SCIENCE
for today and tomorrow

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PREFACE

This book is designed for students following a course of study leading to an O level or CSE examination in General Science or Combined Science, in both the U.K. and overseas.

Subject matter--biology, chemistry, physics and earth sciences—is presented in broad sections, comprising 92 chapters each dealing with a particular topic. Each chapter contains essential facts, ideas, details of experiments, everyday applications and questions for study and revision.

The order of presentation suggests a possible two-year course of study, but the organization in no way assumes that this sequence need be followed. Indeed, we have assumed that teachers will develop the subjects in a wide variety of ways, so our primary concern has been to ensure that students have simple access to information under easy-to-recognize headings. Cross references, where applicable, stress the essential interrelationships between the parts of science, but by exposing students to the 'flavours' of the separate disciplines, we hope to prepare the way for later specialist studies in separate sciences.

M. A., T. D., D. M.

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Section Illustrations

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Cover Photographs

Peacock butterfly (Barbara Jay); Launching of Space-Shuttle 'Columbia' (J. Allan Cash); England Cheshire Chemical Refinery (Tony Stone Associates).

THE RELATIVE ATOMIC MASSES OF SOME ELEMENTS

Element	Symbol	Relative atomic mass	Element	Symbol	Relative atomic mass	Element	Symbol	Relative atomic mass
Aluminium	Al	27.0	Gold	Au	197	Phosphorus	P	31.0
Argon	Ar	39.9	Helium	He	4.00	Platinum	Pt	195
Barium	Ba	137	Hydrogen	H	1.01	Potassium	K	39.1
Beryllium	Be	9.01	Iodine	I	127	Rubidium	Rb	85.5
Boron	B	10.8	Iron	Fe	55.8	Silicon	Si	28.1
Bromine	Br	79.9	Krypton	Kr	83.8	Silver	Ag	108
Cadmium	Cd	112	Lead	Pb	207	Sodium	Na	23.0
Caesium	Cs	133	Lithium	Li	6.94	Strontium	Sr	87.6
Calcium	Ca	40.1	Magnesium	Mg	24.3	Sulphur	S	32.1
Carbon	C	12.0	Manganese	Mn	54.9	Tin	Sn	119
Chlorine	Cl	35.5	Mercury	Hg	201	Titanium	Ti	47.9
Chromium	Cr	52.0	Neon	Ne	20.2	Uranium	U	238
Cobalt	Co	58.9	Nickel	Ni	58.7	Vanadium	V	50.9
Copper	Cu	63.5	Nitrogen	N	14.0	Xenon	Xe	131
Fluorine	F	19.0	Oxygen	O	16.0	Zinc	Zn	65.4
Germanium	Ge	72.6						

THE PERIODIC TABLE

heavy (transition) metals

periods / groups	I	II											III	IV	V	VI	VII	VIII
1							1 H	2 He										
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La	* 72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac	§														

alkali metals ↑ (group I) — alkaline earth metals ↑ (group II) — halogens ↑ (group VII) — noble gases ↑ (group VIII)

*	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	lanthanides
§	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	actinides

Each element in the periodic table is given a number that shows its position. This number is called the *atomic number* and is not the same as the relative atomic mass of the element.

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FORMULAS, EQUATIONS AND CHEMICAL COMPOUNDS

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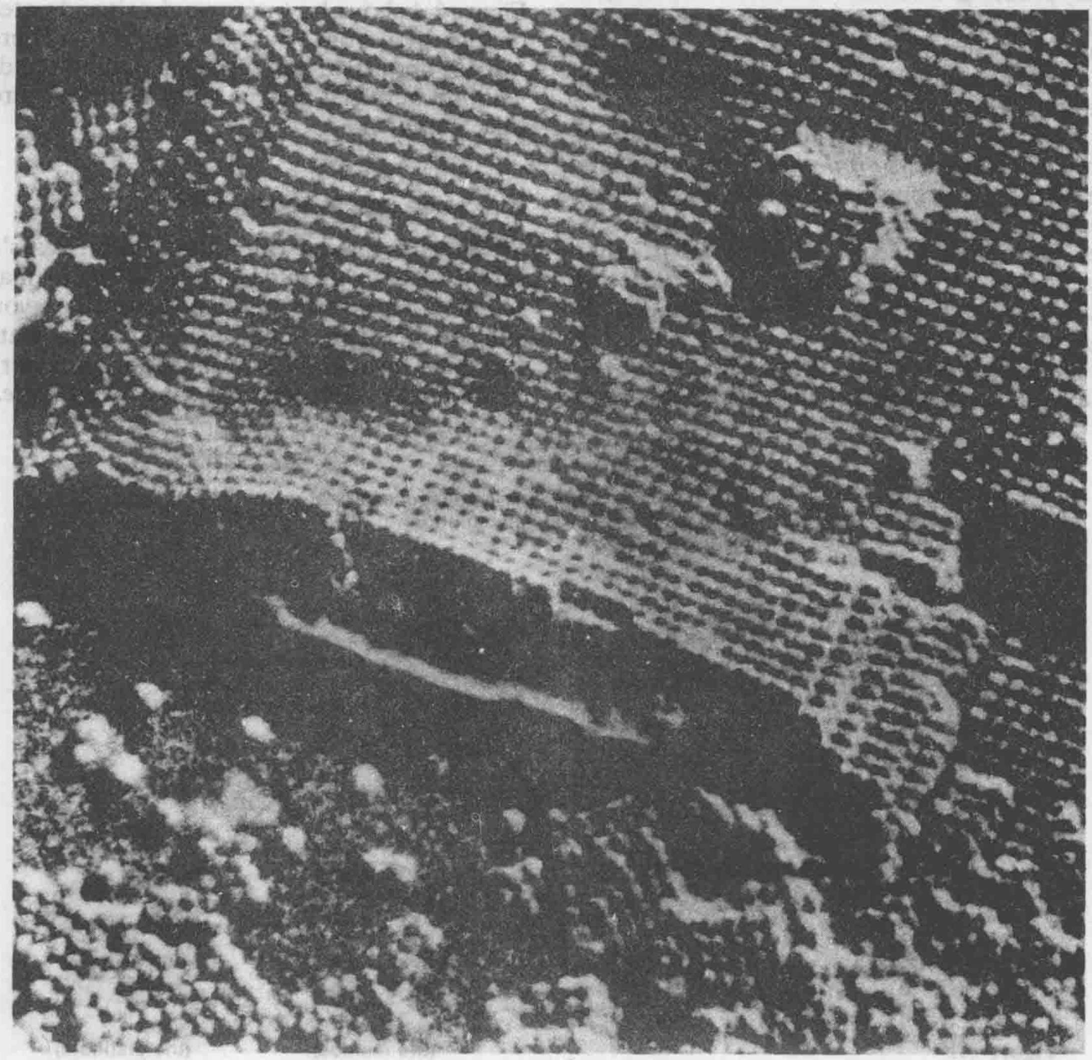
Investigating Matter



1 SEPARATING SUBSTANCES

Pure substances and mixtures

Some substances you see around you are *mixtures* of more than one substance, while others consist of one substance only and are said to be *pure*. Soil, air, grass, beer and milk are all mixtures; sugar is a pure substance.

Sometimes different substances in a mixture can be easily seen, e.g. a mixture of maize and beans, or a sample of soil. But many mixtures, such as beer, look as if they contain only one substance. You can show these are mixtures by separating the substances in them.

To find out whether a substance is pure or impure, we examine its *properties*. Each pure substance has a set of properties that help make it look and behave differently from any other pure substance. So pure water is different from other liquids because it is the only one that freezes at 0 °C, boils at 100 °C (at sea-level) and has a density of 1 g/cm^3.

If a sample of water boils at 102 °C (at sea-level) and has a density greater than 1 g/cm^3, then you know that it must be a mixture of water and something else. Mixtures may sometimes look as if they are pure substances, but their properties are sure to be different in some ways from the pure substances that make them up.

Some separation methods

Figure 1.1 shows how pure sand, salt and water can be separated from a mixture of all three. There are several important words in the diagram and you will find out what they mean as you work through this chapter.

Filtration and evaporation

When salt is shaken with water, it 'disappears'. The salt is said to *dissolve* in the water to make a *solution*. But when sand is added to water, you can still see the grains either 'hanging' in the water or forming a layer at the bottom of the container. Salt is *soluble* in water whereas sand is *insoluble*.

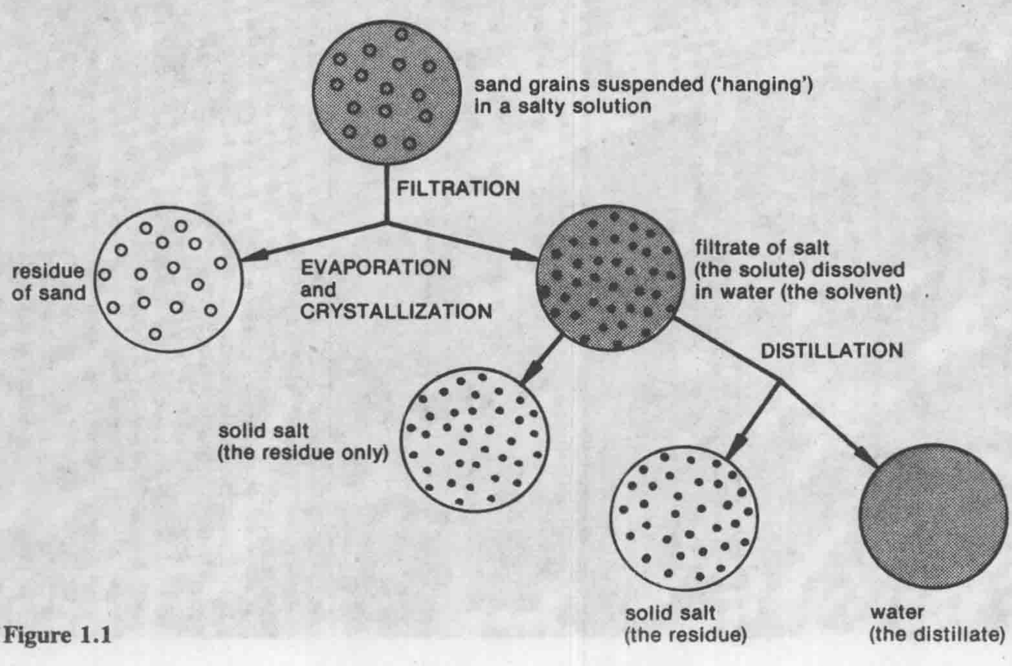
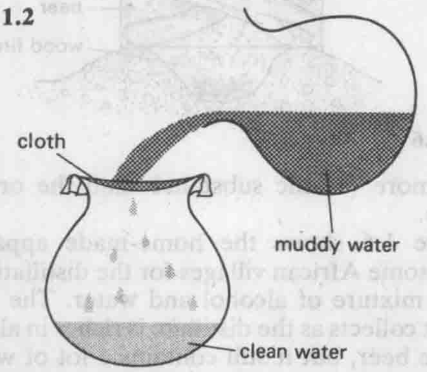


Figure 1.1

Filtration is a method of separating an insoluble solid and a liquid. In some countries, muddy river water is made cleaner by pouring it through a cloth tied to the mouth of a pot (Figure 1.2). The mud and sand grains cannot pass through the very small holes in the cloth but the water can.

Figure 1.2



The water you get from a tap has often been made cleaner by filtration at a waterworks. As it passes slowly down through the beds of sand and stones, the grains get trapped and the water coming out of the bottom of the beds is clear.

Evaporation is a method of separating a soluble solid from its solution. Heat is used to boil off the liquid (the *solvent*), leaving the solid (the *solute*) behind.

If only part of a solvent is evaporated, a more *concentrated* solution is formed. When this is cooled, crystals of the solute often separate out in a process called *crystallization*. This happens because less solute can dissolve in the same volume of solvent at a lower temperature, and so the extra solute appears as solid crystals.

Experiment 1 Separating sand and salt from a mixture

Put a mixture of sand and salt into a beaker of water and stir the water. Filter this mixture using the apparatus shown in Figure 1.3. The filter paper acts like the cloth in Figure 1.2.

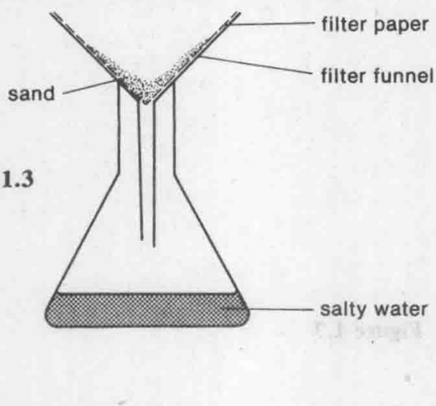
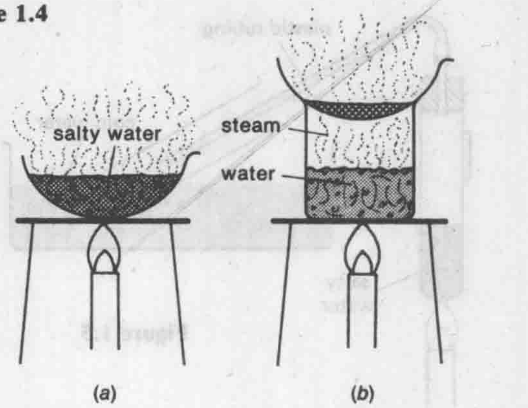


Figure 1.3

Figure 1.4



You now have to get solid salt from the salty solution (the *filtrate*). Pour the filtrate into an evaporating dish (Figure 1.4*a*) and heat it until very little solution is left. Then heat the rest of the filtrate on a steam-bath (Figure 1.4*b*). Look for crystals of salt on the sides of the dish.

Distillation

From Figure 1.4 you will see that there are two ways of getting solid salt from a filtrate. Both ways separate a solvent and a solute from a mixture of the two. But, unlike evaporation, *distillation* allows you to get both substances and not just one of them. This is because the vapour coming off the liquid is 'trapped' and made to condense back to the liquid in another container.

Experiment 2 Getting pure water from salty water

In this experiment you are allowed to taste the liquids. Usually you should never try to taste any substances in the laboratory because many of them could be very harmful.

Dissolve a spatula measure of salt in about 25 cm^3 of water and taste the solution. Pour the solution into a boiling tube and add a few pieces of pumice. Heat the solution using the apparatus shown in Figure 1.5. When boiling begins, turn down the heat so that the liquid boils gently.

- What can you see in the tubing?

Carry on heating until you have got about 2 cm^3 of the liquid in the test-tube.

- Does this liquid taste salty?
- Where is the salt now?

In all distillations, the more *volatile* substances (the ones with lower boiling points) form vapours first,

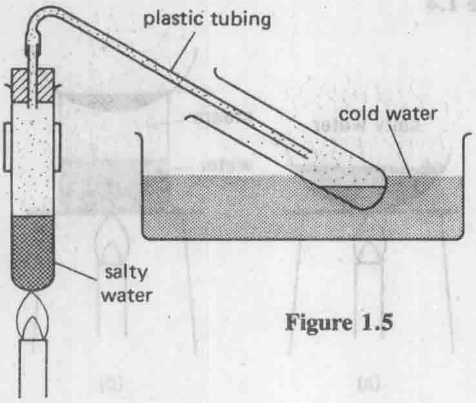


Figure 1.5

so leaving the less volatile substances behind. As the temperature is raised, these less volatile substances may also form vapours. But *involatile* substances like salt only turn into a vapour at very high temperatures.

It is very easy to separate completely a volatile substance like water and an involatile substance like salt by ordinary distillation. It is much more difficult to do this for a mixture of two fairly volatile substances. What usually happens is that the distillate is still a mixture of the two, but it is richer

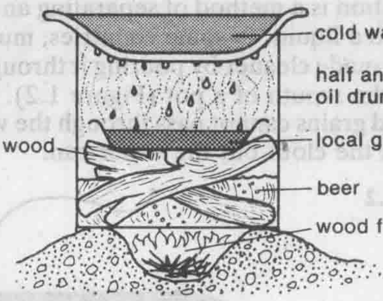


Figure 1.6

in the more volatile substance than the original mixture.

Figure 1.6 shows the home-made apparatus used in some African villages for the distillation of beer, a mixture of alcohol and water. The 'local gin' that collects as the distillate is richer in alcohol than the beer, but it still contains a lot of water.

The complete separation of alcohol and water cannot be carried out using this apparatus. Nearly pure alcohol can be obtained from a mixture of alcohol and water by a special kind of distillation called *fractional distillation* (Figure 1.7). As the mixture rises up the column packed with glass beads, it gets richer and richer in alcohol. At the top, the liquid contains up to 95 per cent alcohol.

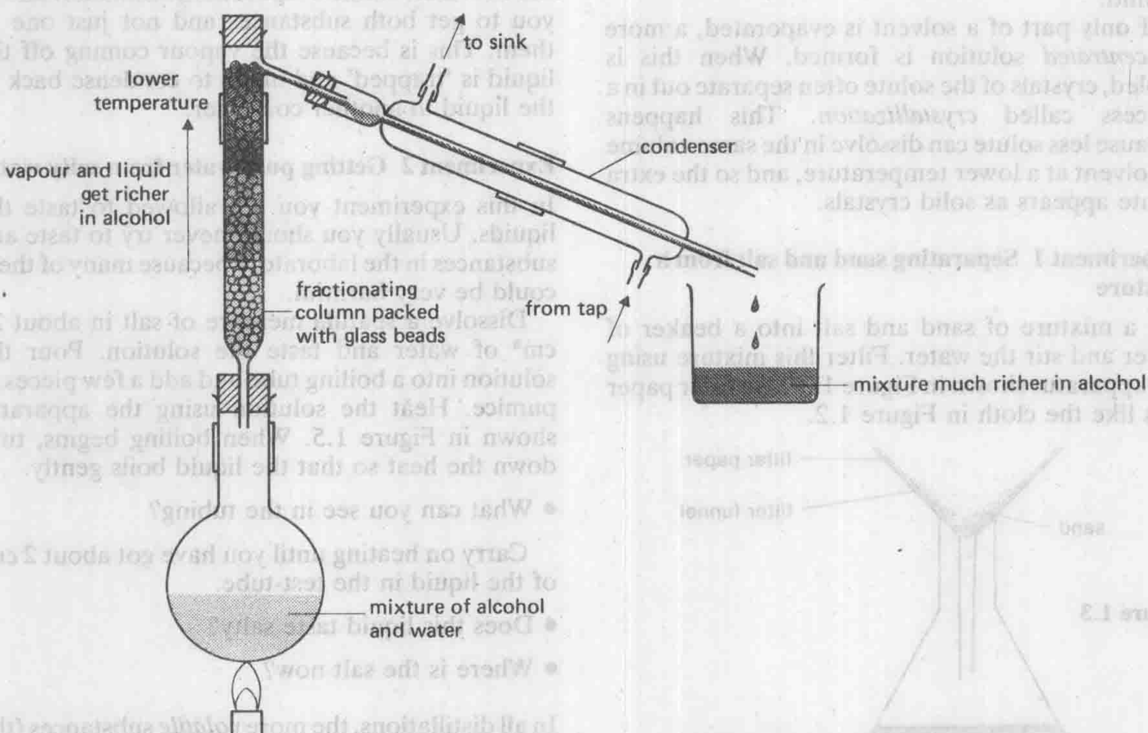


Figure 1.7

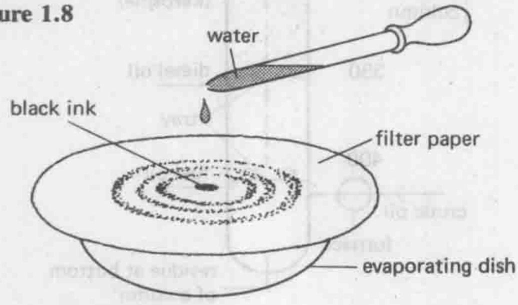
Paper chromatography

A solid is left when some ink is evaporated to dryness. This is the substance that gives ink its colour. The next experiment shows that this dye is not just one substance but a mixture.

Experiment 3 Separating the dyes in ink

Add one drop of ink to the centre of a piece of filter paper which is supported on an evaporating dish (Figure 1.8). Then slowly add drops of water from

Figure 1.8



a dropper on to the ink blot. You get the best results when the water does not flow over the surface of the paper but soaks through the pores of the paper.

As the water spreads out through the filter paper, some of the dyes go with it. But they do not spread out to the same extent so that coloured bands form at different distances from the central blot.

This method can be used to separate small amounts of substances in a mixture. It is called *paper chromatography*. After the experiment the filter paper can be cut up so that each dye is separated from the others.

Questions

1. Complete the following passage about rock salt by filling in the gaps with the words listed below.

crystals, dissolves, evaporated, filtered, filtrate, impure, pure, solution

In many parts of the world, salt can be found in a rock-like form called rock salt. .... of rock salt can be seen in Figure 1.9. When it is dug out of the ground, rock salt often contains sand and so it is ....

To get .... salt from rock salt, you have to crush the rock to a powder and then add it to water. The salt .... but the sand does not. This mixture is .... and the salt .... collects as the .... in the conical

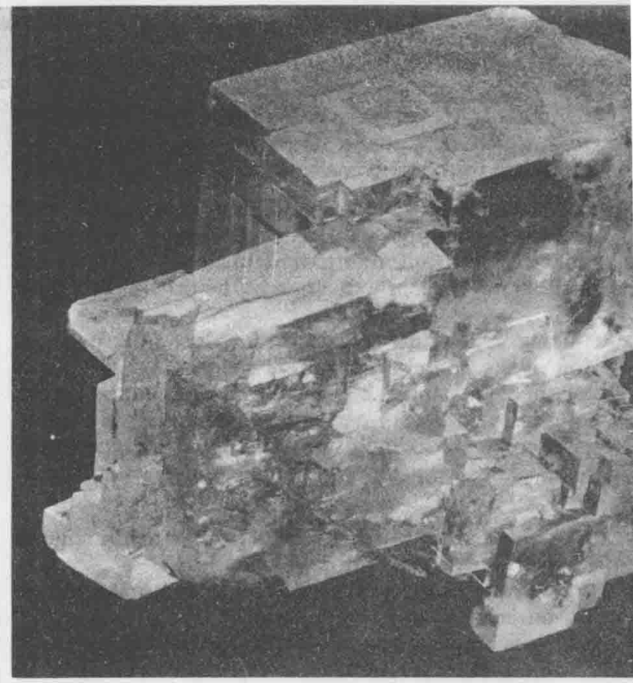


Figure 1.9

flask. The contents of the conical flask are then .... to drive off the water, so leaving the salt behind.

2. Describe how you would obtain pure water from salty water, using materials from your home.

3. Sugar-cane is a mixture of substances. Some, like the sugar itself, are soluble in water, while others are insoluble.

Describe how you would get a solution of the soluble substances from the sugar-cane using materials from your home. How could the solids be obtained from this solution?

4. Figure 1.10 shows some white flowers that grow in the highlands of Kenya. An insecticide called *pyrethrum* can be extracted from these flowers by using hexane as a solvent.

Describe how you would get (*a*) a solution of pyrethrum in hexane from them, and (*b*) pyrethrum from the hexane solution. (HINT: hexane has a much lower boiling point than pyrethrum.)

Figure 1.10

5. Local gin (page 4) is a colourless liquid but the beer from which it is made is brown. Explain how this difference in colour comes about.

6. Crude oil is a mixture of many liquids, all with different boiling points. In an oil refinery crude oil is separated into different parts (fractions) by fractional distillation. There is a diagram of the process in Figure 1.11.

The fractionating column is a more complicated version of the column in Figure 1.7 (page 4). The more volatile liquids form their gases which then move up the column. At different parts of the column, some of the gases condense to liquids on a 'tray' and are tapped off. A few gases reach the top of the column without condensing.

(*a*) What happens to the temperature inside the column going from the bottom to the top?
(*b*) Why do different gases condense to liquids on different trays in the column?
(*c*) Which must be more volatile, the petrol fraction or the fuel oil fraction?
(*d*) What can you say about the boiling points of the substances that reach the top of the column without condensing to liquids?
(*e*) Why do some liquids collect at the bottom of the column as a residue?

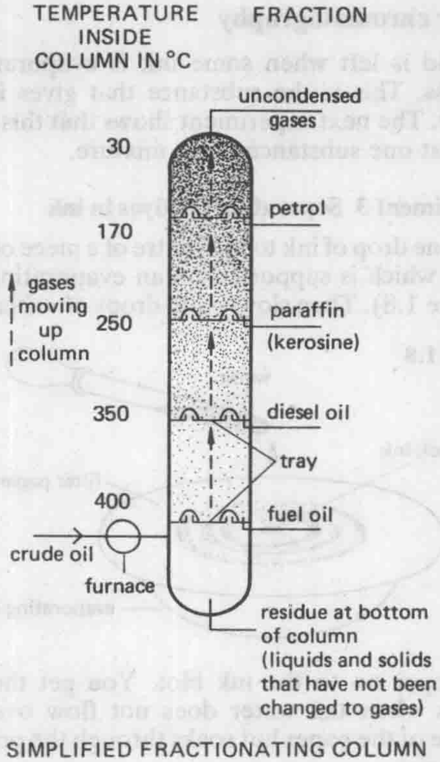


Figure 1.11

2 BREAKING DOWN SUBSTANCES

Making charcoal from wood

In many parts of the world, charcoal is a useful fuel. It is made by heating wood without much air being present so that the wood cannot burn (page 18). Because charcoal is completely different from wood in its properties, a *chemical reaction* must take place when wood is heated.

All substances, whether solids, liquids or gases, are made of particles (page 14). But the properties of wood and charcoal are very different. It follows that the particles of which they are made must also be different.

When there is a change in the kinds of particles so that a new substance is formed, the change is called a chemical reaction.

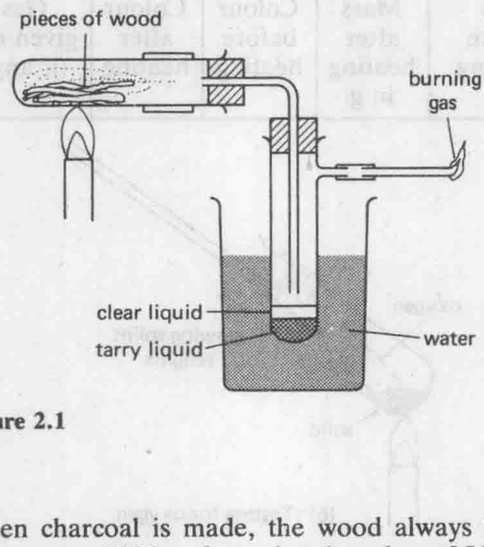


Figure 2.1

When charcoal is made, the wood always loses some mass: 100 kg of wood makes about 25 kg of charcoal. The other 75 kg just seems to 'disappear'. Figure 2.1 shows what happens to this extra mass. It is given off the wood as liquids and some gases that burn. A simple *word equation* for this chemical reaction is:

$$\text{wood} \xrightarrow{\text{heat}} \text{charcoal} + \text{liquids} + \text{gases}$$

The results of the experiment in Figure 2.1 show that wood must contain the liquids and the gases but that charcoal does not. Because of this, wood and charcoal cannot be the same substance. Wood is made of very large and complicated particles. When it is heated, these are broken down into the much smaller and simpler particles of charcoal, the liquids and the gases.

Changing copper sulphate crystals

In Figure 2.2 blue copper sulphate crystals are being heated in a test-tube that is sealed so that nothing can get in or out. Soon the blue colour fades leaving a white solid, and a colourless liquid condenses on the sides of the test-tube away from the flame of the burner.

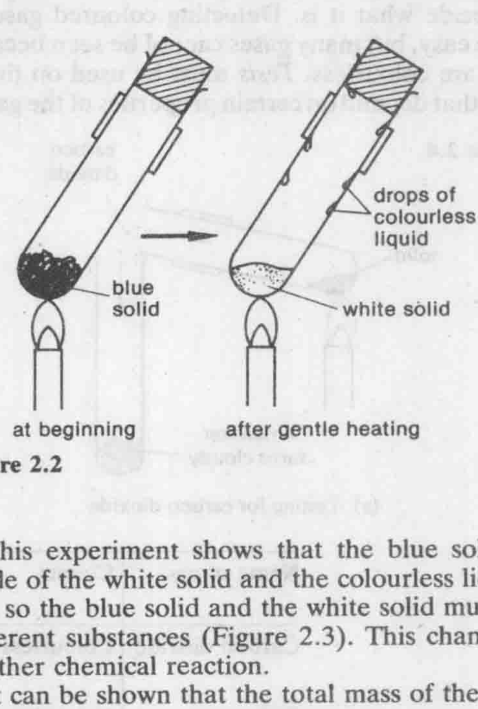


Figure 2.2

This experiment shows that the blue solid is made of the white solid and the colourless liquid, and so the blue solid and the white solid must be different substances (Figure 2.3). This change is another chemical reaction.

It can be shown that the total mass of the test-tube and its contents is the same after heating as before heating. The masses of the white solid and the colourless liquid add up to the mass of the blue solid.

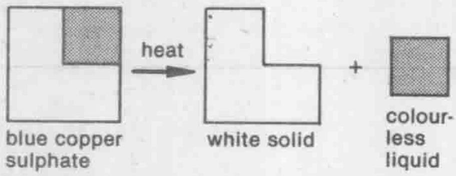


Figure 2.3

In all chemical reactions, the total mass of the substances that react together equals the total mass of the substances formed.

This important idea is known as the *Law of Conservation of Mass*.

All solids that lose mass when they are heated must be giving off a gas. This law shows that the gas must always have a mass equal to the loss in mass of the solid.

Heating some more solids

Before you carry out the next experiment, you need to know how to detect gases. Like all substances, each gas has some properties that help you to decide what it is. Detecting coloured gases is quite easy, but many gases cannot be seen because they are colourless. *Tests* must be used on these; tests that depend on certain properties of the gases.

Figure 2.4 shows the tests you can use to detect two colourless gases called oxygen and carbon dioxide, and also how you should carry them out.

In the experiment that follows, you can try to find out whether heating some solids breaks them down into new substances. You should look for:

(*i*) a change in the colour of the solid
(*ii*) any gases given off
(*iii*) a change in the mass of the solid.

If a solid loses mass by giving off a gas, then it must form a new substance made of different particles.

Experiment 1 What happens when some solids are heated?

Each group should use at least two of these solids:

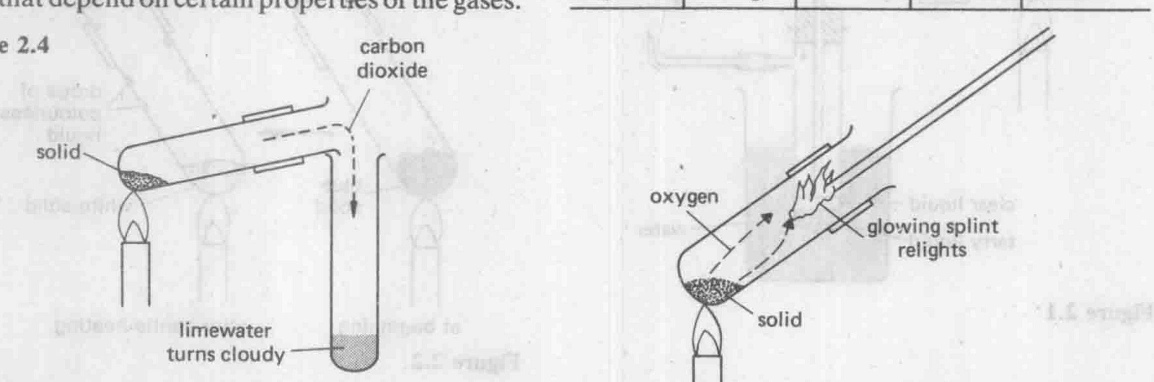
copper carbonate, potassium chloride, potassium permanganate, sodium hydrogencarbonate

Find the mass of a test-tube with about two spatula measures of the solid in it. Then heat the solid and watch for any change that might take place. If you think a gas is being given off, try to detect it using the tests given above. Lastly, let the test-tube cool and then find its mass again.

- Copy and complete a table with these headings.

Mass before heating in g	Mass after heating in g	Colour before heating	Colour after heating	Gas given off (if any)

Figure 2.4



(*a*) Testing for carbon dioxide

(*b*) Testing for oxygen

Name of gas	Colour	Test	Property on which test depends
Carbon dioxide	Colourless	Pass the gas into lime water	Turns lime water cloudy
Oxygen	Colourless	Hold a glowing splint in the gas	Relights a glowing splint

- Write a word equation for each of the chemical reactions that take place. For the heating of potassium permanganate, for example, this would be:

$$\text{potassium permanganate} \xrightarrow{\text{heat}} \text{black solid} + \text{oxygen}$$

When solids are broken down into new substances on heating, the chemical reaction is called *thermal decomposition*. This kind of reaction takes place with three of the solids in the experiment. With the other one, no change at all takes place on heating.

A CHEMICAL REACTION THAT GOES BOTH WAYS

Some changes are *reversible*, that is they can go both ways. Suppose that the test-tube shown in Figure 2.2 (page 7) is cooled and the colourless liquid runs down the sides on to the white solid. The white solid then turns back to the original blue solid. The word equation for this reversible chemical reaction is:

$$\text{blue copper sulphate} \underset{\text{cool}}{\overset{\text{heat}}{\rightleftharpoons}} \text{white copper sulphate} + \text{colourless liquid}$$

If some of the colourless liquid is collected (Figure 2.5), some of its properties can be investigated. These properties show that the liquid is pure water.

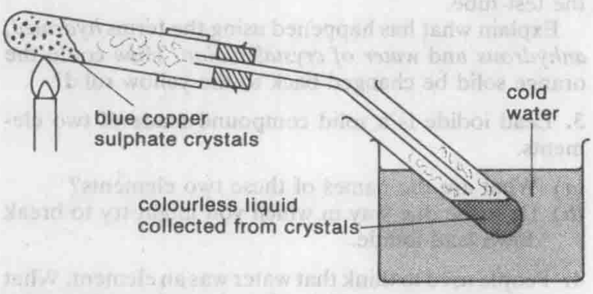


Figure 2.5

Many other crystals also give off water when they are heated. Such crystals are said to be *hydrated*. The new solids formed after the water has been driven off do not have any water in them and these are said to be *anhydrous*.

The water that is 'locked up' in the hydrated crystals is called *water of crystallization*. It is always driven off when the crystals are heated. In one or two cases, as with hydrated sodium carbonate, it may also be given off just by leaving the crystals exposed to the air for a few days.

From compounds to elements

Two ways of breaking down substances are shown in Figures 2.6 and 2.7. When red mercury oxide is heated, it changes to shiny grey drops of mercury and a colourless gas (oxygen) that relights a glowing splint. (WARNING: toxic mercury vapour is given off in this experiment.)

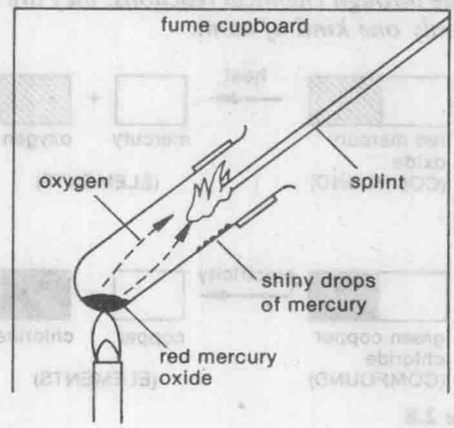


Figure 2.6

Another way of breaking down a substance is to pass electricity through it after it has been melted. Figure 2.7 shows green copper chloride that has been melted to form a liquid. When electricity is passed through it it changes to a green-yellow gas

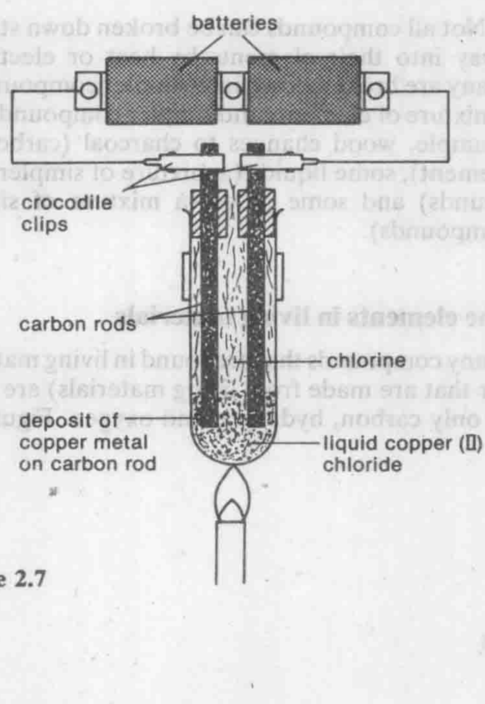


Figure 2.7

(chlorine) with a nasty smell and a red solid (copper metal) that forms around one of the carbon rods.

No matter what is done to the mercury, oxygen, chlorine or copper, none of them can be broken down any further. Even though electricity can pass through both mercury and copper, neither is changed by it. All four substances are called *elements* and the particles they are made of are called *atoms* (page 224).

Elements are the simplest substances that can be made through chemical reactions: they are made of only one kind of atom.

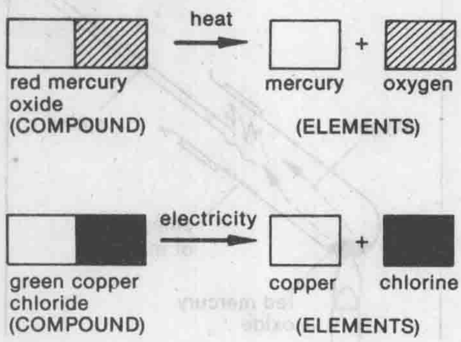


Figure 2.8

Red mercury oxide and green copper chloride are *compounds* made of two elements joined together (Figure 2.8).

Compounds can always be broken down into simpler substances: they are made of the atoms of two or more elements.

Not all compounds can be broken down straight away into their elements by heat or electricity. Many are broken down into simpler compounds or a mixture of elements and simpler compounds. For example, wood changes to charcoal (carbon, an element), some liquids (a mixture of simpler compounds) and some gases (a mixture of simpler compounds).

The elements in living materials

Many compounds that are found in living materials (or that are made from living materials) are made of only carbon, hydrogen and oxygen. Figure 2.9

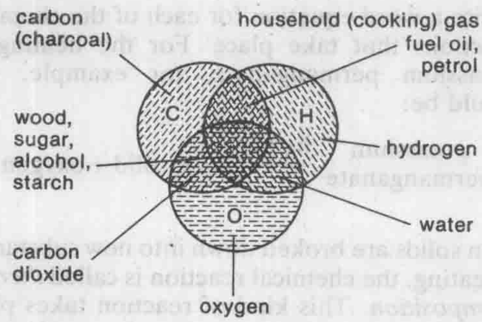


Figure 2.9

gives some of these. The substances in the central area are made of all three elements. Those in the areas where two circles overlap are made of only two of them.

Questions

1. Complete the following passage about blue copper sulphate by filling in the gaps with the words listed below.

anhydrous, crystals, hydrated, mass, water of crystallization

When blue copper sulphate .... are gently heated, there is a loss in .... because their .... is driven off. A white solid called .... copper sulphate is formed. If drops of water are added to this white solid, it goes back again to .... copper sulphate.

2. Cerium sulphate is a yellow solid. When it is heated, it turns orange and a colourless liquid forms on the sides of the test-tube.

Explain what has happened using the terms *hydrated*, *anhydrous* and *water of crystallization*. How could the orange solid be changed back to the yellow solid?

3. Lead iodide is a solid compound made of two elements.

(*a*) What are the names of these two elements?
(*b*) Describe one way in which you might try to break down lead iodide.

4. People used to think that water was an element. What experiments can you think of to show that it is a compound?

5. Write down *three* changes that could happen during a chemical reaction. Two of the changes should concern what happens to a solid and the other should involve another kind of observation.