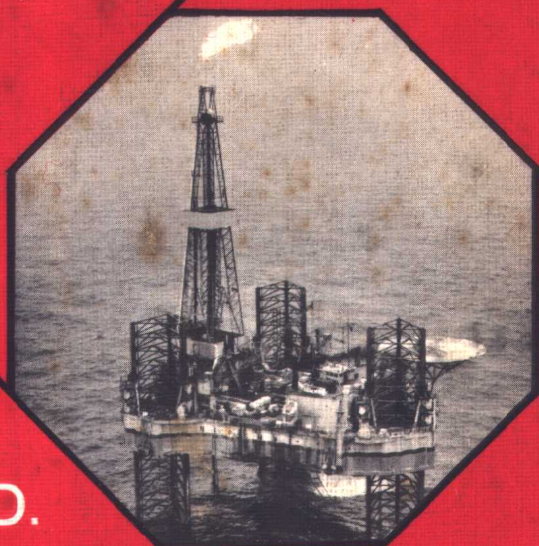
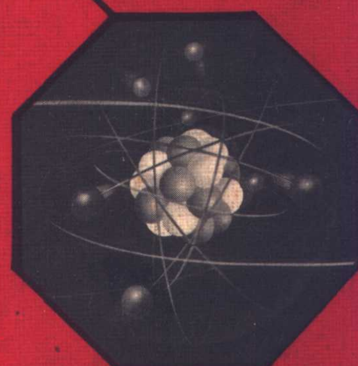
An INTRODUCTION to MODERN CHEMISTRY



D. Abbott, Ph.D.



HULTON

AN INTRODUCTION TO

Modern Chemistry

(S.I. Units and Systematic Nomenclature)

New and Revised THIRD EDITION

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Preface

In modern 'elementary courses' of chemistry, the teacher usually likes to make use of two textbooks with his or her class, one an *introductory book* which lays a firm foundation in the subject and the other a *book for the certificate year* which presents the facts concisely and in a more mature manner, pointing out resemblances and differences in behaviour of various substances.

It is with the first of these requirements in mind that I have compiled this book. It is intended as a beginners' book for both G.C.E. and C.S.E. courses, and other courses at equivalent levels, and for the chemistry part of any General Science course. I have tried to make the treatment fairly thorough so that there will be no difficulty in transferring to the certificate book when the time comes. The course is based on experiment wherever possible, in the spirit of the Nuffield Foundation recommendations; some of these experiments are intended for demonstration by the teacher and others for class practical work. A glance at the contents will show the teacher the type of work covered. This includes most of the standard 'bread and butter' chemistry needed at this level of study, together with topics such as the periodic table, chemical bonding (treated very simply), chromatography, ion-exchange, rates of reaction, atomic structure and very simple organic chemistry. These topics are now finding their way into our chemistry teaching at beginners' level. In titrimetry, I have omitted all mention of equivalent weights of compounds in an effort to encourage students to work in molarities. The book includes a large chapter on chemical calculations, dealing with most of the types met at an elementary level. In working through the book the student is posed leading questions all through the text in order to ensure that his or her mind is fully focused on the topic in hand. A short section of questions intended for use in 'homework' is included at the end of each chapter.

DAVID ABBOTT

Preface to Second Edition

In this edition

(*a*) système international units have been used throughout,

(*b*) compounds have been named, as far as possible, in a systematic manner (International Union of Pure and Applied Chemistry nomenclature).

These changes bring the book into line with requirements of modern examination syllabuses.

In addition, a new index has been included and corrections have been made to the text and diagrams where necessary.

DAVID ABBOTT

Acknowledgements

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Acknowledgement is also made to Macmillan & Co. Ltd., for permission to reproduce Logarithm and Antilogarithm tables from *Four Figure Mathematical Tables* by Frank Castle; and to the Controller of Her Majesty's Stationery Office for Logarithm tables from *Four Figure Tables and Constants for the Use of Students*.

The forgiveness is asked of anyone whose rights have been overlooked.

Contents

List of Plates

Plate 0.1 Early bronze mortars and pestles

1 Introduction

What is science? Chemistry is a *science*. Science is really a detailed study of the complex world that surrounds us, a study of the earth, the stars, the air, the waters, the plants, the animals, and so on. Science involves doing experiments and observing things.

Because *Natural Science*, as we call it, involves so many things, we like to divide it up into departments, some of the most important departments being as follows:

(*a*) *Chemistry* This is the study of materials and the changes they undergo. Chemistry involves a study of the properties of substances and of methods of making them—and, having made them, of decomposing them again to discover something about their structure.

(*b*) *Physics* This is a study of how energy interacts with matter. It can be divided into several categories such as properties of matter, sound, electricity, magnetism, light, heat, hydrostatics, mechanics, atomic energy.

(*c*) *Biology* This is the study of living things, and can be divided into botany—a study of plants, and zoology—a study of animal life.

(*d*) *Geology* This is a study of rocks and minerals.

(*e*) *Astronomy* This is a study of the stars and planets.

(*f*) *Meteorology* This is a study of the weather.

The division between various branches is, for the most part, a matter of convenience, and there is not generally a clear-cut boundary line between one branch of science and another. Chemistry and physics are interlocked—as physical science—and the fact that biochemistry and biophysics have come into their own in recent years means that there is now a bridge between chemistry and biology on the one hand and between biology and physics on the other.

A scientist approaches a particular problem by what we call *scientific method*. This necessitates the compiling of data by *careful* observation and measurement, and then producing a rule from the data obtained. The scientist then puts forward an *hypothesis* which will explain the observations and this is then tested by further experiments. From the experiments the hypothesis is accepted, rejected or modified, and is then

Plate 1.1 The chemist's research bench: the chemist is here seen doing an immunological assay of iodinated insulin

probably accepted as a *theory* unless experimental results indicate that it should be further modified. Should a theory be universally accepted it is stated as a *law*.

In later stages of chemistry you will learn about subjects like plastics, vitamins, explosives, dyestuffs, poisons, drugs and so on, but remember to learn your basic chemistry well and you will be travelling along the road to success in this intricate subject.

Questions

1 Find out and list the names of four scientific subjects not mentioned in this chapter. Write, in each case, a sentence to explain what each subject teaches us.
2 Suggest some good reasons for learning chemistry.
3 In which branch of science would you expect to study:
(*a*) the motion of an artificial satellite in orbit around the earth
(*b*) the distance of the sun from the earth
(*c*) circulation of the blood
(*d*) the structure of metals
(*e*) types of trees
(*f*) the human skeleton
(*g*) substances present in water, i.e. dissolved in it
(*h*) design of spaceships
(*i*) types of clouds
(*j*) design of television sets?
4 Make a list of as many metals as you can and give one use of each.

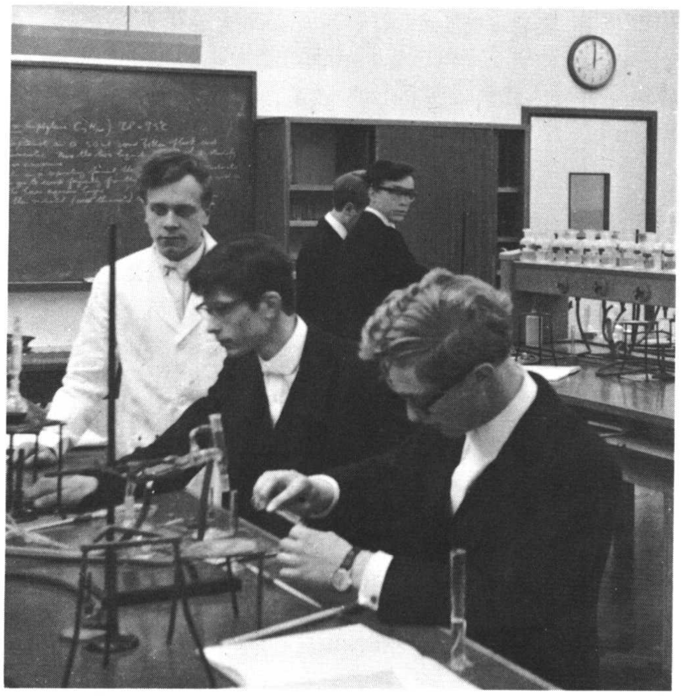


Plate 1.2 Experimental work is a vital part of chemistry

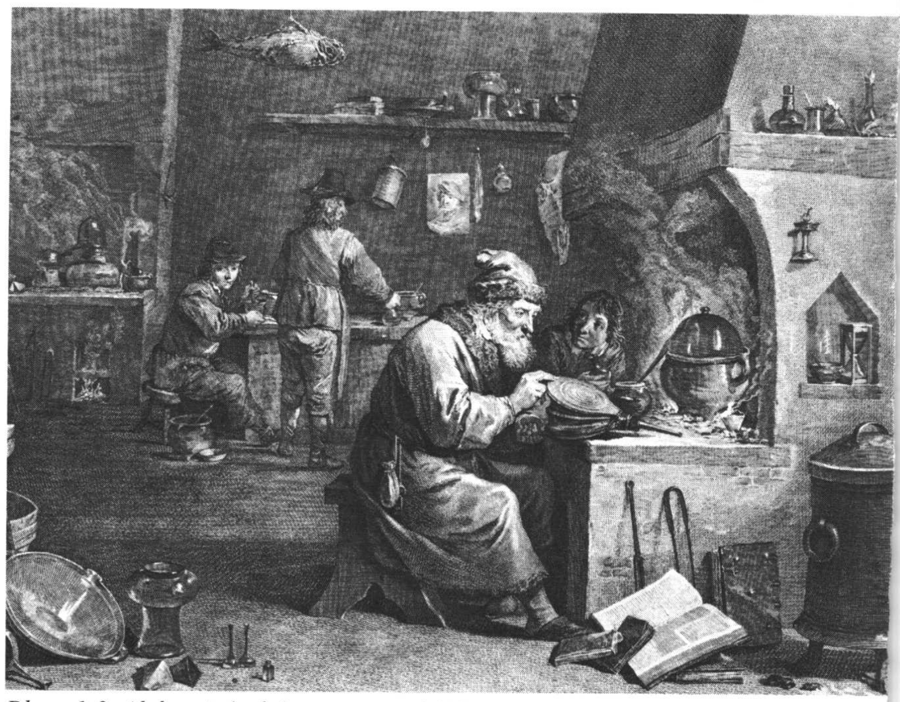


Plate 1.3 Alchemist's laboratory c. 1650

2 Tools of the trade

You will learn most about chemical apparatus from experiments done by yourself in the laboratory.

Test tubes There are many sorts of test tube, the ordinary soft-glass type being about 150 mm long and 15 mm in diameter. Boiling tubes are about 180 mm by 25 mm, while hard-glass ignition tubes are about 75 mm by 10 mm.

When heating a tube containing liquid, always point the mouth away from anyone's face in case a chemical should be ejected from the tube.

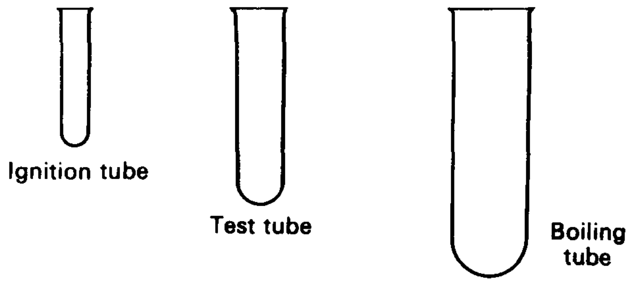


Fig. 2.1 Relative sizes of tubes

Flasks and beakers are used for experiments on a somewhat larger scale. They too, can be obtained in various shapes and sizes. Do not heat any part of the glass by application of a flame if the glass is not in contact with liquid.

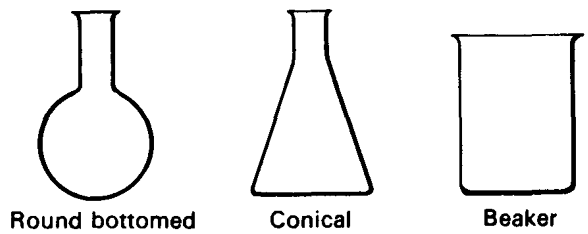


Fig. 2.2 Flasks and beakers

Porcelain ware includes evaporating dishes (basins) and crucibles. They can be heated very strongly without cracking or softening. Crucibles can be heated by placing them on a pipe-clay triangle, resting on a tripod. Always use crucible tongs when lifting hot pieces of apparatus.

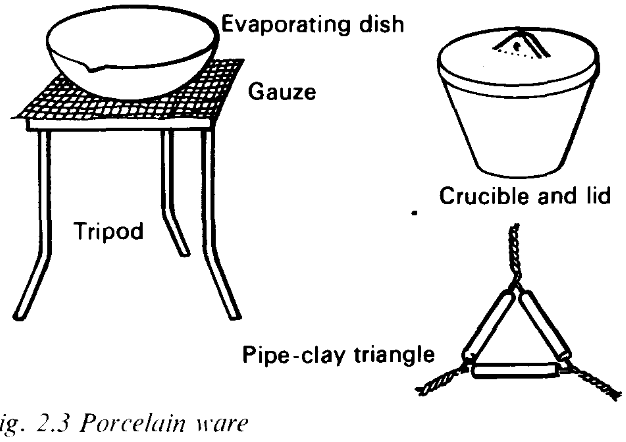


Fig. 2.3 Porcelain ware

Clamps and stands are used for supporting chemical apparatus.

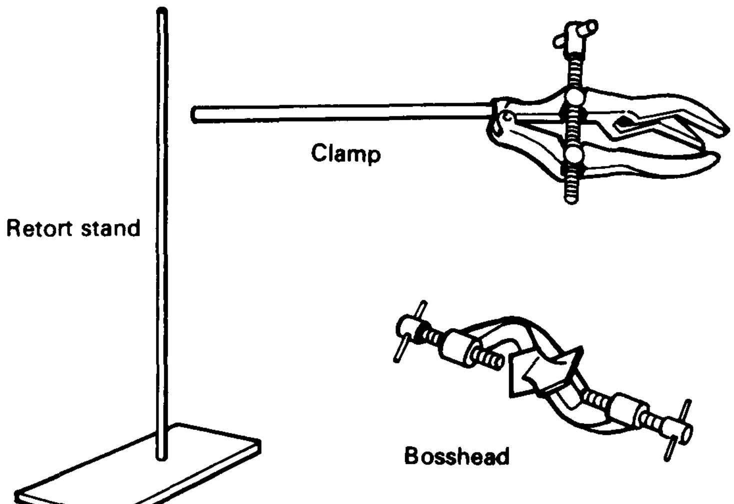


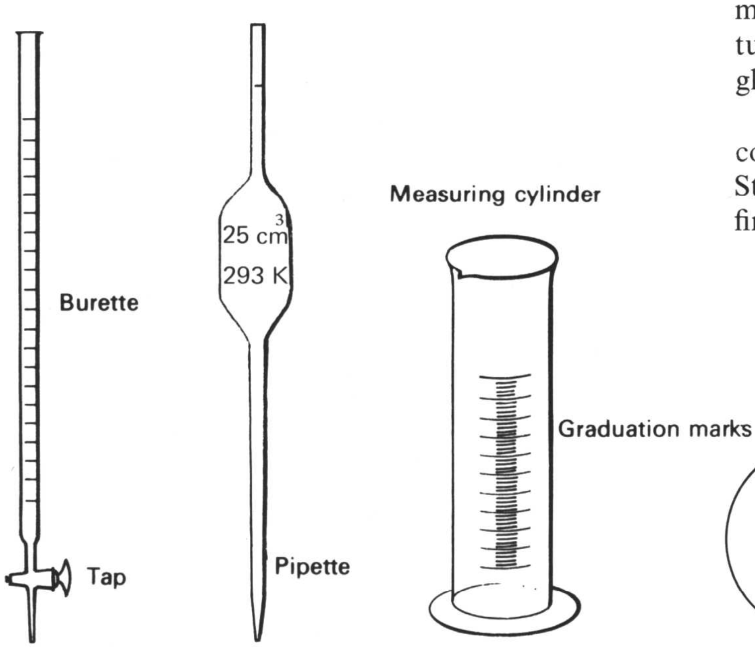
Fig. 2.4 Clamps and stands

N.B. Always make sure that your apparatus is firmly held.

Glass tubing is used for connecting various pieces of apparatus together. To break such tubing you must first make a scratch on the tube with a file. The tubing can then be broken cleanly with the fingers. Remember to round off the broken ends in the bunsen flame so that you do not cut yourself.

Connect up pieces of glass tubing via rubber tubing, which makes flexible joints. It is useful to remember that, if rubber tubing will not fit immediately on to the glass tubing, the glass should be wetted first.

When passing rubber tubing through rubber bungs or corks, the cork should be bored first using a special borer. Start boring the cork (or rubber bung) at the **thinner** end first. Why?



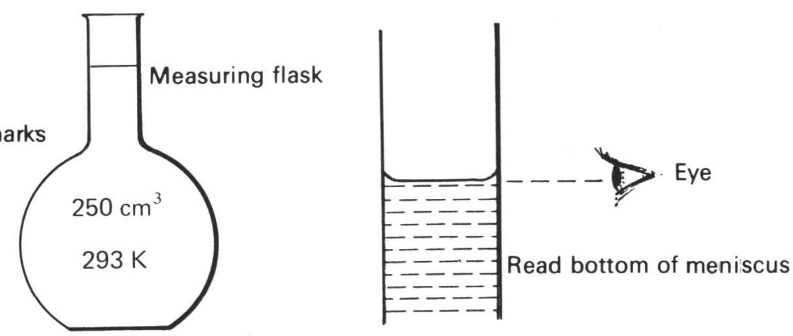


Fig. 2.5 Apparatus for measuring volumes

Apparatus for measuring out volumes of liquid This category includes measuring cylinders, measuring flasks, burettes and pipettes.

Measuring vessels should never be heated, nor should hot liquids be added to them. Can you give a reason why this is so?

The bunsen burner This utilises the fact that a mixture of fuel gas and air, when burnt, burns with a hotter flame than that produced with fuel gas alone.

Look at the diagram of the bunsen burner, and observe the names of the various parts. In most cases the chimney has two holes cut in it, opposite each other, and at the level of the pin-point jet. Over the bottom of the chimney fits the regulating collar, which is a cylindrical piece of metal having two circular holes in it. By rotating the collar the air-holes in the chimney can be either open or closed. With the air-holes closed, gas enters the side-tube and passes via the pin-point jet up the chimney. Pure gas issues from the top of the chimney and when this is ignited it gives a yellow *luminous flame*. With the air-holes open, however, the rush of gas through the pin-point jet and past the air-holes causes air to be sucked in (you will deal with the reason for this in your study of physics) and so it is a mixture of gas and air that issues from the top of the chimney. When ignited this gives a steady non-luminous flame.

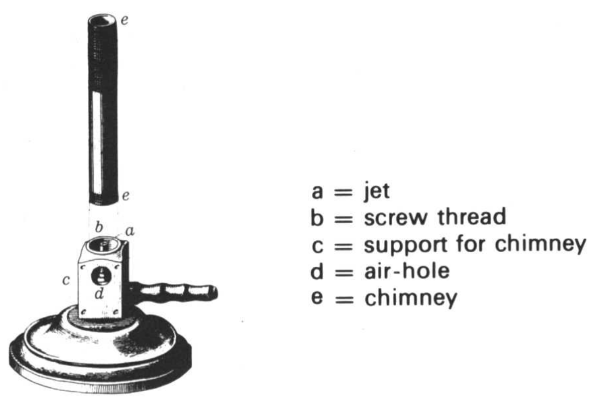
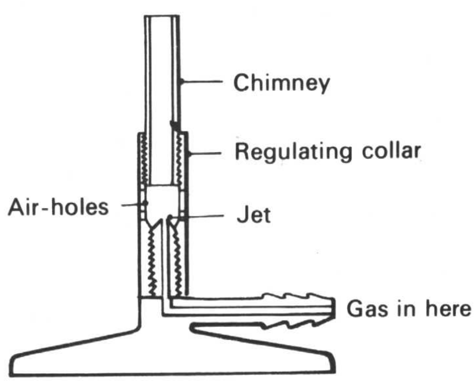


Fig. 2.6 (a) Bunsen burner (original type)



(b) Diagrammatic representation of a bunsen burner

The two distinct types of bunsen flame can be summarised as follows:

Table 2.1

Air-holes closed	*Air-holes open*
1 Pure gas burns in air and flame is luminous, probably caused by the presence of small glowing carbon particles from substances called hydrocarbons in the gas.	**1** Gas/air mixture burns in air and flame is non-luminous.
2 Wavy.	**2** Steadier.
3 Not very hot.	**3** Hotter.
4 Deposits soot—this is again caused by fine carbon particles—on, say, a piece of porcelain held in the flame.	**4** Deposits no soot; the combustion (burning) is more complete and there are no carbon particles.
5 Quiet.	**5** Noisy.
6 No inner cone present.	**6** Has an inner cone.

When the air-holes are open the flame has two distinct cones. The inner cone (pale blue) is cold, as can be seen from the following observations.
1. A wooden splint is not charred when placed there.
2. A live match can be supported there without immediately igniting.

If the gas supply is turned down slowly, having the air-holes of the burner *open*, you will see that the height of the flame gets less and less until eventually, with a slight explosion, the flame shoots down the chimney to burn at the jet. We call this *striking back*; if your burner strikes back, always turn off the gas, allow the chimney to cool, and then relight the gas.

Striking back is caused by the fact that a mixture of a lot of air with only a little gas is explosive. You can show this by the exploding tin experiment. A tin can has a small hole made in the lid and a rather larger one in the base. The top hole is closed while the can is filled with gas through the bottom hole. When full (how do you know that this is so?), the gas supply is turned off and the gas ignited as it leaves the top hole. It burns with a luminous flame to begin with and then, as gas gets used up, the flame gets smaller and smaller and air is drawn in through the bottom hole making the flame more and more non-luminous. Eventually an explosive mixture is formed and the lid is blown off.

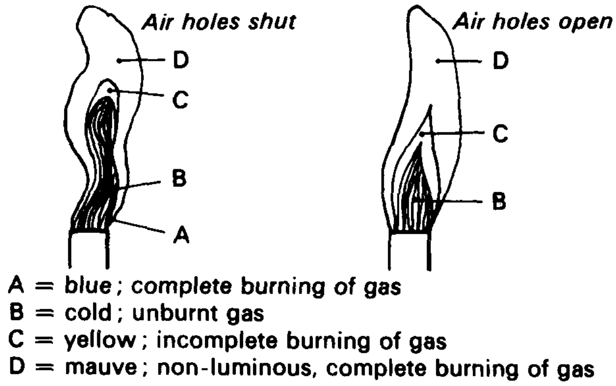


Fig. 2.7 Flames

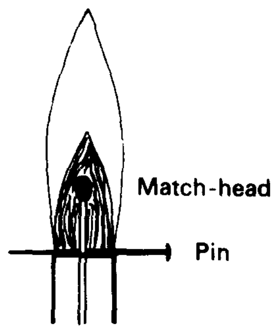


Fig. 2.8 The match experiment

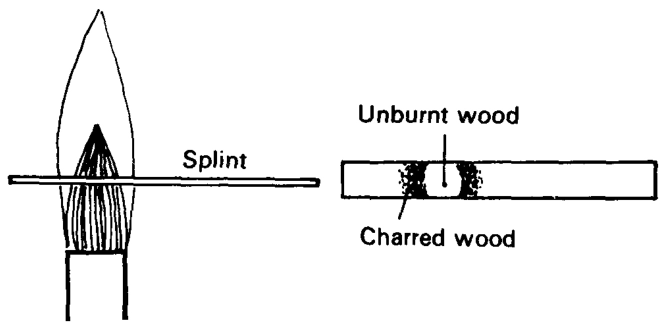


Fig. 2.9 The wooden splint experiment

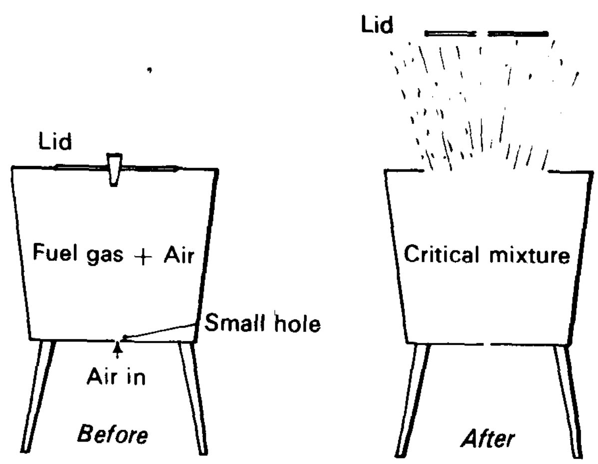


Fig. 2.10 Tin for exploding tin experiment

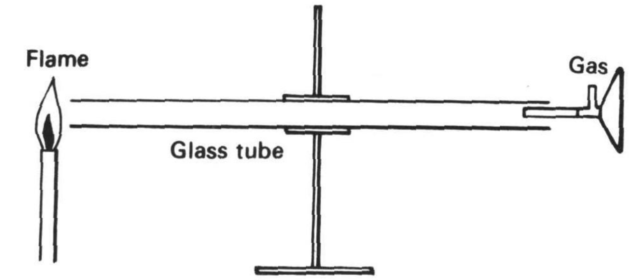


Fig. 2.11 'Big strike-back'

Another experiment to illustrate the explosive nature of a fuel gas/air mixture is the 'big strike back'. The apparatus consists of a long glass tube open at both ends. A bunsen burner is clamped at each end, as shown, and one of them is arranged to produce a non-luminous flame. The gas supply at the other end is turned on. Eventually, an explosive mixture will be present in the tube and a flame will strike back from the lighted burner to the other one with a vivid flash.

Returning to the striking back of a normal bunsen burner, the chimney becomes filled with an explosive mixture and the flame shoots down the chimney to the jet with a small explosion. At the jet there is pure fuel gas and so the flame burns there without any explosion. Alternatively you can imagine that normally the gas/air mixture is passing up the chimney faster than the flame can burn down to the jet. In 'striking back', however, the flame burns down the chimney more rapidly than the gas/air mixture passes up to the top.

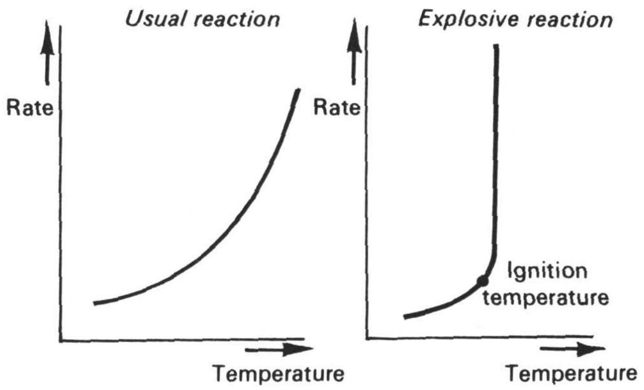


Fig. 2.12 Influence of temperature on rates of reaction

Remember that **explosion is simply a very rapid burning.**

A substance will not inflame until a definite temperature is reached, this being called the *ignition temperature* (igniting means lighting). Thus a burning match can be used to ignite a bunsen burner as the match is above the ignition temperature for fuel gas burning in air. A piece of steel at dull red heat, however, is not at a sufficiently high temperature to light a bunsen burner.

We shall see later on that the rate of most chemical processes increases as the temperature rises. For explosive reactions, the rate of reaction above the ignition temperature is uncontrollably rapid.

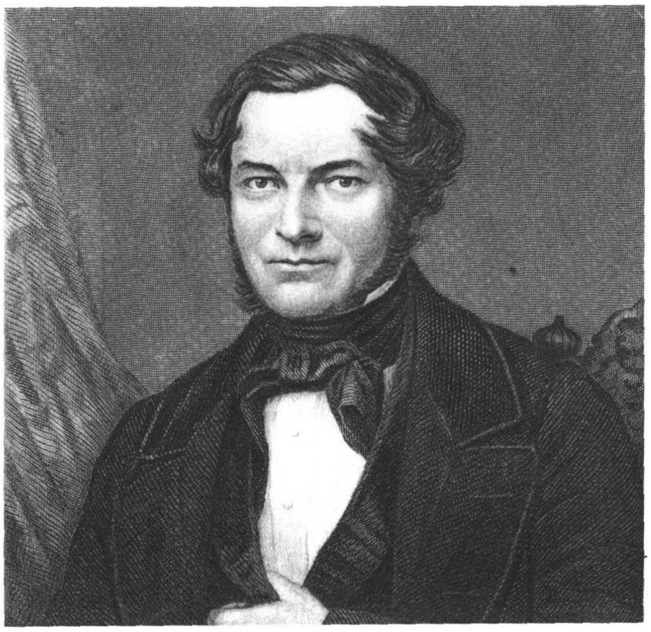


Plate 2.1 Portrait of Robert Wilhelm Bunsen (from an engraving)

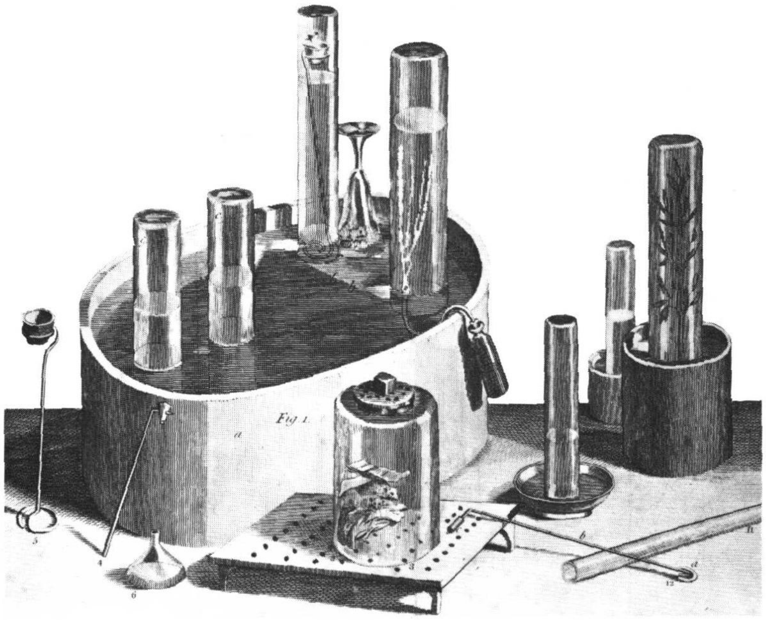


Plate 2.2 Priestley's apparatus for experiments on gases c. 1775 (engraving showing pneumatic trough)

Plate 2.3 Modern scales

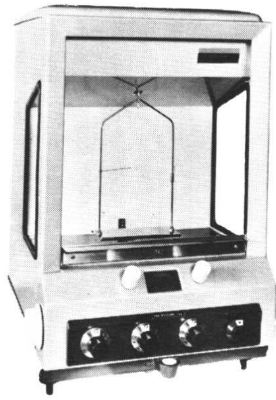


Plate 2.4 A modern precision balance

The balance No chemistry laboratory is complete without a chemical balance, for without it the chemist could not carry out experiments involving weighing things. There are, today, so many types of balance available that it would be pointless to describe a typical one. A balance is simply an accurate pair of scales. You may even find that, in some of your experiments, you use a pair of modern scales, such as those made by Messrs. Oertling Ltd.

Make a drawing of one of the balances in your laboratory, showing all the features, and describe in detail how it operates. Make also a drawing of the box of weights to show the range of weights provided. Explain the use of the 'rider'. Make a list of the precautions you must observe when using your balance. One of your first exercises in practical chemistry should be to weigh a dry solid in a weighing bottle, tip some of the solid out and reweigh, and so on until you have mastered the weighing technique.

Plate 2.5 Reproduction of assayer's balance (after Ercker 1574)

Questions and things to do

1. Draw a cross-sectional diagram of one of the following: (*a*) a fountain pen, (*b*) a pear, (*c*) a bottle. Label your diagram, giving what you consider to be a good name to each part drawn.
2. List, in alphabetical order, all the pieces of apparatus to be found in your laboratory. Attempt to draw each one.
3. What are the advantages and disadvantages of using (*a*) glass, (*b*) porcelain, (*c*) aluminium, (*d*) steel, in making chemical apparatus?
4. Explain the terms (*a*) explosion, (*b*) ignition temperature, (*c*) striking back.
5. Should a bunsen burner be (*a*) oiled, (*b*) painted? Would the burner function if the pin-point jet was too large?
6. Describe the construction and action of a bunsen burner. Compare the types of flame that can be produced with it.
7. What, as far as you know, is the effect of heat on (*a*) a lump of iron, (*b*) wood, (*c*) ice, (*d*) a mixture of a little fuel gas and a lot of air?

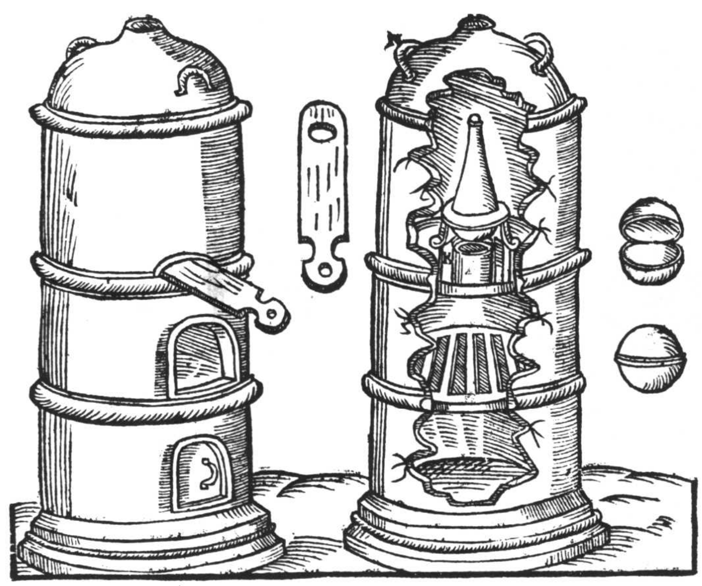


Plate 2.6 Alchemical furnace 'Athanor' from Libarius Alchymia, 1606

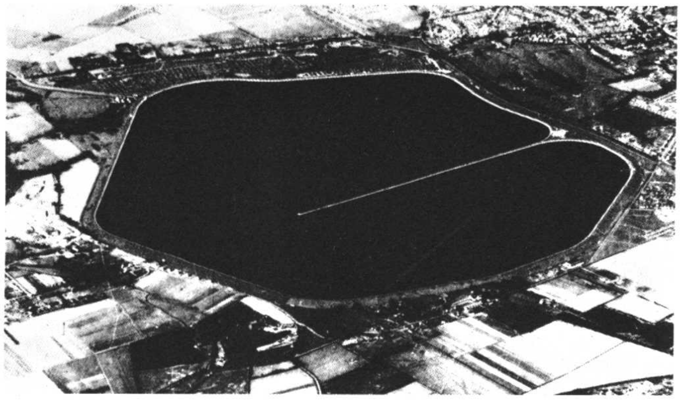


Plate 3.1 Reservoir of (liquid) water

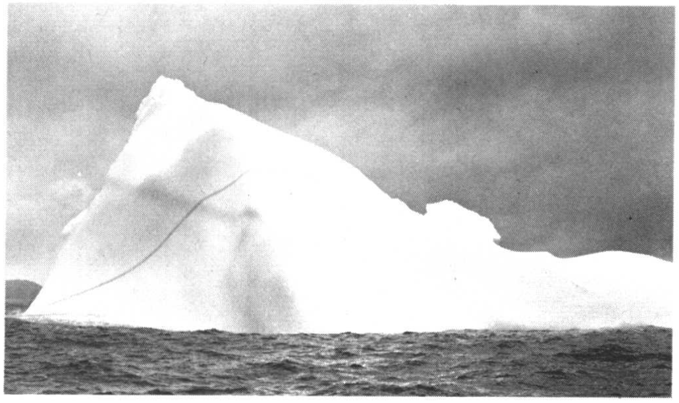


Plate 3.2 Iceberg (solid water)

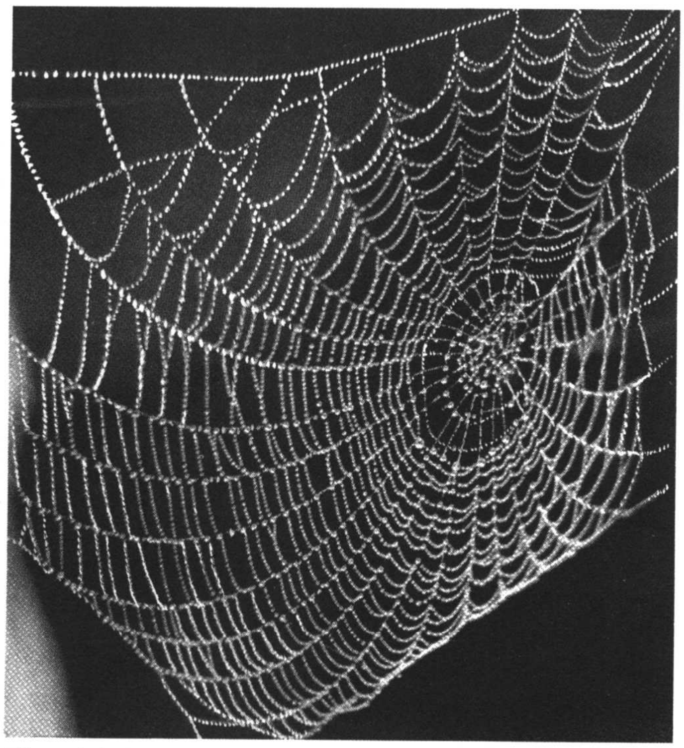


Plate 3.3 Dew on a spider's web (condensation of water vapour from the atmosphere)

3 States of matter: How matter is divided

You all know a lot about water. It is normally encountered as a colourless *liquid* that you drink every day, but we also know it as a *solid*—ice (which you see in winter and in very cold regions) and water *vapour*—this is present in the air and you will probably have seen it separating from this source as dew or hoar frost?

Matter is defined as anything that can be weighed. It exists in three *states*, solid, liquid, and gas or vapour. The term 'vapour' is used when we want to describe the gaseous form of something which is normally found as a liquid or solid, while the term gas is used for something we normally encounter in the gaseous form. Thus, you will appreciate that oxygen is described as a gas while the water in the atmosphere is called water vapour.

Solids have definite shapes and volumes. Liquids have definite volumes but always take up the shape of the containing vessel. Gases expand until they fill the container in which they are placed.

Now how can we change the state of a substance? For some substances a change of temperature is all that is needed. You will recall that, if you heat up water in a kettle, you will eventually see steam issuing from the spout—steam consists of tiny water droplets that have condensed (from water vapour) on the cold air around the spout. For other substances the pressure as well as the temperature should be changed. Oxygen and nitrogen can be liquefied by first cooling the gas to a very low temperature and then applying a high pressure. Carbon dioxide is bought as the highly compressed gas in a cylinder. Examine what happens when the nozzle of such a cylinder is opened and the gas under pressure is allowed to escape, falling on a black cloth. Notice also that the nozzle gets cold—you will find out why this is so later on.

Can you list some substances which cannot be made to exist in all three states of matter? One example is sugar. If heated it melts at 450K to form liquid sugar but at higher temperatures it decomposes to give sugar charcoal and vapours which escape.

Provided there is no decomposition, a pure solid changes into a liquid, when heated, at a definite temperature called the *melting point*. The liquid solidifies again at the same temperature when cooled down, and we then refer to the temperature as the *freezing point*. For water, the melting point of ice and the freezing point of liquid water are both 273K at normal pressures. Again, provided no decomposition