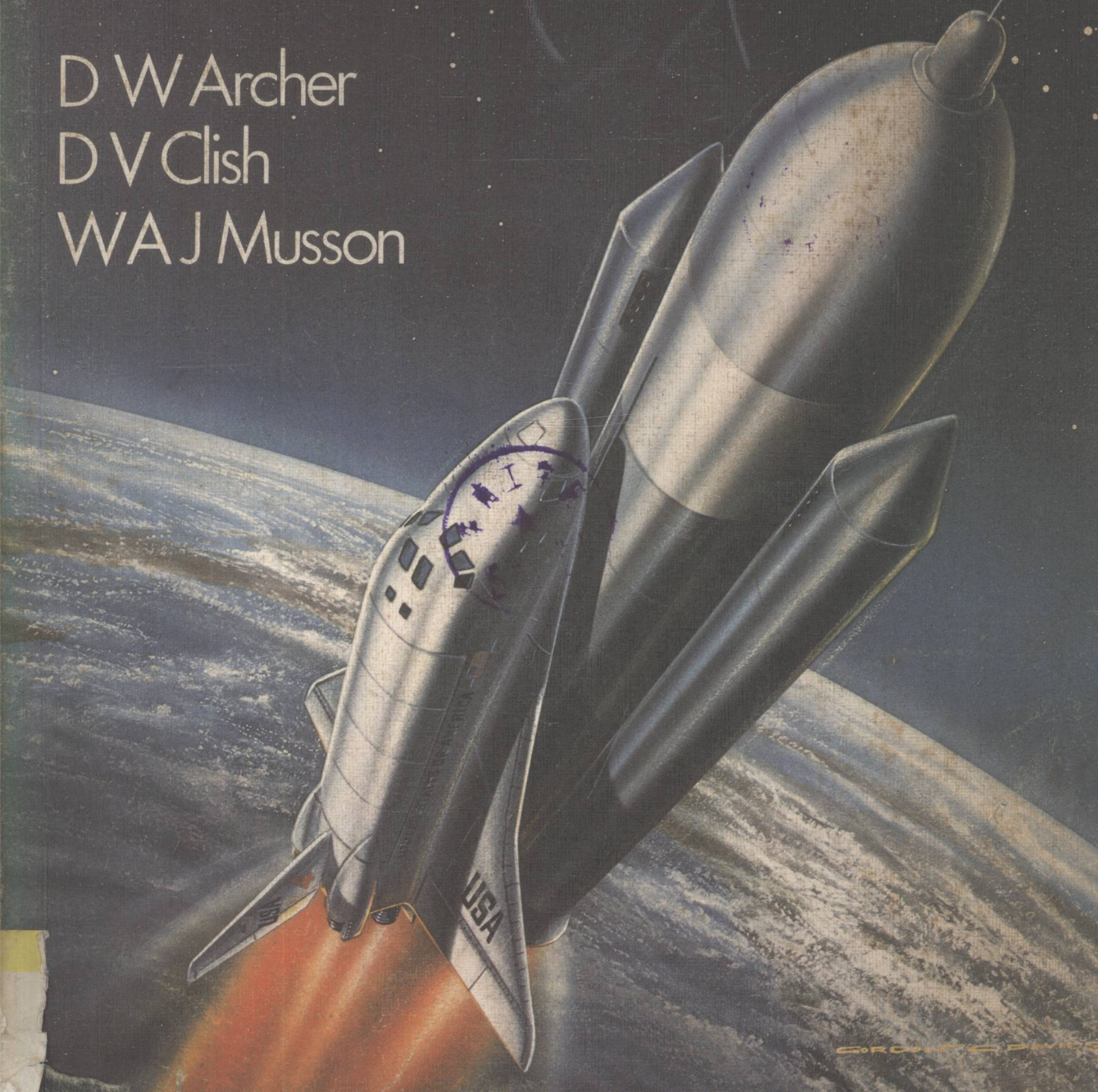
Concise Twentieth Century

Physical Science

D W Archer
D V Clish
W A J Musson



Concise Twentieth Century Physical Science

D W ARCHER *St Luke's College, Exeter*
D V CLISH *St Luke's College, Exeter*
W A J MUSSON
Formerly Head of Science Department,
Loretto School
Sometime Head of Science,
Nigerian College of Arts, Science
and Technology (now Ahmadu
Bello University of Northern Nigeria)

HODDER AND STOUGHTON
London Sydney Auckland Toronto

ISBN 0 340 04968 5

First Printed 1976

Filmset by Keyspools Limited, Golborne, Lancs
Printed in Great Britain for
Hodder and Stoughton Educational,
a division of Hodder and Stoughton Ltd.,
St. Paul's House, Warwick Lane,
London EC4P 4AH
by Butler & Tanner Limited, Frome, Somerset

Preface

This is a time of change and we have tried to include some of the more exciting changes that have occurred in the last decades to illustrate the permanent principles discovered long ago. There are space-ships as in the section on the media as well as lasers.

This century has come to a fuller recognition of the part played by energy in the life of man and we have endeavoured to bring the importance of energy forward in this book. Many syllabuses also emphasize this point of view.

This book is written concisely so as to reduce the amount of time spent in reading. It is assumed that the learner will have the assistance of a teacher particularly on the practical side of the work.

Our book is up-to-date in introducing into a school textbook not only sections on polymers and plastics, but also on natural and synthetic fibres.

The same may be said of the chapters on electronics and their use, and on space travel and astronomy.

We write as experienced teachers who have been in touch with the changes that have taken place in the field of education and we trust that our book will be of use to those preparing for examinations in Secondary Schools.

D.W.A.
D.V.C.
W.A.J.M.

Acknowledgements

The authors would like to thank the following sources for kindly supplying photographs and giving permission for their reproduction.

J. Allen Cash Ltd. 78, 273
Australian News and Information Bureau 191
Avo Ltd. 160
B.A.C. 54, 196, 224, 260
B.O.C. Ltd. 186, 281
B.P. Co. Ltd. 234, 237, 241
British Cellophane Ltd. 260
British Gas Corporation 235
British Rail 58, 79, 191, 271
B.S.C. 206, 219, 220, 221, 222, 223
Calor Gas Group 238
C.E.G.B. 122, 231
Cement and Concrete Association 266
Central Office of Information—*Crown Copyright* 164
Central Press Photos 310
Chloride Automatic Batteries Ltd. 131
Collection Musée de l'Homme 269
Copper Development Co. Ltd. 225
Courtaulds 259
Dunlop Rubber Co. 249, 250, 251
Electricity Council Application Testing Labs. 135
Fibreglass Ltd. 68
Ford Motor Co. 41
Fox Photos Ltd. 29, 60, 95, 103, 127
Glass Manufacturers Federation 266, 267
Griffin and George 3, 4
Phillip Harris 91
Hawker Syddeley Dynamics Ltd. 20
Hulton Picture Library 173, 206, 305, 312
I.C.I. 172, 187, 194, 213, 245, 248, 261, 262, 265, 270, 281
Johnson, Mathias and Co. 64, 228, 230
Laporte Industries Ltd. 200
L.B.C. 264
London Transport 27
Malayan Rubber Fund Board 249
M.O.D.—*Crown Copyright* 13, 105, 299, 300
Mullard Ltd. 284, 289
Erwin Müller 165
Opax Ltd. 118
Malcolm Pendrill Ltd. 208
Permutit Co. Ltd. 274
Pictorial Press 96
Pilkington 267
Popper 190, 193, 256
The Prestige Group Ltd. 73
Reed Group Ltd. 258
Ronan Picture Library 99, 229
Royal Astronomical Society 320
Science Museum—*Crown Copyright* 62, 179, 294, 321, 327
Shell 240, 242
The Shirley Institute 255, 256, 257
Lynda Sullivan 28
Sun Photo Bureau 208
Triplex 268
U.K.A.E.A.—*Crown Copyright* 215, 228, 306, 314, 315, 316
Unilever 277
Van den Burghs 198
Vickers Ltd. 45
Westland Aircraft Ltd. 12
Yardley of London Ltd. 279

Acknowledgement is also made to the following examining bodies for their permission to reprint questions from their G.C.E. O level and C.S.E. papers.

South-East Regional Examination Board (S.E.)
Associated Examining Board (A.E.B.)
University of Cambridge Local Examinations Syndicate (Camb.)

Frontispiece: Pouring molten iron.

Contents

Chapter One

Matter and Density

THE THREE STATES OF MATTER

Some 2000 years ago the Ancient Greeks suggested that there were four categories into which we could group all things, namely earth, air, fire, and water. It is easy to see that some things are solid like rocks of the earth, some things are liquid like water, and some things are gaseous like air, but we think of **energy** like heat in a fire rather differently.

Let us have a look at the world as the scientist looks at it today.

We can group all materials roughly as **solid**, **liquid**, or **gas**, ignoring for the moment jellies and treacles and foams etc. If we change the temperature enough by adding heat energy they will turn from one to the other, provided that they do not decompose. Have you ever thought that water, for example, can exist in all three states, as ice, water, and water vapour (steam)?

Here are some examples of:

Solids	**Liquids**	**Gases**
Brick	Methylated spirit	Air
Wood	Petrol	Coal gas
Iron	Vinegar	Butane gas
Lead	Mercury	Chlorine
(Solid state)	**(Liquid state)**	**(Gaseous state)**
Ice	Water	Water vapour (steam)

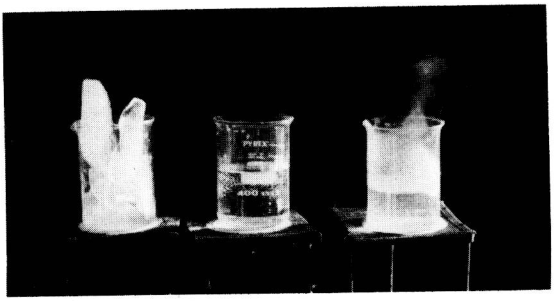


Fig. 1.1 Water exists as solid (ice), liquid (water) and as a vapour (steam).

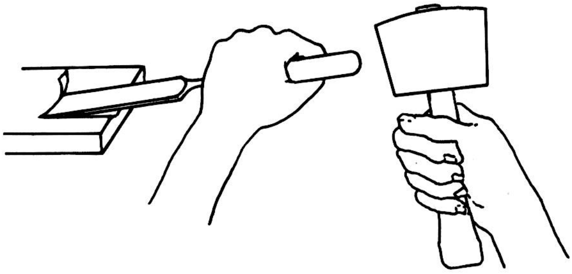


Fig. 1.2 The solid chisel transmits the thrust from the mallet to wood and has a definite shape.

No doubt you can go on adding to the list.

To think of **solids** we may consider the solid unchanging rock of the Sphinx carved thousands of years ago in the desert. It has a very **definite volume** and **shape**, and resists the forces that tend to change them. This is true of all solids and, because of their firmness or rigidity, they are able to transmit a thrust or push: for example the solid handle of a chisel **transmits** the **thrust** from the carpenter's hand to the blade.

To think of **liquids** we may consider water flowing from a tap (the water **changes** its **shape** as it flows out but there is **no change in volume**).

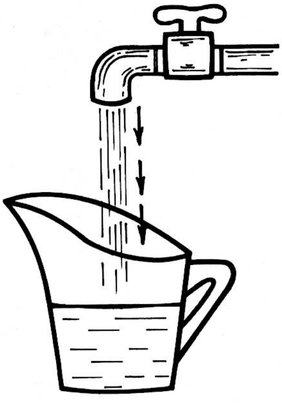


Fig. 1.3 The liquid water flows from the tap and changes its shape, but keeps the same volume.

We cannot have a handle of water to transmit thrust but we shall see later that in a cylinder enclosing a liquid (as in a water pistol) **pressure is transmitted.**

To think of **gases** we may consider the gas from a cylinder filling a small balloon. It is easy to see that the gas has **no definite shape or volume.** It expands to fill completely any empty bag or balloon into which it is directed and **transmits pressure** equally in all directions.

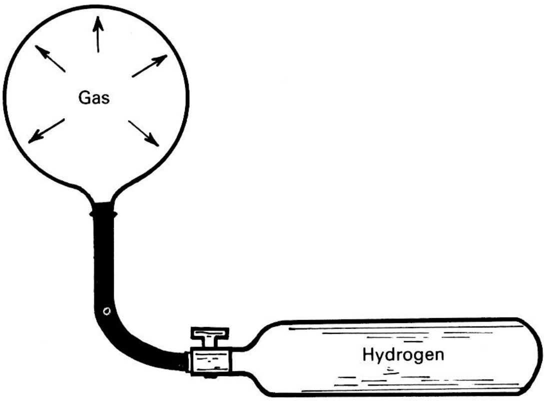


Fig. 1.4 The hydrogen gas expands into the balloon and blows it up.

What is matter made of?

When sugar is examined carefully under a hand lens it is seen to exist in definitely shaped particles called **crystals** with flat shiny surfaces. All sugar crystals have similar shapes. Even finely crushed sugar examined under a microscope shows similarly shaped crystals. Most solids, even metals, exist in the form of crystals though

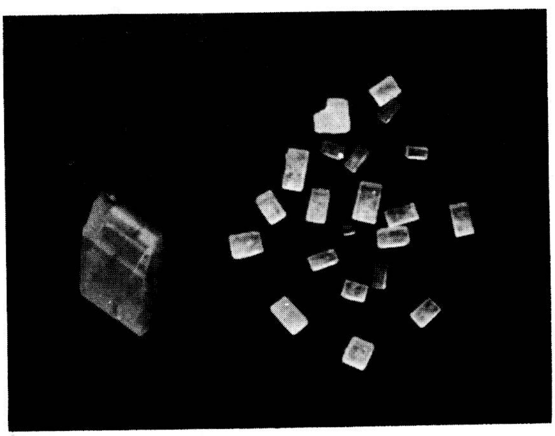


Fig. 1.5 Crystals of sugar all have the same shape, but differ in shape from crystals of copper sulphate.

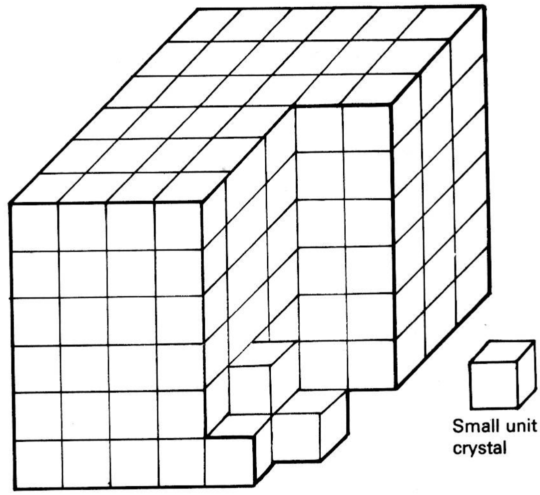


Fig. 1.6 A large crystal is made up of small unit crystals each containing atoms far too small to be seen and too complicated to represent easily.

some are difficult to distinguish. Crystals exist in many different shapes and colours but each particular material shows a characteristic crystal shape, and large crystals can be broken down into smaller and smaller crystals of the same basic shape. Just as a house is built up of basic building bricks, so is a crystal built up of basic particles called **atoms**. There are only about 100 different kinds of atom and often some atoms combine together in a small group called a **molecule**. The atoms in a molecule may all be of one kind as in an oxygen molecule (made of 2 oxygen atoms) or of two or more different atoms as in common salt molecules (one sodium atom and one chlorine atom). Some so-called large molecules are made up of many hundreds of atoms bound together by mutual attractions, into a more or less stable group.

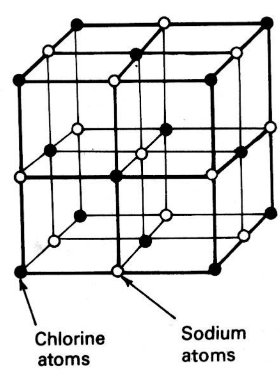


Fig. 1.7 A crystal of salt. The atoms are held together forming cubical crystals.

Molecules are so small that it is difficult to understand their size. This can be shown easily by dissolving a very small purple crystal of potassium permanganate in a large beaker of water. The purple colour of each drop of the solution shows that some potassium permanganate is present in each drop. The original small crystal must have been sub-divided into many thousands of even smaller parts and distributed throughout the water.

In a gas, molecules are quite far apart (some ten times their diameter), and move at high speed. Hydrogen, the fastest, moves at approximately 2 kilometres per second (2 km/s) at ordinary temperatures. Indeed molecules 'fill' any container by constant movement.

In a liquid the molecules are much closer together and their mutual attractions are so powerful that they are only able to glide by one another like fishes in a school. The volumes of liquids are not easily changed in contrast to their shapes, which readily alter.

In a solid, the molecules (or the atoms of which they are composed) are arranged in regular patterns like a honeycomb and the atoms are only able to vibrate and are not free to move about. Thus neither the volume nor the shape of solids are easily altered.

Fig. 1.8 A model of a large molecule made of many atoms.

The movement of molecules

Have you ever wondered how the 'smell' reaches your nose from some scented liquid which has been spilt? Molecules of scent travel from the liquid to your nose. The molecules are moving quite quickly.

The movement of liquid molecules can be shown as follows. Fill a jar $\frac{3}{4}$ full of water; then carefully run into the bottom of the jar some concentrated potassium permanganate solution using a long stemmed thistle funnel. (Fig. 1.10) This solution is more dense than water. Carefully remove the funnel and allow the jar to stand. You will notice the purple colour of the potassium permanganate slowly spreading upwards into the water. This movement of the potassium permanganate molecules is known as **diffusion**.

The movement, or diffusion of gas molecules appears to be more rapid. As they are more widely separated, the gas molecules can travel further before bumping into other molecules.

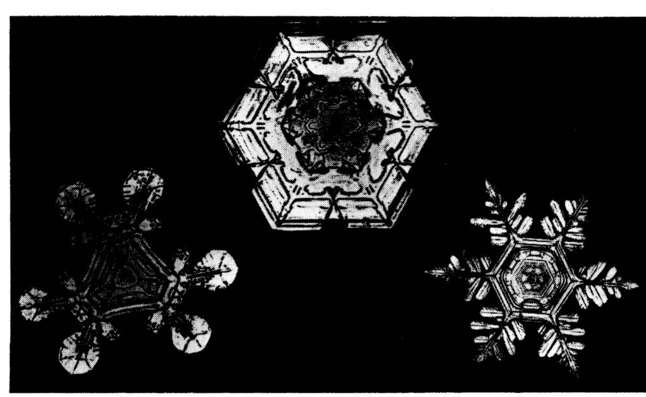


Fig. 1.9 Ice crystals are made of water molecules.

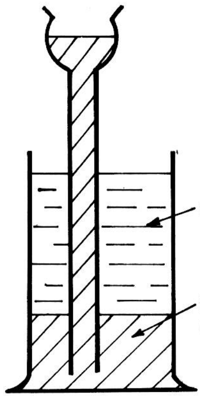


Fig. 1.10 Potassium permanganate solution diffuses slowly into water.

They have greater freedom of movement. An interesting experiment to illustrate this is to generate some red–brown gas, nitrogen dioxide, in a flask by pouring a few drops of concentrated nitric acid onto copper turnings placed in the bottom of the flask. The flask must be sealed by means of a rubber bung immediately after adding the acid. The red gas soon fills the flask. If a second flask of air is now connected by rubber tubing above the first flask and the clip opened (Fig. 1.11) the nitrogen dioxide gas will diffuse upwards very slowly. The air molecules in the upper flask slow down the movement of the gas molecules.

If this experiment is repeated, however, using instead of the second flask of air, another flask from which all air has been pumped out, the nitrogen dioxide gas will rush up and fill the flask in a fraction of a second.

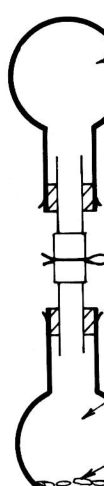


Fig. 1.11 Nitrogen dioxide gas diffuses into air.

Brownian motion

Though we cannot see the tiny molecules moving we can see the effect of air molecules bumping into small visible smoke particles. A puff of smoke is enclosed in a glass cell on a microscope stage and illuminated by a small electric light bulb. (Fig. 1.12) Under the microscope the small smoke particles appear as bright specks and move about in a random manner. They are being bombarded by rapidly moving invisible air molecules. This effect, first noticed by the botanist Robert Brown, is known as **Brownian motion**.

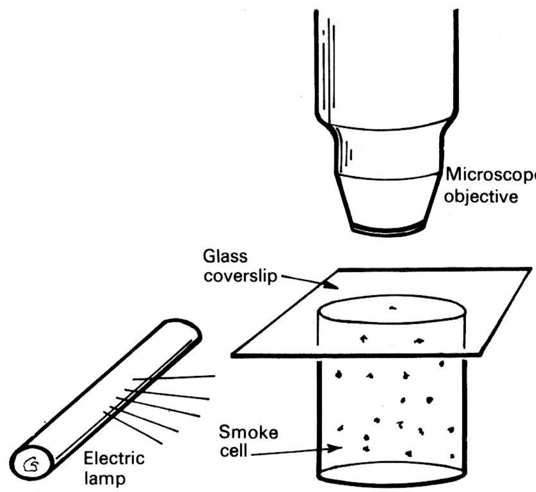


Fig. 1.12 Brownian motion apparatus.

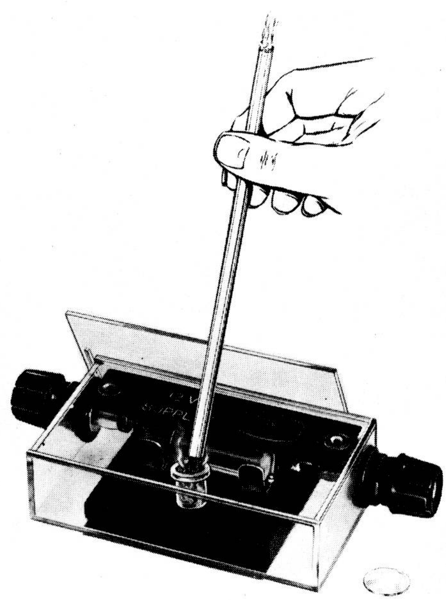


Fig. 1.13 A Whitley Bay cell shows Brownian motion.

THE OIL DROP EXPERIMENT

Let us try to estimate the actual size of these tiny particles of matter called molecules. One way is to spread the substance, say a drop of oil, as widely or as thinly as it will go until it is only one molecule thick.

To show where the oil is on the surface of water we may dust the surface with talcum powder—the powdered surface will be drawn back as the oil spreads.

For our experiment a large clean metal tray about 50 cm across is filled with water and the surface lightly coated with talcum powder. Now a very small drop of olive oil is picked up on the end of a fine wire loop and viewed through a magnifying glass against a scale. In this way it is possible to estimate its diameter and find its volume. The oil drop is then placed in the centre of the talcum powdered surface of the water in the tray, and is seen to spread out into a large clear circular patch. As the oil spreads over the top of the water it forms an extremely thin layer one molecule thick. The diameter and hence the area of this oil patch is measured with a rule.

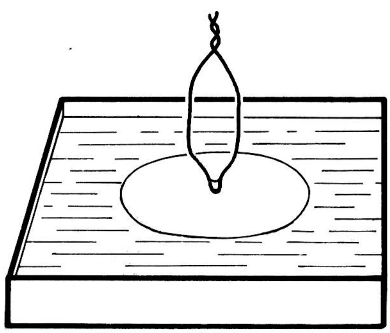


Fig. 1.14 The oil drop spreads out on the water in the tray forming a clear patch.

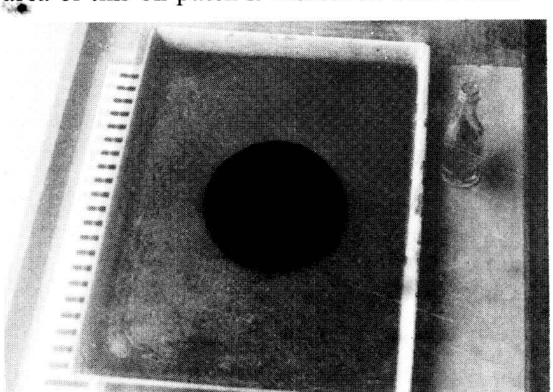


Fig. 1.15 Circular patch formed by one small oil drop on water.

In our calculations we assume that the volume of oil in the drop remains unchanged, so that the original volume of the oil drop will equal the whole area of the oil patch multiplied by the thickness of the oil in the patch.

In our experiment, the readings found were

(1) Diameter of oil drop in loop of wire = 0.10 cm
and therefore radius = 0.05 cm
(2) Diameter of oil patch = 40.00 cm

Volume of oil drop (assumed spherical)

$$= \tfrac{4}{3}\pi r^3$$
$$= \tfrac{4}{3} \times 3.1 \times (0.05)^3$$
$$= 5 \times 10^{-4} \text{ cm}^3 \text{ approx.}$$

Area of oil patch $= \pi \times r^2$
$$= 3.1 \times 20^2$$
$$= 1240 \text{ cm}^2$$

Thickness of oil patch $= \dfrac{\text{Volume}}{\text{Area}}$
$$= \frac{5 \times 10^{-4}}{1240} \text{ cm}$$
$$= 4 \times 10^{-7} \text{ cm}$$

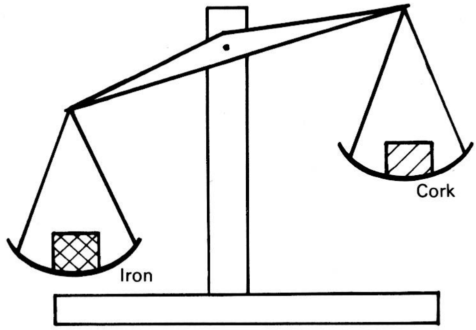
The molecules are indeed very small, and in a single gram of sugar there are more than a thousand, million, million, million molecules.

VOLUME AND DENSITY

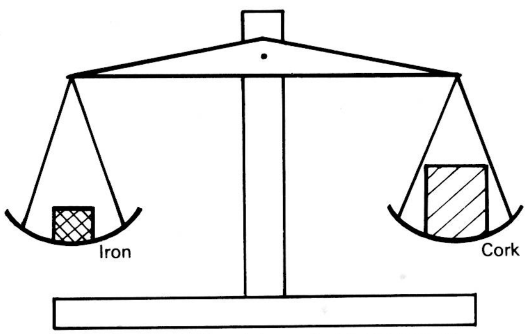
Some materials feel much heavier than others, but it is important to compare equal sized amounts. Remember a cork life belt is heavier than an iron nail. We say that the mass of the life belt is greater than the mass of the iron nail. The mass of an object may be measured using a balance. In the metric system mass is measured in grams (symbol g) or kilograms (symbol kg), and records the quantity of matter (atoms and molecules) the object contains. One kg equals 1000 g. Occasionally a much larger unit of mass, the tonne is used. One tonne equals 1000 kg or 1 000 000 g.

MEASUREMENT OF DENSITY OF SOLIDS

If **equal volumes** of cork and iron are weighed on a balance the iron weighs much more than the cork and we say it is more **dense**. It is convenient to find the mass of unit volume of each material i.e. the mass of one cubic centimetre. This is known as the **density** of the material. Density is



Iron is much heavier than an equal volume of cork



A great volume of cork is needed to balance an equal mass of iron

Fig. 1.16 Iron is much heavier than an equal volume of cork.

measured in the metric system in grams per cubic centimetre, g/cm^3.

To find the density of an object we must first weigh it to find its mass and then find its volume. We can then calculate the mass of unit volume of the material by dividing.

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

The density of a material must depend on the heaviness of the different atoms and molecules of which it is made and also on how closely they are packed together. Density is often a good guide to what an object is made of; the object might be a heavy gold ring or a light aluminium rivet. With a knowledge of the density we shall know whether a block will float or sink.

Formulae for Common Regular Solids

Volume of solid with perpendicular sides and with top parallel to base = Area of base × perpendicular height.

Volume of sphere = $\frac{4}{3}r^3$ where r is the radius

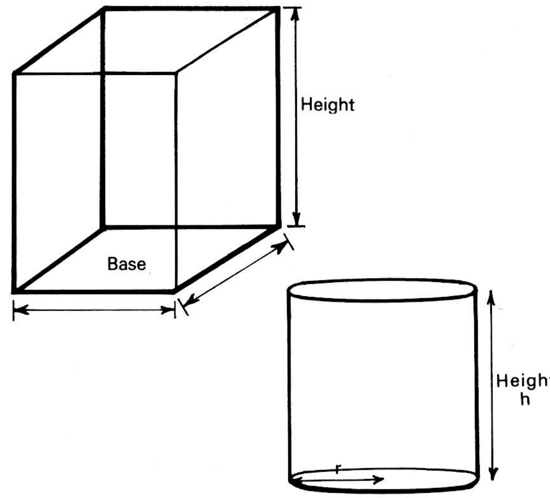


Fig. 1.18
Volume of rectangular block = Base Area × Height
Volume of cylinder = $\pi r^2 h$

MEASUREMENT OF VOLUME

(a) By direct measurement

To find the volume of an object accurately is easy if it has a regular shape, such as a cube, or sphere. In such cases after measuring the linear dimensions with a ruler or micrometer the volume can be calculated by using a formula, two of which are detailed above.

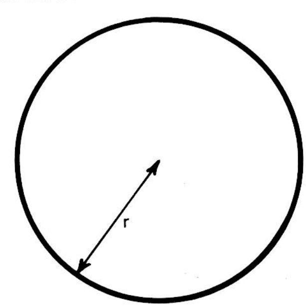


Fig. 1.17 A sphere of radius r has volume = $4/3\ \pi r^3$.

(b) By displacement

The volume of a solid such as an aluminium cylinder can be found by displacing water in a measuring cylinder.

A measuring cylinder is partly filled with water and the level of the water surface carefully read. The surface will be slightly curved so that the reading of the bottom of the curve is taken with the eye on the same level as illustrated in Fig. 1.19. The metal cylinder is lowered into the

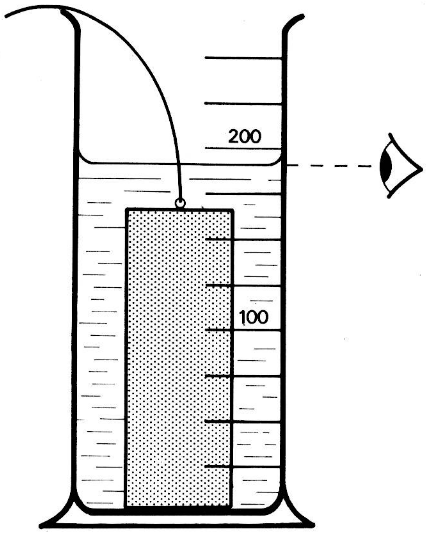


Fig. 1.19 A measuring cylinder.

water by means of a thread and the new height of the water surface read off on the scale. The volume of the cylinder will be given by the difference between the two readings of the level.

(c) Using an overflow vessel

If the object is not a suitable shape to place in a measuring cylinder, some form of vessel which overflows into a narrow measuring cylinder may be used. Water is first poured into the overflow vessel up to the spout. Then the object is lowered gently into the water. An equal volume of water overflows into a measuring cylinder which records the volume of the object.

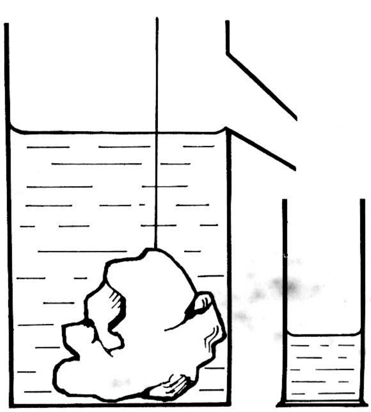


Fig. 1.20 A displacement can.

CALCULATION OF DENSITY FROM THE MASS AND VOLUME

In an experiment with an aluminium block, the volume was found by displacement of water in a measuring cylinder. The readings were as follows:

Mass of aluminium block	= 352 g
Volume of water in measuring cylinder	= 65 cm^3
Volume of water and block in the measuring cylinder	= 195 cm^3
Volume of block alone	= 195 − 65
	= 130 cm^3

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{352\ \text{g}}{130\ \text{cm}^3}$$

Density of aluminium block = 2.71 g/cm^3

MEASUREMENT OF THE DENSITY OF LIQUIDS

It is easy to measure out, using a measuring cylinder, a given volume of a liquid, say 200 cm^3. A vessel (a beaker will be satisfactory or a tin can) is weighed empty and then the measured volume of liquid is carefully poured into the vessel, which is then weighed again. By subtracting the mass of the empty vessel from this combined mass the mass of the liquid is found.

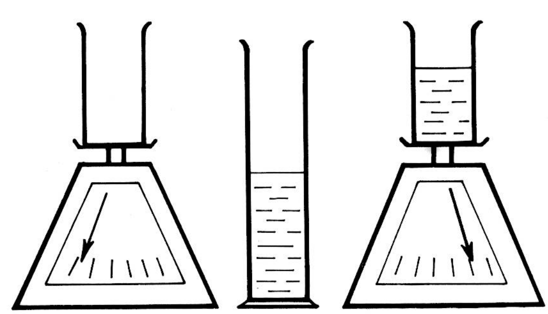


Fig. 1.21 Determining the density of a liquid.

Then the density of the liquid can be calculated by dividing the mass by the volume.

The results from such an experiment using water are given below.

Measured volume of water $= 200\ cm^3$
Mass of empty beaker $= 40\ g$
Mass of beaker plus water $= 240\ g$
Mass of water $= 200\ g$

$$\text{Density of water} = \frac{\text{Mass}}{\text{Volume}} = \frac{200\ g}{200\ cm^3} = 1\ g/cm^3$$

This value of $1\ g/cm^3$ for the density of water is important as you will see later.

RELATIVE DENSITY

The density of a substance may be compared with the density of water. This ratio is known as the **relative density**.

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

For example: The density of copper is $9\ g/cm^3$
The mass of $1\ cm^3$ of water is 1 g

From the ratio:

$$\frac{\text{mass of } 1\ cm^3 \text{ copper}}{\text{mass of } 1\ cm^3 \text{ water}} = \frac{9\ g}{1\ g} = 9$$

= relative density of copper

It is seen that the numerical value for relative density is the same as that of the true density, but it has no units.

Table of Densities of Common Materials (g/cm^3)

Solids		Liquids	
Aluminium	2.7	Water	1.0
Iron	7.9	Methylated spirits	0.8
Copper	9.0	Turps	0.84
Brass	8.4	Olive oil	0.9
Lead	11.3	Paraffin	0.8
Glass (crown)	2.6	Mercury	13.6
Wood (oak)	0.7	Carbon tetrachloride	1.6
Cork	0.25		
Rubber	1.1		
Wax	0.9		
Expanded polystyrene	0.017		

Gases

Air	0.0012
Hydrogen	0.00009
Carbon dioxide	0.0020
Methane	0.0007

(At normal room temperature and pressure.)

MEASUREMENT OF THE DENSITY OF AIR

You might think that air weighed nothing, but here is a method to measure the density of air.

A large plastic container of at least 10 litres is fitted with a tightly fitting rubber bung with outlet tube closed by a screw clip. First this container is weighed on a balance to the nearest half gram. Then by means of a bicycle pump air is forced into the container and the outlet tube is screwed tightly shut. The container is reweighed and the difference between the two weighings gives the mass of air that has been pumped in. How can the volume of this mass of air be found?

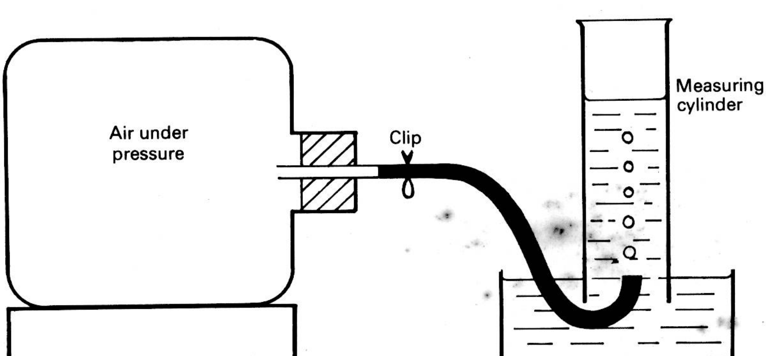


Fig. 1.22 Determining excess volume of air pumped into the container.

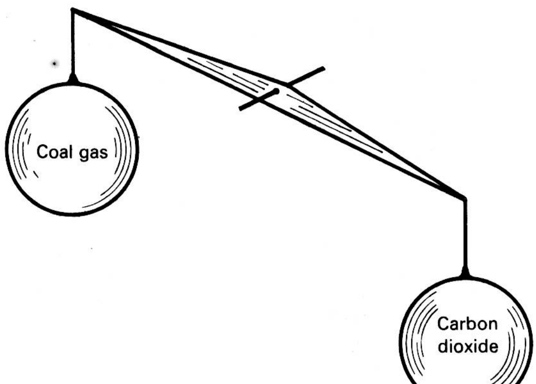


Fig. 1.23 A balloon of carbon dioxide weighs more than a balloon of coal gas of equal size.

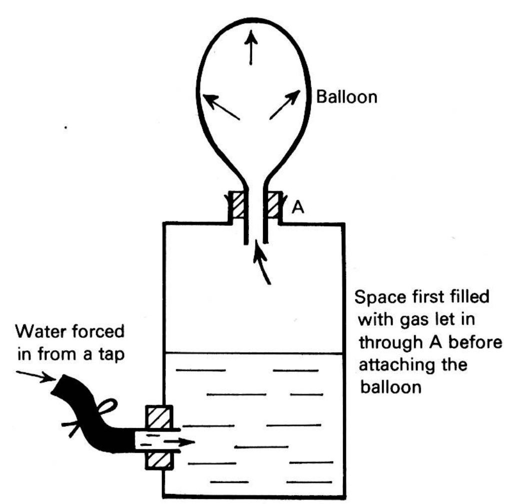


Fig. 1.24 Method of filling balloons with gas.

The outlet tube of the container is carefully opened under a large graduated vessel full of water and inverted in a sink full of water. The air, originally pumped in by the bicycle pump, now escapes and displaces an equal volume of water in the graduated vessel. Its volume can be determined.

An actual experiment gave the following results:

Mass of plastic container = 802 g
Mass of container + air = 805 g
Mass of air = 3 g
Volume of air = 2.5 litre

$$\text{Density of air} = \frac{3}{2.5} \text{ g/litre} = 1.2 \text{ g/litre} = 0.0012 \text{ g/cm}^3$$

From this experiment it can be seen that a gas like air has a much smaller density than the liquids and solids mentioned before. The molecules are much further apart. It is not very easy to determine the density of other gases directly like this, but a lot can be learned about the comparative densities of other gases by filling balloons with them and comparing the weights of the balloons. A balloon filled with coal gas (containing hydrogen) weighs much less than a similar balloon filled with air, while a balloon filled with carbon dioxide weighs more than the air balloon.

Note: Balloons can be filled by first filling a large plastic container as shown in Fig. 1.24 with the gas through tube A at the top. Then by running water into the container from a tap, the gas is forced into a balloon later attached to tube A.

QUESTIONS

1 What are the main differences between solids, liquids, and gases? Explain the fundamental difference in the arrangement of the molecules in each case.

2(a) A boy, looking through an ordinary microscope at some water, says 'I can see the molecules of water'. Is he correct? Give reasons for your answer.

(b) When one looks at suitably illuminated smoke through a microscope one sees small bright specks constantly jigging about in a random manner. (i) What are these bright particles? (ii) Suggest why they are jigging about. What can you deduce from this?

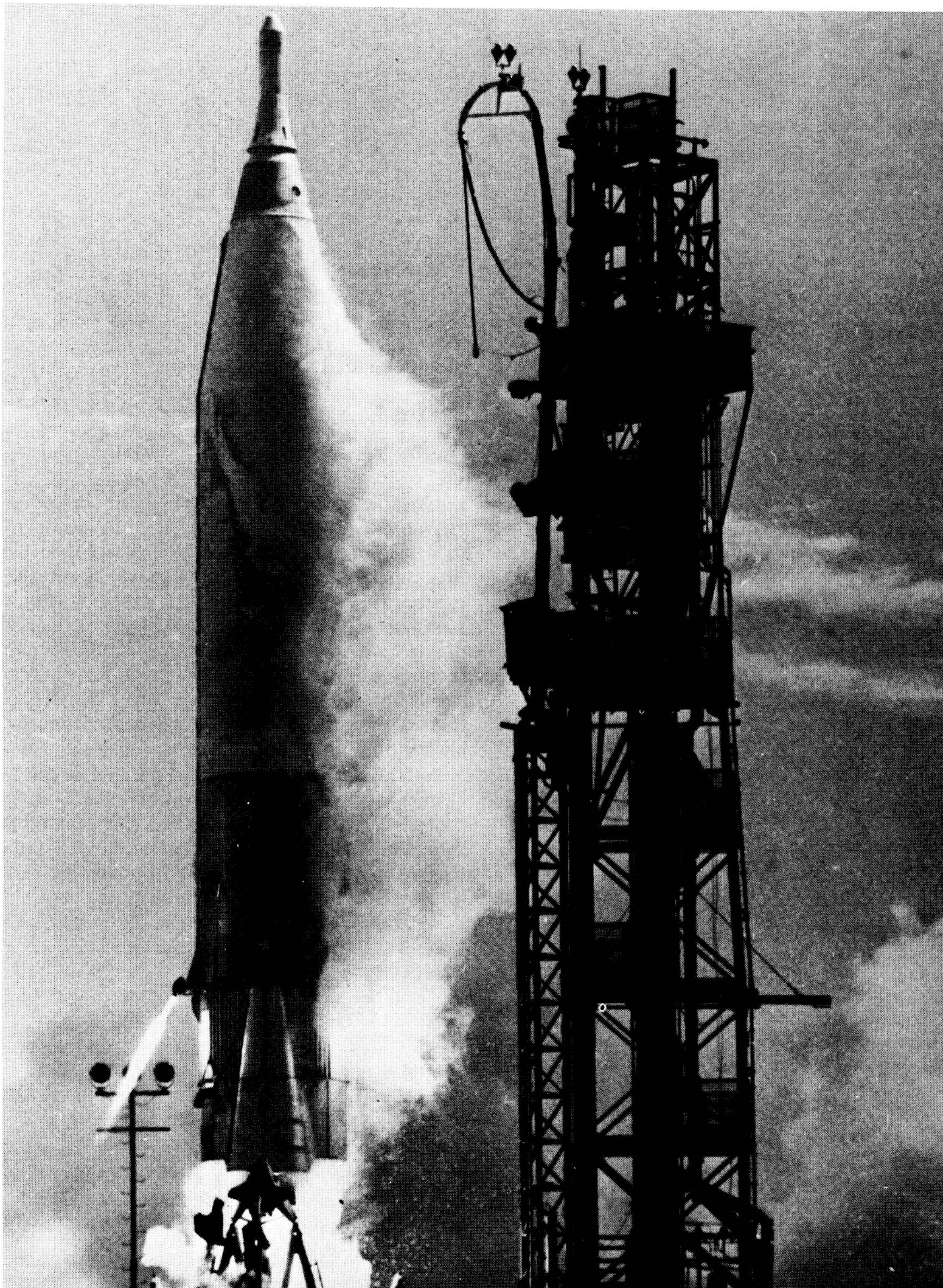
(c) Describe an experiment which you could perform to estimate the size of a molecule of oil. Explain briefly how you would calculate the answer from the measurements taken.

3 A block of wood is 10 cm long, 2 cm deep, and 4 cm wide: its mass is 56 g. What is the density of the wood? Show your working. (SE)

4 A measuring cylinder weighs 300 g. Sand is put into it up to the 50 cm^3 mark and it now weighs 375 g. From these figures calculate a value for the density of sand.
Why is your answer not the true density of sand?

5 Describe carefully how you would determine the density of air in the laboratory.

6 A block of metal, of volume 20 cm^3, weighs 100 g. Calculate its relative density.



UNIT 2. Frontispiece: Atlas rocket taking off.