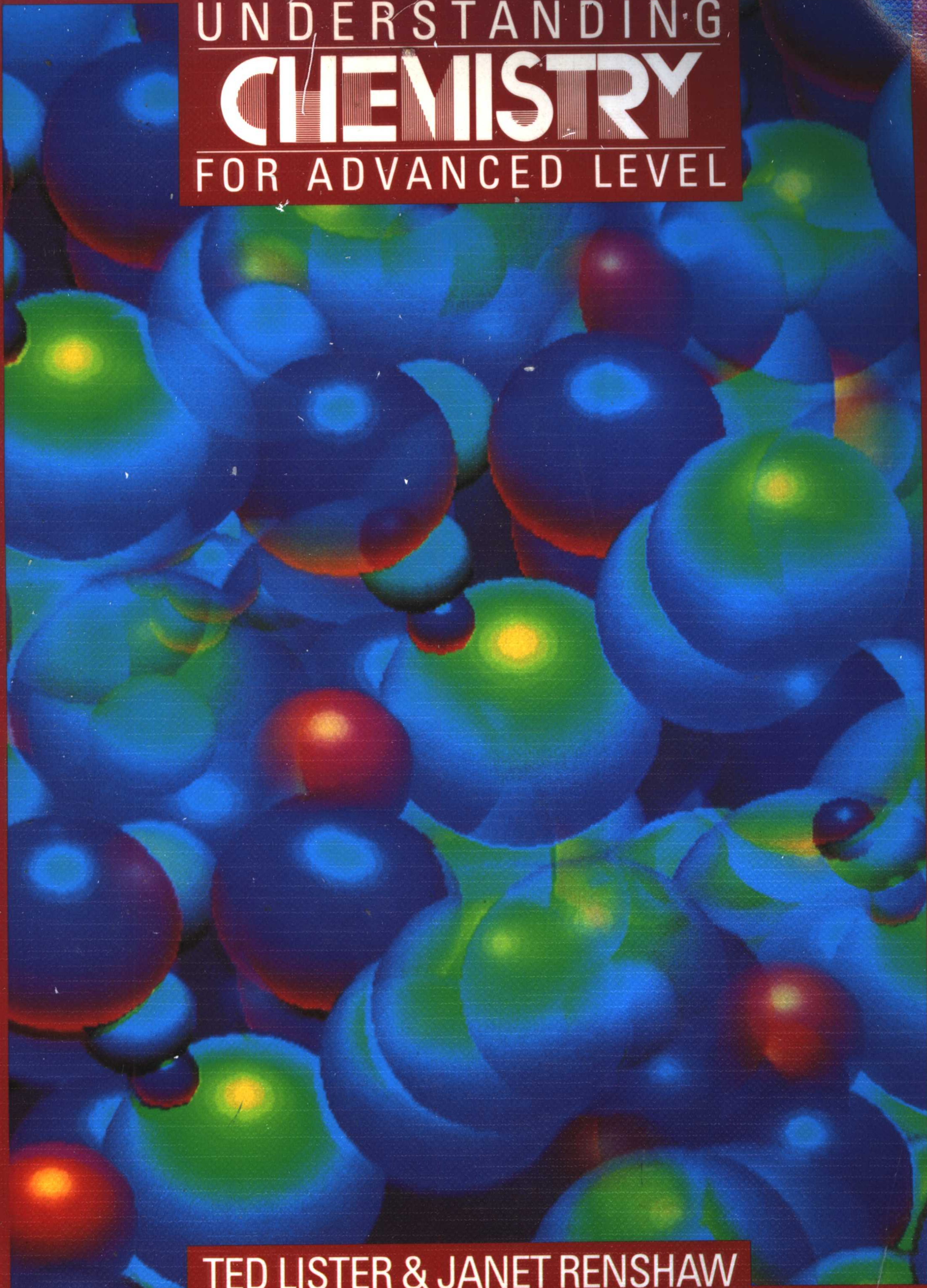
UNDERSTANDING CHEMISTRY FOR ADVANCED LEVEL



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Understanding Chemistry

for Advanced Level

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For Les and Roy

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1 Introduction

1.1 The importance of chemistry

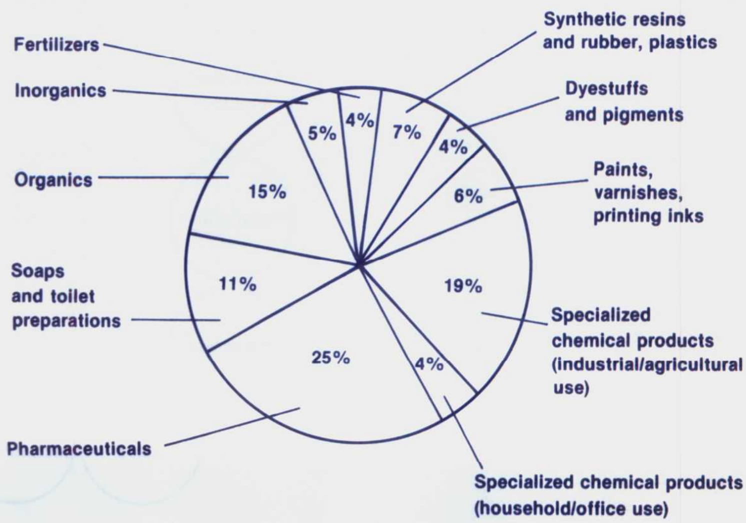
Chemistry is the branch of science which is concerned with materials of every description. It is often called the central science as it overlaps with both biology and physics. On the one hand, chemists unravel the chemical reactions which are responsible for life, and on the other, they investigate new materials with exciting and potentially useful properties such as superconductors and electrically conducting plastics. Chemists are interested in the properties of substances—such as whether they are gas, liquid or solid, how hard, strong or brittle they are, whether they conduct electricity, and so on. They are also concerned with how to change one substance into another. Indeed chemistry evolved from the work of the early alchemists who tried to turn so-called base metals into gold. Although they failed they learned a lot of chemistry on the way.

Products of crude oil

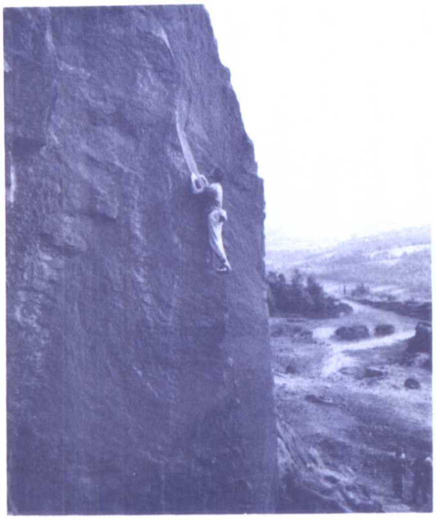
Modern chemists are concerned with equally dramatic changes, turning, for example, crude oil into a whole range of useful and diverse products, such as nylon, aspirins, paint, adhesives and petrol. Other spectacular transformations include sand into glass and silicon chips, and nitrogen from the air into fertilizers and explosives. In fact we use very few materials which have not been changed in some way by a chemist. Even wood is likely to be treated by fungicides to prevent rot, and then painted or varnished.

All this means that chemistry is big business. The UK chemical business is the nation's fourth largest industry and it is the fifth largest chemical industry in the western world. It is our largest export earner with overseas sales of almost £10 billion in 1986. Two hundred major chemical companies employ 6 per cent of the UK work force, producing many diverse products, **Figure 1.1.**

Figure 1.1 Products of the UK chemical industry



Disused quarries need not be just an eyesore



Chemistry has also created some serious problems:

• Quarrying for limestone and other raw materials for industry has produced what most people consider to be blots on the landscape.

• Accidents in industry, such as Flixborough in 1974 where a cyclohexane plant blew up, Seveso in 1976 where dioxin escaped, and Bhopal in 1984 where a cloud of methyl isocyanate poisoned the surroundings, have hit the headlines.

• Pollution problems such as acid rain, depletion of the ozone layer and the greenhouse effect are issues which must be tackled.

• Many people are worried about the long-term effects on health of food additives.

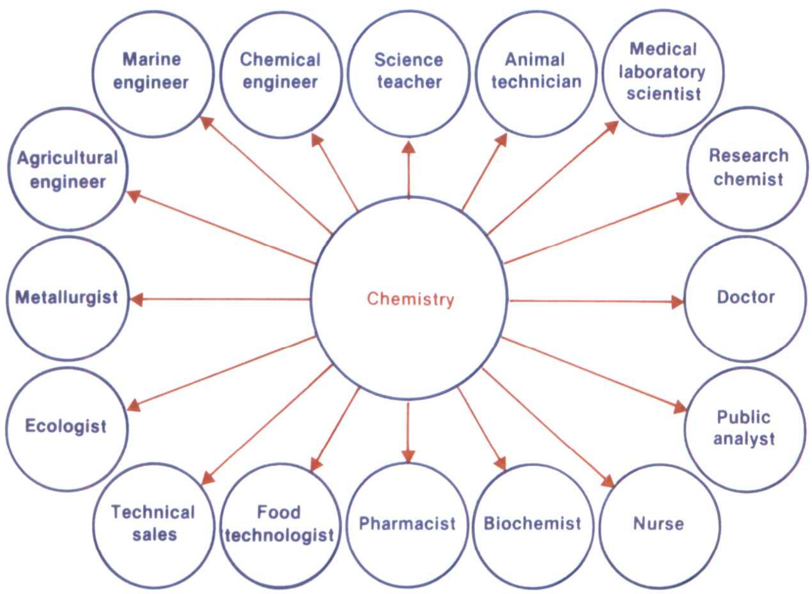
Chemical research may be 'targetted', where it is dedicated to making new substances which are more effective, cheaper and with fewer disadvantages than those used at present, or 'fundamental', where it is designed to further our understanding of how and why things are as they are. One of many current growth areas is biotechnology which involves tailoring enzymes, the super-efficient biological catalysts, to bring about useful reactions faster and with less drastic conditions. Recently it has become possible to synthesize 'factor 8', the clotting component of blood, by biotechnological means, instead of extracting it from blood. This eliminates the risk of haemophiliacs contracting AIDS from contaminated blood. What is undeniable is that chemistry affects the lives of every one of us.

1.2 Careers, higher and further education in chemistry

What use is an A-level or A/S-level qualification in chemistry? Broadly speaking, there are three possibilities.

You may go into a career in the field of chemistry itself where your A level will be directly relevant. You may go in a direction where chemistry is not your main interest but acts as a useful or even essential back-up. Medicine would be a good example. Thirdly, your future career may lie in a direction where your chemistry is not relevant but the fact that you have successfully studied the subject shows your intelligence, application and ability to learn. **Figure 1.2** shows just some of the many career options in chemistry itself. Some of these may be entered directly after leaving

Figure 1.2 Some career directions which are possible with a qualification in chemistry



school with A levels, probably with on-the-job training or day release to gain further qualifications. Others may best be entered after further study, such as a degree or further education in chemistry or a related subject.

Figure 1.3 shows some of the further/higher education paths. Careers in which chemistry acts as a supporting subject offer an even wider choice—literally from agriculture to zoology. Again there is a choice of entry into employment either direct from school or after further or higher education. **Table 1.1** (below) shows a range of courses which could follow A- or AS-level chemistry. Careers following higher education offer the widest choice of all. Depending on your other A-level subjects very few career choices are barred. In our experience, students with combinations of chemistry and art and chemistry and foreign languages have been successful.

Figure 1.3 Further qualifications in chemistry

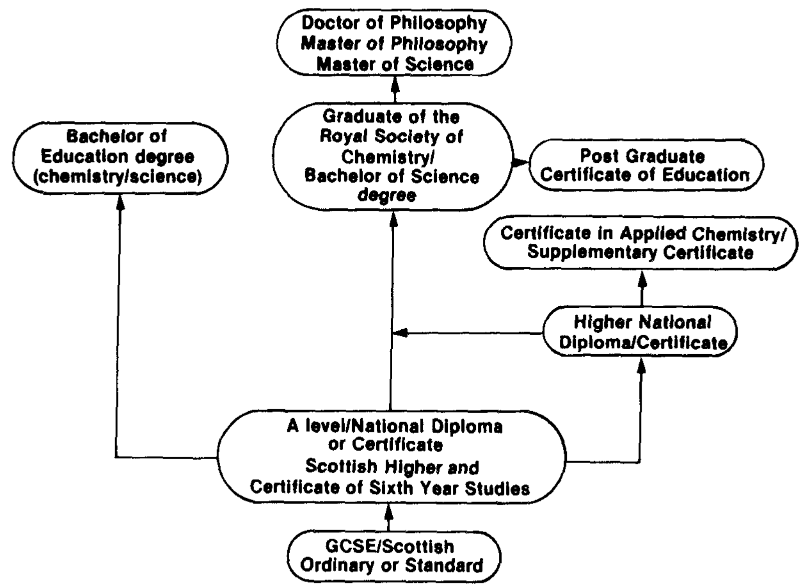


Table 1.1 Courses which could follow advanced study in chemistry

- Agriculture
- Agricultural sciences
- Agricultural bacteriology
- Agricultural biochemistry
- Agricultural botany
- Agricultural chemistry
- Agricultural zoology
- Analytical chemistry
- Animal biology
- Animal nutrition
- Animal physiology
- Animal sciences
- Applied biochemistry
- Applied biology
- Applied electrochemistry
- Bacteriology
- Biochemical engineering
- Biochemistry
- Biological chemistry
- Biology
- Biological sciences
- Biomedical electronics
- Biomedical engineering
- Botany
- Brewing
- Cell biology
- Ceramics
- Chemical education
- Chemical engineering
- Chemical physics
- Chemical process
- Chemical technology
- Chemistry
- Colour chemistry
- Colour technology
- Crystallography
- Dentistry
- Development physiology
- Dietetics
- Dyeing and dyestuffs technology
- Earth sciences
- Environmental sciences
- Exploration science
- Farm animals (physiology and biochemistry)
- Fibre science
- Food science and technology
- Forestry
- Fuel science
- Genetics
- Geochemistry
- Geology
- Glass technology
- Human biology
- Human ecology
- Human sciences
- Inorganic chemistry
- Materials science
- Material technology
- Marine biology
- Marine botany
- Marine zoology
- Medical biochemistry
- Medicine
- Metallurgy
- Microbiology
- Mineral exploitation
- Mineral sciences and technology
- Minerology
- Molecular sciences
- Natural sciences
- Neurobiology
- Nutrition
- Oil technology
- Paper science
- Pathology
- Petrology
- Pharmaceutical chemistry
- Pharmacology
- Pharmacy
- Physical chemistry
- Physical sciences
- Physiology
- Plant sciences
- Polymer chemistry
- Polymer and colour science
- Polymer engineering
- Polymer sciences and technology
- Science (general)
- Science (history and philosophy)
- Soil science
- Textile technology
- Theoretical chemistry
- Veterinary science
- Virology
- Wood science
- Zoology

1.3 Study skills for A- and A/S-level chemistry and how to use this book

This book has been written as an aid to studying, understanding and passing A-level and A/S-level chemistry. It is not a 'teach yourself' book and no book can be a substitute for the work you will do in the class with your teacher. In particular, no book could be a substitute for practical work, for chemistry is essentially a practical subject.

Many A-level students make the mistake of taking things easy during the lower sixth. This is unwise as the pace of sixth form work is such that it is very difficult to catch up. A good habit to cultivate would be to read through the notes you take *after each lesson* and relate them to the relevant section of this book. Then check that you have understood the work by trying the relevant questions at the end of the chapter. If you get stuck, read the chapter again. The summaries at the end of each chapter will also be useful—you can use these to do some quick revision, and again go back to the chapter content if you need help.

Understanding Chemistry for Advanced Level has been written after a thorough analysis of all the A and A/S syllabuses. While there is a common core of content for all the syllabuses, each one differs slightly so that it would be a good idea to find out which syllabus you are following and get a copy of it (or better still ask your teacher) to check which topics you should be studying. This will apply even more to A/S levels whose content is around half that of an A level.

Most chapters contain boxes featuring extension material, reference material or applications. It should be possible to follow the chapter without reading the boxed material and you may wish to do so at a first reading. **Extension boxes** (marked E) contain material which is harder than that in the main chapter and may go beyond the strict bounds of A level. For example, there might be the derivation of an equation which you would be happy to simply accept. **Applications boxes** (marked A) might best be read when you have grasped the main gist of the chapter or section, but you should not ignore them. The social, economic, environmental and technological applications of chemistry are increasing in importance in A- and A/S-level syllabuses and exams. **Reference boxes** (marked R) contain data, equations and definitions which may be needed throughout the chapter.

Chapters 2–7 we have called 'foundations', and they are just that. They are an attempt to bridge the gap between GCSE (either chemistry or double award science) and A or A/S level. This is basic material that you should thoroughly understand before starting your A-level course. It can also be used to revise the basics at any time during your course.

The rest of the book is divided into parts on physical chemistry, inorganic chemistry and organic chemistry. We have arranged them in what we believe is a logical sequence. There is no reason to tackle them in this order although the first chapter of both the inorganic and the organic parts sets the scene for the rest of the part.

1.4 Examinations in chemistry

If you have understood and revised your work you should have little to fear from the final examination. However we shall give you a few points to help you get the maximum marks from what you know.

One very important point is good preparation. Make sure you know well in advance the dates of your chemistry exams. This will help you plan your revision. Most A- and A/S-level exams have more than one paper—so you need to know when they are, how long they last and the format of the paper, i.e. the number, type and choice of questions. You should be able to get this information from your teacher but it will also be in the up-to-date syllabus of your course.

You should make a point of studying past papers to see the format as well as to practise questions. Once you know the format of the papers you can devise a plan as to how much time to spend on different sections of the paper. Where there is a choice of questions, allow time to read all the alternatives carefully. It is only too easy to make a hasty choice which you may regret later. For example, question 7 in Chapter 14 could easily be taken to be about organic chemistry, while it is actually about reaction rates. Even if you are pressed for time, *always* attempt the correct number of questions. Exam questions are almost always written so that the first few marks are easy, the next few a little harder and so on, until the last few marks will be gained by almost no one. So it makes sense to try and pick up the easy marks on all the questions rather than to try and complete answers to just a few. Do not attempt more than the maximum number of questions—the examiner will not be allowed to pick the best; he or she will usually have instructions to mark your answers in the order they are written, and ignore questions after the maximum asked for.

It should go without saying that you should make sure that you arrive at the exam in good time and fully equipped with pen, pencil, calculator, etc. including spares. Finally, some chemistry exams allow you to use data books, data sheets and even specified text books (*note*: only in one paper in the Nuffield exams from 1990). Make sure you know what, if anything, you are allowed to use and make sure you are familiar with the sheet, book or books.

1.4.1 Types of exam questions

There are four main types of questions used in A- and A/S-level chemistry exams. They are illustrated in the examples below.

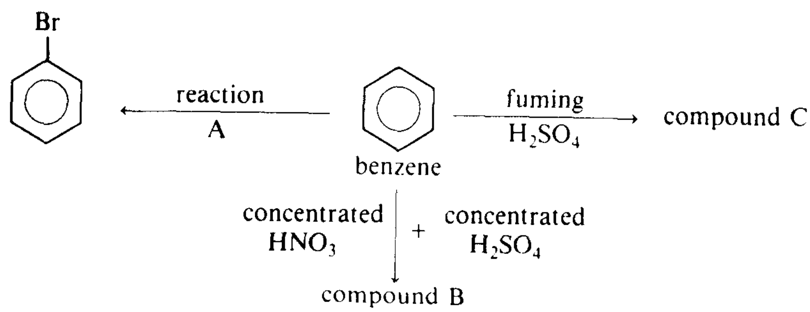
Example 1

Which of the following analytical techniques makes use of vibration within molecules?

A) Infra-red absorption spectroscopy
B) Measurement of dipole moments
C) Mass spectroscopy
D) Nuclear magnetic resonance
E) X-ray diffraction (Nuffield 1988)

Multiple-choice questions such as Example 1 are normally answered on a machine-read answer sheet. Try to see a copy of the type you will actually be using so that you are familiar with it. The usual time allowed is something like one hour for forty questions. Usually you have to select the best response from five. There are different types of multiple-choice questions such as ones where you have to select which *combination* of statements is correct. Again, find out what types you should expect.

Example 2



A) State the reagent and conditions required for reaction A. (2 marks)
B) Give the name and structural formula for compound B. (2 marks)
C) Give the name and structural formula for compound C. (2 marks)
(Nuffield 1983)

Short-answer questions such as Example 2 are normally answered on the paper itself. The amount of space allowed for the answer is a guide to how much you are expected to write. The marks available for each part of the question are usually given. You are guided through most calculations.

Example 3

An organic liquid, A, when refluxed with 100% phosphoric acid, produced a low boiling liquid, B, containing carbon and hydrogen only. When the organic liquid, A, was oxidized with nitric acid a solid, C, was formed which was a dibasic acid.

0.240 g of A gave 73.5 cm^3 of vapour at 100 °C and 1 atmosphere pressure.

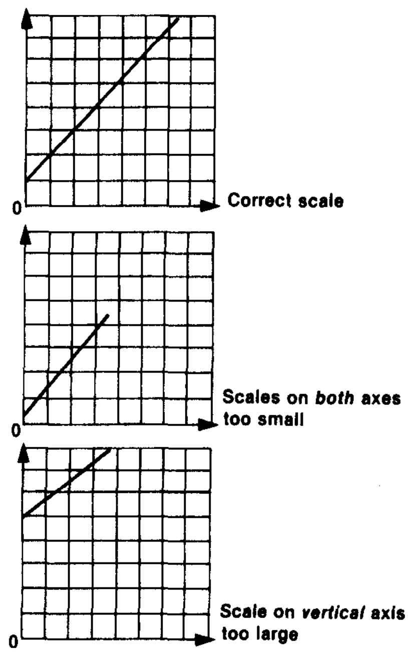
0.372 g of B on combustion produced 1.20 g of carbon dioxide and 0.410 g of water.

0.150 g of C when titrated with 0.1 M sodium hydroxide solution gave an end point at 20.5 cm^3.

Use the data and information provided to calculate the empirical and molecular formulae of A, B, and C. Draw diagrams of their molecular structures and write equations for the formation of B and C from A.

(Nuffield 1985)

Figure 1.4 Scaling graphs



Example 4

Describe the main reactions of alcohols, quoting formulae and equations wherever appropriate.

The behaviour of the hydroxyl group in phenol is often significantly different from its behaviour in ethanol. Give examples of such differences in behaviour and explain them. (Nuffield 1985)

Free-response questions such as Examples 3 and 4 are longer. They may require an extended calculation, an extended essay-type answer or something in between. Either way, once you have chosen the question, some planning of the answer is required, particularly for the essay-type questions. Note that although the term 'essay-type' is often used, the examiners do not require a structured essay unless they specifically ask for it. An answer set out using headings will almost always be preferable and easier to do in a short time. Whenever you refer to a chemical reaction, write a chemical equation if you can. Ideally it should be a balanced symbol equation including state symbols. Long answers may include tables of data, graphs and diagrams. Make sure that tables of data have headings with units (if appropriate) and that graphs have titles, labels (with units) on axes, an appropriate scale (see examples in **Figure 1.4**) and that points are clearly plotted and a straight line or smooth curve (as appropriate) is drawn.

Numerical answers to problems should always have units.

1.5 Practical skills and techniques

Chemistry is essentially a practical subject, so anyone qualified as a chemist must be able to show that they can work safely in a laboratory and that they have mastered some practical skills. Thus all A-level examinations assess practical skills in some way—either by a practical exam or by continuous assessment during the course, carried out by your teacher.

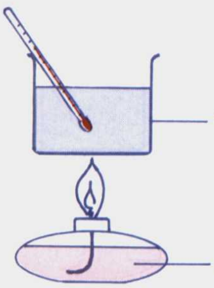
If you are to be assessed by an exam, find out the details of the exam's format, what you will be expected to do and what books or notes you will be allowed. Most practical exams allow you to take in books or notes as it is your practical skills that are being tested.

If your practical work is to be assessed by your teacher, he or she will explain the system to you.

Safety and careful, methodical working are the keys to good practical work. Always wear eye protection when doing practical work, and ideally a lab coat as well. Take seriously any safety warnings given in instructions or on chemical bottles. Carefully check the names on bottles and above all make sure you know what you are doing before starting. Try to obtain a clear working area of bench and keep it clear with only the chemicals and equipment you need around. Good practical skills can be gained only by practice but a few tips may be useful.

- When reading scales you should aim for an accuracy of half the smallest scale reading. For example when reading a burette, where the smallest marked division is 0.1 cm^3, you should estimate the reading to 0.05 cm^3, i.e. decide whether the meniscus is exactly on the division, in which case the reading should be given as *x*.00, or in between divisions in which case the reading should be given as *x*.05.
- Try to estimate the likely errors in your experimental work. These may be of two types—systematic (to do with the design of the experiment) or measuring (to do with how accurately a measuring instrument can be read).

Figure 1.5 A simple apparatus for measuring the enthalpy (heat) change of combustion of an alcohol



For example: suppose we have to measure the enthalpy (heat) change of combustion of an alcohol using simple apparatus, as shown in **Figure 1.5** (see **section 9.3.1**). Systematic errors revolve around the fact that much of the heat fails to enter the water in the beaker, and that some of that will be lost from the sides and top. Also, incomplete combustion may occur. Measurement errors occur in reading the thermometer, weighing the alcohol and weighing the water.

Try to develop the idea of looking critically at experiments. Point out any systematic errors and suggest ways of overcoming them—for example the use of a lid and insulation for the sides of the beaker in the above experiment. Try to estimate likely measuring errors, for example, 'the initial temperature of the water was 21.5 °C ± 0.5 °C'. If the temperature rose by 10 °C in the experiment this gives an uncertainty of ± 1.0 °C on a measurement of 10 °C (± 0.5 °C for two readings). This is a possible error of

$$\frac{1.0 \times 100}{10} = 10\%$$

It would be foolish to quote the enthalpy change of combustion as $-2056.3712\ kJ\ mol^{-1}$ with this sort of experiment. $-2060\ kJ\ mol^{-1}$ might be appropriate, so think carefully about errors and their sizes.

If possible, repeat measurements to get a check on their accuracy. In titrations, for example, you should aim to get two titres within 0.1 cm^3 and then use the average of these two in your calculations.

Part A Foundations

2 The kinetic particulate theory of matter

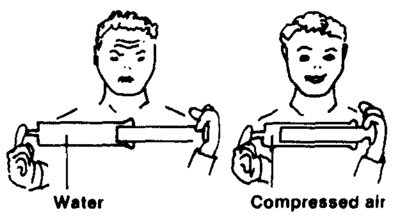
2.1 Introduction

One of the key ideas of science is that matter, which is anything with mass, is made of small particles, that is, it is *particulate*. These particles are in motion, and so the whole idea is called 'the *kinetic* particulate theory of matter' (kinetic meaning moving). This is important because it gives us a picture of matter (a model) which we can use to explain things like rates of reactions or properties of gases.

2.2 The three states of matter

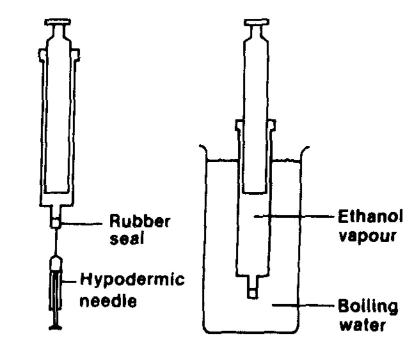
Table 2.1 sets out the model for the three states of matter. Some of the experimental evidence is described later and this is marked*. It is very rare for a single piece of evidence to be conclusive.

Figure 2.1 **Compressing liquids and gases**



Water in a syringe cannot be compressed   **Air in a syringe can be compressed easily**

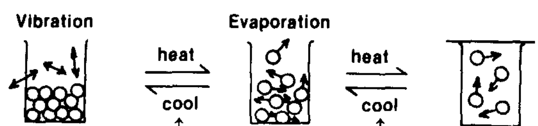
Figure 2.2 **A drop of ethanol liquid takes up 500 times more space when made into a gas**



Injecting a syringe with 0.1 cm^3 of ethanol (a small drop)   **0.1 cm^3 of liquid becomes about 50 cm^3 of vapour**

Table 2.1 **The three states of matter**

	Solid	**Liquid**	**Gas**
Arrangement particles	Regular	Random	Random
Evidence	Crystal shapes have straight edges. Solids have definite shapes.	None direct but a liquid changes shape to fill the bottom of its container.	None direct but a gas will fill its container.
Spacing	Close	Close	Far apart
Evidence	Solids are not easily compressed.	Liquids are not easily compressed. (See **Figures 2.1 and 2.2.**)	Gases are easily compressed.
Movement	Vibrating about a point	Rapid 'jostling'	Rapid
Evidence	*Diffusion is *very* slow. Solids expand on heating.	*Diffusion is slow. Liquids evaporate.	Diffusion is rapid. *Gases exert pressure. *Brownian motion
Models	Particles vibrate about a point.	Particles move but are too close to travel far except at the surface.	Particles are free and have rapid random motion.



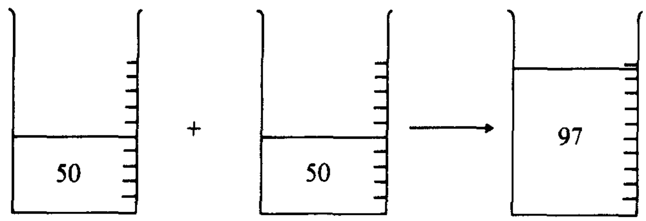
Melting temperature T_m Boiling temperature T_b

2.3 Evidence for particles

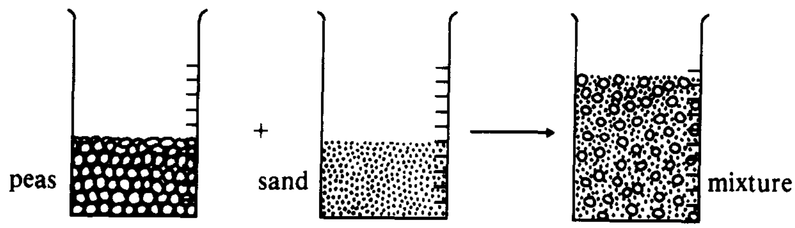
There is very little *direct* evidence that we can observe in the school laboratory for the particulate nature of matter, and indeed most of the behaviour of matter could be explained using a model of matter as being continuous, perhaps like a stretchy piece of gum. (This could be why the idea of matter being made of particles was rejected by the ancient Greek philosophers.) The results of the following simple experiment are not easily explained, except by using the idea of particles.

2.3.1 Mixing liquids

If 50 cm^3 of ethanol is mixed with 50 cm^3 of water, the final volume of the mixture is around 97 cm^3. Mixing water and water or ethanol and ethanol gives the expected 100 cm^3, so spillage or evaporation cannot be the cause.



However, the same kind of loss of volume would happen if peas and sand were mixed together.



This suggests that the two liquids could be made of particles of different sizes. On mixing, the smaller particles can fit into the gaps between the larger ones, thus reducing the total volume of the mixture.

2.4 Evidence for movement

2.4.1 Diffusion

The tendency for substances to spread out and mix due to the motion of their particles is called **diffusion**.

Gases diffuse rapidly, which is why we can smell the gas from a distant gas tap a few *seconds* after it is turned on.

Liquids also diffuse, but more slowly. We can see this if we pour ethanol very carefully on to a solution of copper sulphate, so that two layers form. It will take a few *weeks* for the two layers to become a uniform colour, see **Plate 1**.

If two different solid metals, such as silver and gold, are clamped together, some small evidence of diffusion may be seen after several *years*. The particles, which are vibrating, can gradually intermingle at the face where they meet.