy from the sun into electricity.

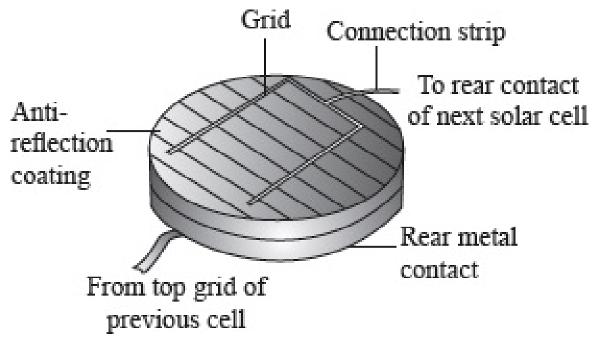


Fig. 10.29: Solar cell

The solar cell contains a special crystalline material based on silicon which absorbs energy from the sun resulting in generation of electrons hence current flow.

Solar cells are used in:

(i) Solar calculators and mobile phones.

Fig. 10.30: Solar calculators and mobile phones

(ii) Solar powered cars

Fig. 10.31: Solar powered car

(iii) Powering of space stations

Fig. 10.32: Space station

Revision Exercise 10

1. In terms of their electrons, distinguish between good conductors, poor conductors of electricity and insulators.
2. (a) Define electric current and state its SI unit.
   (b) (i) A charge of 180 coulombs flows through a lamp every minute. Calculate the current flowing through the lamp.
   (ii) Calculate the number of electrons involved (charge of an electron is 1.6×10^{-19} C).
3. A battery circulates charge round a circuit for 1.5 minutes. If the current is held at 2.5 A, what quantity of charge passes through the wire?

4. Define electromotive force and distinguish it from potential difference of a cell.

5. (a) Draw a circuit diagram of a three-cell torch.

   (b) Define the following terms:

      (i) open circuit.

      (ii) closed circuit.

6. Explain why lights in a house are wired in parallel and not in series.

7. (a) Give three differences between primary and secondary cells.

   (b) In making a simple cell, the two electrodes used are not of the same metal. Explain.

8. You are provided with a car battery, a switch and two car headlights. Draw a possible circuit diagram for the arrangement that will allow the driver to switch on the two lights simultaneously.

9. (a) Draw a well-labelled diagram of a dry cell and explain how it works.

   (b) What are the defects and their remedies in the working of a dry cell?

   (c) How are dry cells maintained?

10. Eight dry cells can be arranged to produce a total emf of 12 V, just like a car battery.

   (a) Find the emf of an individual cell.

   (b) Explain why it is possible to start a car with the lead-acid accumulator, but not with the eight dry cells in series.?

11. (a) Draw two separate diagrams showing a lead-acid accumulator when it is:

      (i) charging.

      (ii) discharging.

   (b) Describe the changes that are observed during the two processes above.

   (c) Explain why it is dangerous to light a match near a charging car battery.

12. (a) What do you understand by the term capacity of a lead-acid accumulator?

   (b) Explain why it is effective to charge a car battery over a long time with a small amount of current rather than a big amount of current over a short time.

   (c) A car battery is rated 40 Ah and it is expected to supply a constant current for 120 minutes. What is the strength of current delivered.

13. State at least five precautions that you would take to maintain accumulators in your laboratory.

14. State the advantages and disadvantages of lead-acid accumulators over alkaline accumulators.

This book is the first title in the KLB Secondary Physics series. It comprehensively covers the Form One syllabus as per the new curriculum.

The edition is rich in detail, has numerous worked-out examples and puts emphasis on a practical approach. This enables the learner to appreciate more the concepts under study.

Each title in the series is accompanied by a teachers' guide which, apart from providing the teacher with vital tips on methodology, gives answers to questions in the revision exercises.

Cover photograph: *Section of a bridge running across Kaiti river, Makueni. The strength, density, expansivity and elasticity of the materials used in its construction are of vital importance for its stability. Note also that the sheer force and upthrust of moving water make it dangerous to attempt crossing the older passage when the river is swollen.*

KENYA LITERATURE BUREAU

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