# Some Recent Developments in Chemistry Teaching in Schools

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## 1 Introduction

'It is important to distinguish between *scientific information* and *training in science*. Both of these are valuable, but the scientific habit of mind, which is the principal benefit resulting from scientific training, can better be attained by a thorough knowledge of the facts and principles of one science than by a general acquaintance with many.'

'A master who is teaching a class quite unfamiliar with scientific method ought to make his class teach themselves by thinking out the subject of the lecture with them, taking up their suggestions and illustrations and criticizing them, hunting them down, and proving a suggestion barren or an illustration inept.'

It would come as no surprise to learn that the above two extracts had been taken from the general introduction to a publication produced by a curriculum project in science sometime during the last ten years. In fact, they were written over a century ago, in 1867, by one of the pioneers of science teaching in schools, Canon Wilson, who subsequently became Headmaster of Clifton College. It is encouraging to note that the 'founding fathers' had the root of the matter in them, and that from the beginning there has been a body of opinion in favour of the separate sciences as teaching (or, better, learning) vehicles in schools.

Chemistry, with the other main science disciplines, arrived relatively late on the educational scene. A chair of chemistry was founded in Oxford towards the end of the seventeenth century and one at Cambridge at the beginning of the eighteenth, but little serious science was taught in universities before the middle of last century. In schools, chemistry teaching began at the City of London School in 1848, and chemistry laboratories were in use at Rugby and Uppingham some ten years later. The subject had to infiltrate into a curriculum that was considered overcrowded already; it was consequently starved of teaching time, and hence it often degenerated into rote learning of facts and principles in order to hold its own in examinations with the more pampered subjects on the arts side of schools. This defensive attitude can still be detected in some teachers of chemistry; it can constitute a grave handicap to professional progress.

Three events in the second half of the nineteenth century had a profound influence on the spread of chemistry in schools. The first was the vigorous campaign by T. H. Huxley, Herbert Spencer, and John Tyndall to alert public opinion to the value of the science subjects as contributors to a liberal education. The second was the support and advocacy of the so-called heuristic method of teaching chemistry by H. E. Armstrong. The third event occurred at the turn of the century, when four masters at Eton College proposed the formation of an organization to be devoted to the improvement of science teaching. Thus was born the Association of Public Schools Science Masters (with the distinguished chemist Sir Henry Roscoe as its first president) which became the Science Masters' Association in 1919 and, by merger with the Association of Women Science Teachers in 1963, the Association for Science Education.

Armstrong's proposals have been much maligned in recent years; one not infrequently finds them distorted into an insistence that pupils discover everything for themselves. What Armstrong wanted was to give pupils experience of the joys of real investigation, so that they could see chemistry as a method of solving specific problems, for which planning and gradually-acquired experience were necessary. This has been the basis of almost all sound chemistry teaching. It is much more stimulating to be asked to find what proportion of marble consists of a gas that can be expelled by heating, than to verify that calcium carbonate contains 44% carbon dioxide; or to investigate the effect of temperature change on the volume of a gas rather than to verify Charles' law. The heuristic method brought practical work back into school chemistry.

In this review we shall be concerned mainly with the present state of chemistry teaching in schools, so it is time to jump forward to the second half of the twentieth century.

## 2 Some More-recent History

Pressures for a change of direction in science teaching began to build up some 15 years ago. In 1957 the S.M.A. and A.W.S.T., always active in the educational field, renewed again a plea for the treatment of the sciences as core subjects in the school curriculum, with status equal to that accorded to English, mathematics, and modern languages. This was done in a Policy statement[1] that was widely circulated amongst individuals and organizations responsible for administration and policy making in the school system. Four years later a panel of chemistry teachers produced[2] 'Chemistry for Grammar Schools' giving details of teaching methods and course content for pupils aiming at O-level and A-level examinations (proposals for Secondary Modern School Science had been published earlier). Other growth points began to form at about the same time. The Scottish Education Department produced new syllabuses for the Ordinary and Higher Grades of the Scottish Leaving Certificate in 1962.[3] These were the first radically-new approaches to chemistry teaching to be put on an operational basis and represented a major reorientation of thought on both course content and examinations.

Overseas, two important projects were launched in the U.S.A.—the Chemical Bond Approach Project in 1957 and the Chemical Education Materials Study

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[1] A Policy Statement issued by The Science Masters' Association and the Association of Women Science Teachers, John Murray, London, 1957.

[2] 'Chemistry for Grammar Schools,' John Murray, London, 1961.

[3] Scottish Education Department, Circular No. 512, 1962.

in 1959; both published their final proposals in 1963.[4,5] These two (and to a lesser extent the Scottish schemes) were the first examples of large-scale curriculum development exercises in chemistry. Very considerable financial resources were made available to the American ventures by the National Science Foundation so that many professional chemists, both inside and outside schools, could be seconded to further their progress, and large numbers of teachers and students could be involved in trials of the draft materials produced. During the planning stages of the CHEM Study, for example, over 500 schools and upwards of 50 000 students co-operated in school trials; the final publications were produced by a group of 27 school and university teachers. The initiative for the American projects came from above, as one method of improving the supply of technologists equipped to face competition from their Soviet counterparts.

As has been seen, in this country the teacher organizations (now combined in the A.S.E.) provided the first impetus for change. In 1961 it was decided that outside assistance would be essential if the suggestions outlined in 'Chemistry for Grammar Schools' were to be implemented within a reasonable space of time. Through the generous assistance and support of the Nuffield Foundation, a project in chemistry for the more able pupils in the 11—16 age range (the O-level project) was put on an operational basis in 1962, and this was followed, in 1965, by the Advanced Chemistry Project. These formed but two of a group of ten major projects sponsored by the Nuffield Foundation during the period extending from 1962 to the present time, with a total cost well in excess of a million pounds. Thus there is a contrast between the U.S.A. and the U.K. in both origin and method of finance of major educational projects. In the former the initiative and necessary finance came from government sources; here chemistry teachers in schools made the first moves and provided guide-lines for further advance, and a private charitable organization supplied the financial backing. The Nuffield projects also involved substantial numbers of professional scientists and students: for O-level chemistry some 70 professional chemists from schools, universities, technical colleges, and industry took part in the production of material for teachers and students, and the school trials programme covered 84 schools, over 200 teachers, and some 5000 students; a similar state of affairs occurred in the Advanced Chemistry project. Printed versions of the O-level material began to appear in 1966,[6] and those for the Advanced project in 1970.[7]

Events in Scotland, the remainder of the U.K., and the U.S.A. have been described briefly in illustration of what has been going on in the past 15 years. They are part of a world-wide movement towards reappraisal of chemistry

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[4] Chemical Systems (Students' Book and Teachers' Guide), Investigating Chemical Systems, Chemical Bond Approach Project, McGraw Hill, London, 1964.

[5] Chemistry—An Experimental Science (Students' Book, Teachers' Guide, Laboratory Manual), Chemical Education Materials Study, W. H. Freeman, London, 1963.

[6] Publications of Nuffield Foundation O-level Chemistry Project, Longmans/Penguin Books, London, 1966—68.

[7] Publications of Nuffield Foundation Advanced Science Project: Chemistry, Penguin Books, London, 1970—71.

teaching in schools, in which notable missionary roles have been sustained by organizations such as the British Council, the Centre for Educational Development Overseas, the National Science Foundation of America, the United Nations Educational, Scientific, and Cultural Organization, and the Organization for Economic Co-operation and Development. It is probably fair to say that the projects referred to above form the primary growth centres in the global exercise. The important point to make here is that the teaching schemes in chemistry now finding favour in many schools result from exercises in which all parts of the profession of chemistry have been involved. This co-operation may well prove one of the more-lasting benefits to emerge from these ventures. This has indeed been a happy partnership in which tertiary education teachers and industrial scientists have been willing to offer both information and advice on matters chemical and technological, whilst leaving the final decision on what shall be attempted in schools, and how it shall be treated, to those most fitted by experience to make these decisions—the teachers of chemistry in the secondary schools.

The two Nuffield projects in chemistry have been aimed mainly at the more academically oriented students in secondary schools, but the needs of those less inclined to academic studies were not forgotten, and the Nuffield Secondary Science Project[8] was set up to cater for them. The teaching of science in primary schools has also become much more common in recent years, fostered by the Nuffield Junior Science Project[9] and the project 'Science 5/13' sponsored jointly by Schools Council, the Nuffield Foundation, and the Scottish Education Department.[10]

## 3 What is Chemistry, and Why Do We Want To Teach It in Schools?

Chemistry, in common with the other sciences, advances by seeking the answers to questions, a process in which posing the question is often more important than the method of finding an answer. During the course of history the questions of importance to chemists have changed. There was a time when those concerned with the idiosyncrasies of matter sought answers relating to the transmutation of metals and the search for the universal solvent; at another time they were much occupied with the cure of bodily ailments. In the early years of last century the question 'what makes a chemical reaction take place?' was not helpful in advancing the study of chemistry. Now it has some significance, even though an answer in terms of *a priori* prediction may not be possible. In the early years of the emergence of chemistry as a science its practitioners were preoccupied with experimental techniques, leading to the methods of separation, analysis, and preparation necessary for the extensive collection of factual information which must precede the development of theoretical principles. It was towards the end of this phase that the teaching of chemistry in schools began

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[8] Publications of Nuffield Foundation Secondary Science Project, Longmans Group, London, 1970—71.

[9] Publications of Nuffield Foundation Junior Science Project, William Collins, London, 1967.

[10] Trial Editions of Schools Council 'Science 5/13' Project, Macdonald, London, 1969—70.

and what was taught reflected largely the attitude of chemists at large to their subject. Clearly a relationship between the chemistry taught in the schools and the current views of the subject as a whole must persist, which means that the teaching of the subject will change as the professional image of the subject alters. When considering curriculum revision it becomes important, therefore, to examine current views of what chemistry is and what is its scope as a discipline, not least because students will at some stage require an answer to the question 'What is chemistry?'.

As part of the golden anniversary of its Division of Chemical Education, the American Chemical Society sponsored an International Conference on Education in Chemistry, held at Snowmass-at-Aspen, Colorado, in July, 1970.[11] To it were invited an international group of 86 chemists known to be experienced and authoritative in this field. Perhaps a slight twitch of the eyebrows might be permitted at the fact that none of them was a currently-practising teacher of chemistry in a school, but they were a highly distinguished body. One of their discussion panels was concerned with the structure of chemistry, and from its deliberations arrived at the following definition: 'Chemistry is the integrated study of the preparation, properties, structure, and reactions of the chemical elements and their compounds, and of the systems which they form.' If the words 'integrated' and 'structure', and the final phrase 'and of the systems which they form', are removed from this definition, it could serve as a summary of the treatment of the subject at school level over the past 50 years or more. It is only recently that thoughts of integration within the subject, of structure at the molecular level, and of chemical systems as worthy of detailed study have begun to be brought to bear on chemistry as it is taught in schools. The title of the student's text for the C.B.A. project—'Chemical Systems'—is significant in this context.

The definition above gives no indication whether there are any benefits—material, social, or aesthetic—to be derived from the study of chemistry; indeed, such considerations could be said to be outside the brief of the panel concerned. Nevertheless, if chemistry is to be a component of a liberal education, and not solely the first stages in professional training, the consequences of the activities of the chemist to society at large must form part of the treatment. Extending the definition somewhat, we can arrive at the pattern of chemistry indicated in Figure 1.* Such a pattern can provide a basis for the construction of any course in chemistry for use in schools; the degree of importance attached to the parts of the pattern will vary with age and ability, and at times some of them will be neglected altogether. Professor H. F. Halliwell[12] was making much the same point when he wrote: 'A pattern of treatment which seems to be emerging is that education through chemistry involves exercise in the follow-

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* The Reviewer is indebted to H. R. Jones for the idea on which Figure 1 is based.

[11] International Conference on Education in Chemistry, sponsored by Division of Chemical Education, American Chemical Society, Snowmass-at-Aspen, Colorado, U.S.A., Preliminary Report, 1970.

[12] H. F. Halliwell, *R.I.C. Rev.*, 1968, **1**, 217.

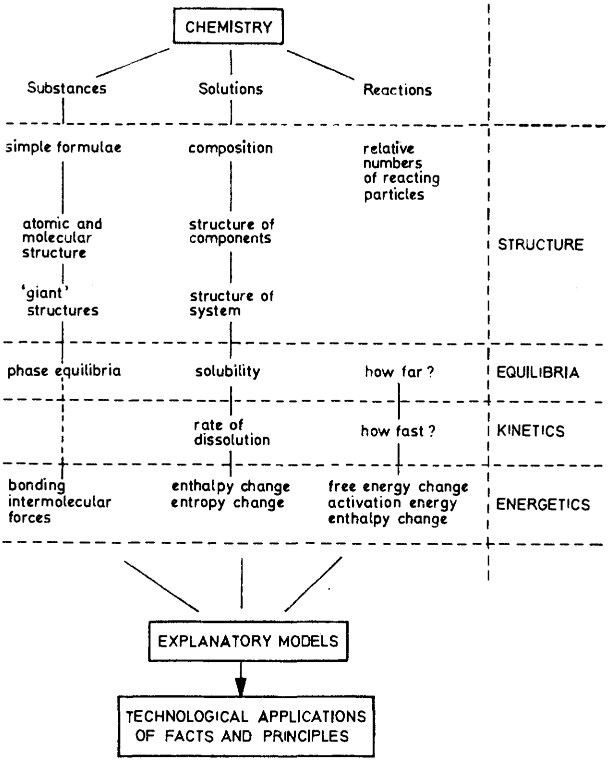

**Figure 1** *A pattern for school chemistry*

ing five questions: (*i*) What material changes are going on and why should I bother with them? (*ii*) Do they fit into a wider pattern and does it help to think about them in terms of atoms, molecules, ions, and giant structures? (*iii*) How fast is the change and can it be adjusted? (*iv*) How far does the change go and can it be controlled? (*v*) What energy changes also take place and do they throw any light on what is happening?' All five questions are posed on the assumption that the study of chemical systems will be a main aim of what is done.

The answer to 'Why should I bother with them?' in the first question is of the highest importance in a chemistry course designed for the citizens of today; without it any treatment of the subject becomes an academic exercise of limited appeal. This brings in question the reasons why chemistry can claim to be an essential component of a liberal education. The Reviewer, faced with the necessity of defending this thesis some years ago, advanced the following reasons for its inclusion in the school curriculum: 'It is rich in examples of the power and scope of the human intellect and its great generalizations can match the highest achievements of mankind in any other department of learning. Examples of its applications touch almost every aspect of our daily existence and no one can be said to be fully educated if he is ignorant of these, and of possible advances in them.'[13] From this viewpoint, the main advantage of chemistry over the other sciences is that it can provide a host of technological applications of easily perceived importance and relevance by taking stock of any environment, however restricted. Further, it is possible to frame questions about such applications which are amenable to investigation on an experimental basis, using techniques which are both quick and simple. Discussion of such investigations can lead to clear-cut answers to some of the questions asked, but in many cases involves the taking of decisions on incomplete information, which is usually the state of affairs which obtains in 'real life'.

H. F. Halliwell[14] takes a somewhat different viewpoint: 'The educational justification for the inclusion of chemistry is thus twofold: for all, to differing degrees, it can establish, through personal commitment with the transformation of material, a personal involvement in a major basis of society in a way not possible in any other field of experience; to the more capable it uniquely offers an area for the development of critical, integrating speculation about the observable in terms of the unobservable. Physics, chemistry, and biology form a complementary but ill-defined and merging trio. The first, at school level, is predominantly concerned with patterns of specific behaviour, the third with patterns of individual and fluctuating behaviour.'

The difference between the two quotations illustrates the change that has taken place in what is desirable and possible in chemistry teaching in schools. The first is concerned with content rather than method; the second refers to how, as well as to why and what. 'Personal involvement' and 'critical, integrating speculation' refer to activities of students much canvassed during the past decade. In a teaching situation the approach and attitude to a subject are at least as important as the content of a course.

## 4 How Should Chemistry Be Taught?

There are many ways in which chemistry can be taught, and which of these is used depends to a large extent on the purpose which a course has to fulfil. Didactic teaching, by lectures with or without demonstration experiments, is a most effective method of imparting information and is, rightly, used by professionals for exchanging information amongst themselves. Sometimes, regrettably, it has to be used extensively by teachers starved of the time required for the proper development of their subject. There is a place for this method in the school situation, but it must be used with discrimination lest it degenerate into a perpetuation of the dogma of 'the revealed truth'. To secure the maximum degree of student involvement mentioned above, a much more fluid class situation is required, in which students and teacher are partners in an exploration to which each must contribute. Since chemistry is still predominantly an experimental

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[13] E. H. Coulson, *Proc. Chem. Soc.*, 1957, 276.

[14] Ref. 12, p. 214.

science, a course which accurately reflects its nature must have a large content of practical work, preferably carried out mainly by the students themselves. If a course objective is the training of practical workers, it will include a wide variety of experimental techniques, which must be practised as such. On the other hand, if a course objective is to give students personal experience of the ways in which the principles of chemistry have been developed, they must learn to use experiments as a means of finding out, and practical techniques must be subservient to methods of investigation. It must be made clear that class discussion and personal investigation do not make for rapid assimilation of information, here the lecture and teacher demonstration clearly have the advantage; they can, however, promote a deeper understanding of the subject matter being studied, and can foster habits of critical appraisal.

The attitude to course content is important also. There are those who advocate the historical approach as the best method of introducing the study of chemistry, so that young boys and girls should follow the methods and speculations of the pioneers responsible for the development of the subject. There may be a few inspired teachers who can arouse and maintain enthusiasm for such a course. It does, however, present formidable difficulties; in science, advance is rarely a matter of straight-line extrapolation, and a historical trail is apt to peter out in unproductive branches as well as entailing some rather ridiculous encounters with nomenclature and units. The tone of voice in which the overheard remark by a chemistry graduate beginning a course for an education certificate 'and we spent the *whole* of our first term at school *disproving* the phlogiston theory' was made probably summed up the student's outlook on prolonged exposure to the historical method. But here again, there is a place for snippets of historical information; introduced at the appropriate time (which will vary with every class) they can fascinate young people. Discrimination again is the secret, and the realization that historical topics make unpalatable examination fodder.

Until quite recently, it was customary with older students in schools (mainly in the sixth form) to sub-divide chemistry into its 'traditional' branches—inorganic, organic, physical, analytical. It is not unlikely that this was due to practice in university departments filtering downwards. Whilst there is something to be said for this approach to teaching, it can hamper considerably the integration of theory and practical work, which is a major aim of most of the projects which have been operative in the past ten years. It is therefore becoming commoner to treat the subject more as an integrated whole, but again this must not be too-rigidly interpreted—there are times when it is advantageous to concentrate on the study of a group of related elements, or a particular element, or to learn a new analytical technique.

A wise teacher uses a variety of methods, altering the balance between the various alternatives to suit each fresh teaching situation. He will also select from the learning aids developed by educational technology, such as films, overhead projectors, programmed texts, and computers, but always because he judges them to be the best available methods for a given purpose, never merely because they happen to be there. It is the teacher's judgment, made on the spot, which makes learning effective: neither the printed word nor the machine can replace a teacher in this function.

Each of the projects referred to earlier in this review has placed considerable emphasis on approaches and attitudes to the teaching of chemistry. Their proposals regarding the position of balance between the alternatives available are indicated by the quotations given below, which are in chronological order.

**A. Chemistry for Grammar Schools.**—'It is important at all stages that hypotheses and theoretical concepts should be clearly distinguished from facts and generalizations which they are designed to explain, that they should arise from direct observation and experiment, and that their validity should be tested by using them to make predictions to be tested by further experiment.'[15]

**B. The Scottish Education Department.**—'As far as teaching method is concerned, any course in chemistry must be firmly based on experimental work. An exploratory method must be used in which pupils devise their own experiments as far as possible. The early part of the work consists almost entirely of experiments performed by the pupils themselves. As the work becomes more complicated some of the experiments must, of course, be demonstrated, but these should be reduced to a minimum.[16]

**C. The Chemical Education Materials Study.**—'*Chemistry—An Experimental Science* presents chemistry as it is today. It does so with emphasis on the most enjoyable part of chemistry: experimentation. Unifying principles are developed, as is appropriate in a modern chemistry course, with the laboratory work providing the basis for this development. When we are familiar with these widely applicable principles we no longer have need for endless memorization of innumerable chemical facts.'[17]

**D. The Chemical Bond Approach Project.**—'Chemistry combines imaginative ideas and a great many facts into an intelligible whole, from which a student can get an introductory view of a modern science. It is the process of weaving ideas and facts that should occupy the attention of the student of chemistry—a process in which he can participate.'[18]

**E. The Nuffield O-level Chemistry Project.**—'That the pupil should see the point of experimental work is of the greatest importance. He must learn that chemicals, test-tubes, thermometers, and sources of heat and electrical energy are tools to which he should always turn to settle a point of curiosity or of speculation. He must learn that it is proper, and not wrong, to have an opinion or an idea

[15] Ref. 2, p. 3.
[16] Ref. 3, p. 18.
[17] Ref. 5, Preface to Students' Book.
[18] Ref. 4, Preface to Students' Book.

about something he observes, but he cannot begin to think that he is scientific if he does not check whether his idea fits the observed experimental facts.'[19]

**F. The Nuffield Advanced Chemistry Project.**—'The approach to the teaching of the subject must also encourage students to attempt interpretation and explanation of phenomena for themselves. The goal should be understanding, rather than the mechanical reproduction of factual material. This must not be taken as implying that factual information is considered unimportant, but rather that facts should be given their proper place in the study of the subject—indispensable as the basis for speculation about possible explanations of the behaviour of matter, and playing a crucial role in disciplining such speculation. Theory which outruns facts can have no lasting place in science, but it is proper and permissible to make imaginative leaps forward, provided that these are checked against known facts, or are used to guide the search for further factual information, against which they can be tested. There is, of course, nothing new or revolutionary about this approach. It has been the basis of good chemistry teaching for many years.'[20]

What both teachers and students get out of a chemistry course reflects the methods used to encourage learning, which is often by no means confined to the students. It seems fitting, therefore, to list some of the characteristics that might be expected of a course at school level.

(*i*) It must be fun. Any exercise of this kind which does not give intellectual and aesthetic pleasure to both teacher and taught operates under a grave handicap.

(*ii*) It must be up to date and reflect current thinking in chemistry.

(*iii*) There must be maximum student involvement; real learning is never passive.

(*iv*) It must encourage an investigational outlook on the part of the student. Much of the course should be practically based but the necessity of vicarious experience becoming increasingly important, the farther a student progresses, must be borne in mind.

(*v*) It must foster understanding, not solely memorization and recall.

(*vi*) It should be integrated within itself.

(*vii*) Since, for the majority of students, most school courses will be terminal, it should be complete in itself, contributing to a broad education, whilst at the same time providing a preparation for further study.

(*viii*) Any form of assessment associated with the course must be consonant with it, reflecting the approach and attitude adopted to the subject, as well as the course content.

## 5 Course Content

Tables 1—6 (pp. 505—508) indicate the contents of six of the teaching schemes

(*text continued on p. 508*)

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[19] Ref. 6, Introduction and Guide, p. 4.

[20] Ref. 7, Teachers' Guide I, pp. 7—8.

**Table 1** *Section headings from the Alternative Chemistry Syllabus, Part I, Ordinary Grade, published by the Scottish Education Department in 1962*

1 Physical and chemical change
2 The nature of matter
3 Air
4 Water
5 The earth
6 The sea
7 Atoms and molecules
8 Chemical combination
9 Activity and electrochemical series
10 Acids, bases, and salts
11 Sulphuric acid
12 Nitric acid
13 Fuels
14 Foods and related compounds
15 Macromolecules
16 The halogens

**Table 2** *Section headings from the Alternative Chemistry Syllabus, Part II, Higher Grade, published by the Scottish Education Department in 1962*

17 Chemical theory
18 Further development of electronic theory of valency. Periodic table
19 Chemical reaction
20 Carbon compounds

**Table 3** *Chapter headings from 'CHEMISTRY—An Experimental Science', prepared by Chemical Education Materials Study*

1 Chemistry: An Experimental Science
2 A Scientific Model: The Atomic Theory
3 Chemical Reactions
4 The Gas Phase: Kinetic Theory
5 Liquids and Solids: Condensed Phases of Matter
6 Structure of the Atom and the Periodic Table
7 Energy Effects in Chemical Reactions
8 The Rates of Chemical Reactions
9 Equilibrium in Chemical Reactions
10 Solubility Equilibria
11 Aqueous Acids and Bases
12 Oxidation–Reduction Reactions
13 Chemical Calculations
14 Why We Believe in Atoms
15 Electrons and the Periodic Table
16 Molecules in the Gas Phase
17 The Bonding in Solids and Liquids
18 The Chemistry of Carbon Compounds
19 The Halogens
20 The Third Row of the Periodic Table
21 The Second Column of the Periodic Table
22 The Fourth-Row Transition Elements
23 Some Sixth- and Seventh-Row Elements
24 Some Aspects of Biochemistry: An Application of Chemistry
25 The Chemistry of the Earth, the Planets, and the Stars

**Table 4** *Part and chapter headings from 'Chemical Systems' by the Chemical Bond Approach Project*

| | |
|---|---|
| PART I | The Nature of Chemical Change |
| 1 | The science of chemical change |
| 2 | Mixtures and chemical change |
| 3 | Gases, molecules, and masses |
| PART II | The Electrical Nature of Chemical Systems |
| 4 | Electricity and matter |
| 5 | Charge separation and energy |
| 6 | Electrical nature of matter |
| PART III | Models as Aids to the Interpretation of Systems |
| 7 | Chemical and electrical structures |
| 8 | Kinetic-molecular theory |
| 9 | Temperature-changing capacity |
| 10 | Electrons, nuclei, and orbitals |
| PART IV | Bonds in Chemical Systems |
| 11 | Metals |
| 12 | Ionic solids |
| 13 | Ions in solution |
| PART V | Order, Disorder, and Change |
| 14 | Free energy and electron transfer |
| 15 | Concentration and chemical change |
| 16 | Acids and bases |
| 17 | Time and chemical change |
| 18 | Water |

**Table 5** *Topic headings from the Sample Scheme produced by the Nuffield O-level Chemistry Project, 'Nuffield Chemistry Introduction and Guide'.*

STAGE I Exploration of materials

| | Alternative A | | Alternative B |
|---|---|---|---|
| 1 | Getting pure substances from the world around us | 1 | Separating pure substances from common materials |
| 2 | The effects of heating substances | 2 | Acidity and its cure |
| 3 | Finding out more about the air | 3 | Fractional distillation as a way of separating substances |
| 4 | The problem of burning | 4 | The major gases of the air |
| 5 | The elements | 5 | Finding out more about substances by heating them |
| 6 | Competition among the elements | 6 | Using electricity to decompose substances |
| 7 | Water as a product of burning | 7 | The elements |
| 8 | The effects of electricity on substances | | |
| 9 | Chemicals from the rocks | | |

Alternative A

10 Chemicals from the sea

Alternative B

8 Further reactions between elements
9 Investigation of common processes involving the air: (*a*) burning and breathing, (*b*) rusting
10 Competition among the elements

### STAGE II Using ideas about atoms and particles

The ideas that chemists use

11 Atoms in chemistry
12 Investigation of salt and 'salt gas'
13 Looking at the elements in the light of the Periodic Table
14 Finding out how atoms are arranged in elements
15 Solids, liquids, and gases
16 Explaining the behaviour of electrolytes
17 Finding the relative number of particles involved in reactions
18 How fast? Rates and catalysts
19 How far? The idea of dynamic equilibrium
20 Investigating the substances called 'acids'

Getting the mastery over chemicals

21 Breaking down and building up large molecules
22 Chemistry and the world food problem
23 Chemicals and energy
24 Radiochemistry

### STAGE III A course of options

(At least two to be chosen from those given below)

Option 1 Water
2 Crystals and their orderliness
3 Colloids
4 Metals and alloys
5 Chemical changes and the production of electrical energy
6 An investigation of the structure of a few compounds
7 Giant molecules
8 The chemical industry
9 Historical topics
10 Acidity–alkalinity
11 Analysis with a purpose
12 'Atoms into ions'
13 Periodicity and atomic structure

**Table 6** *Topic headings and Special Studies for the Nuffield Advanced Chemistry Course, 'Nuffield Advanced Science, Chemistry, Teachers' Guide I'*

THE BASIC COURSE

1 Amount of substance
2 Periodicity
3 The masses of molecules and atoms; the Avogadro constant
4 Atomic structure
5 The halogens and oxidation numbers
6 The *s*-block elements; and the acid–base concept
7 Energy changes and bonding
8 Structure and bonding
9 Carbon chemistry, part 1
10 Intermolecular forces
11 Solvation
12 Equilibria: gaseous and ionic
13 Carbon chemistry, part 2
14 Reaction rates
15 Equilibria: redox and acid–base systems
16 Some *d*-block elements
17 Equilibrium and free energy
18 Carbon compounds with large molecules
19 Some *p*-block elements

SPECIAL STUDIES
(One to be covered by each student, occupying 4—6 weeks of the second year of the course)

Biochemistry
Chemical Engineering
Food Science
Ion Exchange
Metallurgy

considered in some detail in this review. The contents of the courses proposed in 'Chemistry in Grammar Schools' provided the basis for the two Nuffield schemes and have not been included. The outlines provided give a very approximate idea of the scope of the schemes. They are not strictly comparable, being designed for different age ranges. The two Nuffield programmes are intended for the 11—16 years (O-level) and 16—18 years (A-level) age ranges, respectively. The Scottish Ordinary Grade examination corresponds fairly closely to the O-level examination in the rest of the U.K., but it is quite common for the Higher Grade examination to be taken only one year after the Ordinary Grade. The two American schemes are intended to cover one year's study only, generally at about 16—17 years; even with a liberal time allocation and relatively mature students the courses are intensive, and practical experience of students necessarily limited.

There is something of an evolutionary sequence in the six schemes. The Scottish proposals of ten years ago are nearer to the traditional courses; the Nuffield schemes have an element of flexibility in that there are prescribed and optional elements in the courses, thus allowing teachers, and sometimes students, to exercise individual interests and preferences.

Running through all the courses are the main themes of structure, rates, equilibria, and energetics, the emphasis and depth of treatment varying with course and age of students. In each of them, periodicity of properties is introduced early, and used thereafter, through the Periodic Table, as a means of providing a unifying pattern for the properties of the elements and their compounds. The 'why bother?' factor—'What use is this to me and to the society in which I live?'—is given greatest prominence in the Nuffield schemes, where technological applications are given special treatment.

Basically, in approach and attitude to the subject, the six schemes differ little, as the extracts quoted above show. As illustrations in detail of the general method of treatment, two sequences from the Nuffield Advanced Chemistry course are given below, solely because the Reviewer is more familiar with this scheme than with most of the others. The first extract is taken from Topic 10, Intermolecular Forces, because it shows well how practical work and theory can be quite closely integrated. In the second illustration, from Topic 4, Atomic Structure, direct experimental investigation is not possible at school level and second-hand evidence must be used, but here also there is a problem-solving situation.

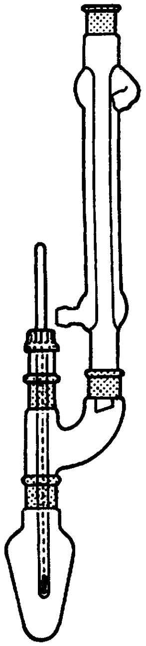


**Figure 2**

**A. Extract from Topic 10.**—At the beginning of this Topic, the teacher initiates an investigation of the way in which the boiling points of mixtures of two liquids vary with composition (% by volume for simplicity). The class could be asked to predict possible results before practical work is undertaken. Quite simple apparatus, such as that in Figure 2, suffices for the collection of data. By class co-operation a quite large amount of information can be collected in a short time and represented graphically, as in Figure 3. An explanation for the quite different behaviour of the three pairs of liquids is now sought. To assist the discussion, a restricted treatment of Raoult's work on the vapour pressures of liquid mixtures is introduced to students. so that the notion of an ideal solution can be considered. A look at vapour pressure–temperature relationships, Figure 4, enables vapour-pressure rise to be associated with a decrease in boiling point,

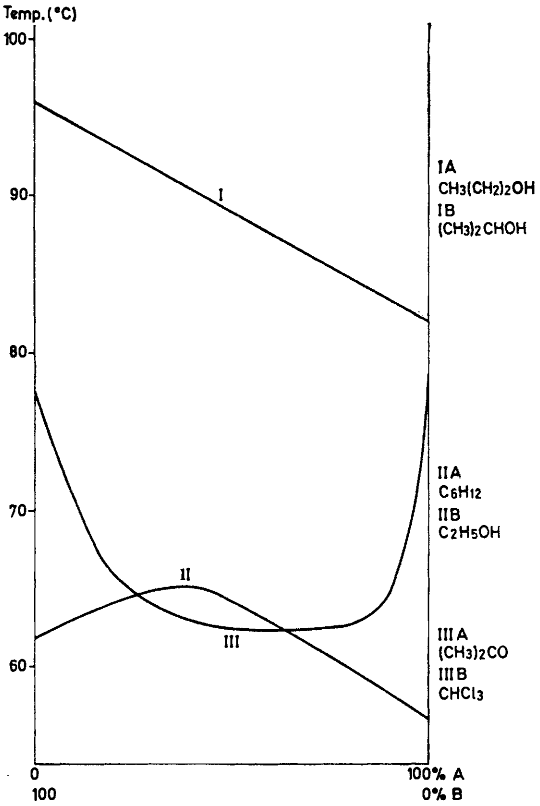


**Figure 3** *Boiling point–composition curves for some liquid mixtures*

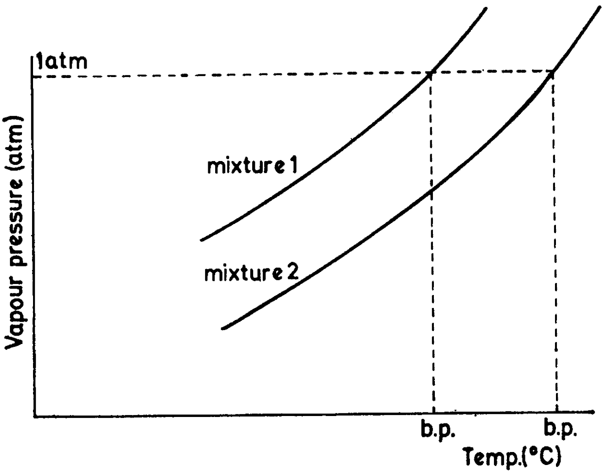
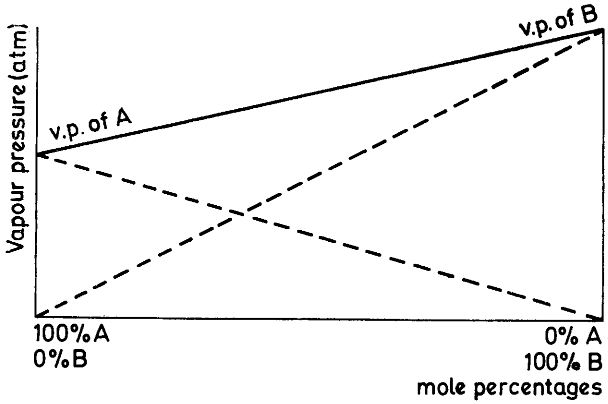


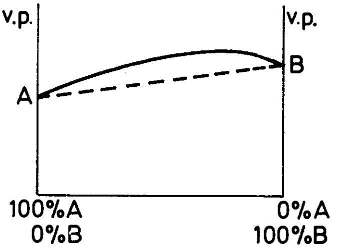
**Figure 4** *Relationship between vapour pressure and temperature for mixtures*

so that our three mixtures can be seen in general terms to behave as shown in Figure 5, at the same time introducing the idea of positive and negative deviations from Raoult's law. It now becomes plain that in mixtures showing positive deviation (vapour pressure higher than expected) it is not unreasonable to suppose that the escaping tendency of one or both of the components has increased. Conversely, the escaping tendency might be expected to decrease when mixtures show negative deviation. Discussion can now be led into possibilities of bond-breaking in the first case, and to bond-making in the second. But previous experience has shown that bond-breaking is normally an endothermic process (Topic 7) whilst bond-making is exothermic—a speculation readily susceptible to experimental test. Investigation shows that when cyclohexane and ethanol are mixed (mixture II), there is a fall in temperature (the continuous variation technique shows a maximum of about 3°), but for mixture III, trichloromethane and acetone, there is a quite considerable temperature rise, with a maximum exceeding 10°. We now have some evidence for intermolecular bonding in liquids. Is it possible to discover the atoms participating in the bonds? For this purpose mixture III is most rewarding, since variations in the components produce pertinent information. Qualitatively, a set of results such as those shown in Table 7 can be obtained quickly.

The results from mixtures I—IV show that the most likely bonding link when trichloromethane and acetone are mixed is between the hydrogen atom in trichloromethane and the oxygen atom in acetone. The term 'hydrogen bond' can now be introduced. Mixture V shows that a similar bond can be formed between nitrogen and hydrogen. The smaller temperature rise with mixture III than with mixture I can provoke an interesting discussion. The small drop in



Positive deviations from Raoult's law



Negative deviations from Raoult's law

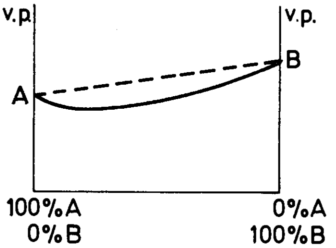


**Figure 5** *Vapour pressure curves for ideal and non-ideal mixtures of liquids*

**Table 7** *Temperature changes when liquids are mixed*

| | *Mixture* | *Temperature change** |
|---|---|---|
| I | $CHCl_3$–$(CH_3)_2CO$ | + |
| II | $CCl_4$–$(CH_3)_2CO$ | – (small) |
| III | $CH_2Cl_2$–$(CH_3)_2CO$ | + |
| IV | $CHCl_3$–$C_6H_{14}$ | 0 |
| V | $CHCl_3$–$(C_2H_5)_3N$ | + |

* + = Temperature rise, – = Temperature fall.

temperature when carbon tetrachloride and acetone are mixed can be used later to provide an introduction to dipole–dipole attractions.

The problem of determining the enthalpy change on formation of a hydrogen bond in mixture I can now be presented to students, who can be asked to plan and carry out an experiment for this purpose. The value obtained, usually of the order of $-2$ to $-4$ kJ mol$^{-1}$, shows that the bond is weak, but it is important to emphasize that the bond strength varies considerably with the system by quoting other values, such as *ca.* $-120$ kJ mol$^{-1}$ for the hydrogen bond in liquid hydrogen fluoride.

The way is now open for the discussion of a large number of systems containing hydrogen bonds, such as water, ice, organic acids, hydrated crystals, proteins, carbohydrates, and nucleic acids.

In the Nuffield scheme two other types of intermolecular bonding are discussed, *viz.* dipole–dipole attractions and van der Waals' forces.

**B. Extract from Topic 4.**—The general subject of this Topic is Atomic Structure. The early work in the Topic leads to the establishment of methods available for the determination of relative masses of atoms, and of a model of the atom as consisting of a massive nucleus plus surrounding electrons in an unspecified arrangement. The problem in this extract is to obtain information about the arrangement of electrons. If chemical reaction involves electron transfer or electron sharing, it might be useful to know how much energy is required to remove electrons from atoms, *i.e.* how to measure ionization energies. Two possible approaches are discussed, based on electron impact and spectra, respectively.

The electron-impact method is introduced by describing a possible sequence of events when the potential difference between grid and cathode is increased in a triode valve containing a gas at low pressure, using the circuit shown in Figure 6. The story presented is a simplified one; collisions between electrons, in the stream from cathode to grid, and gas particles in the valve become increasingly violent as the potential difference rises and the energy content of the electrons becomes larger. Eventually a stage should be reached at which the particles lose an electron apiece in the collisions. This will result in positive ions being formed and moving towards the anode of the valve, which is maintained at a small negative potential. The small current thus produced can be detected by using a sensitive ammeter. Using a quite cheap, commercial valve containing argon, the ammeter needle 'kicks' at an applied potential difference of about 18 V, giving a value of 1740 kJ mol$^{-1}$ for the first ionization energy of argon (this, of course, is somewhat high, but the method is a quite rough one).

The second approach to the ionization energy problem is *via* spectra. Starting from observation of the line emission spectra of a number of elements, using discharge tubes and direct-vision spectroscopes, discussion proceeds through the origin of the lines in the emission of energy as electrons fall from a higher to a lower energy level. The quantization of energy emitted in this way has to be

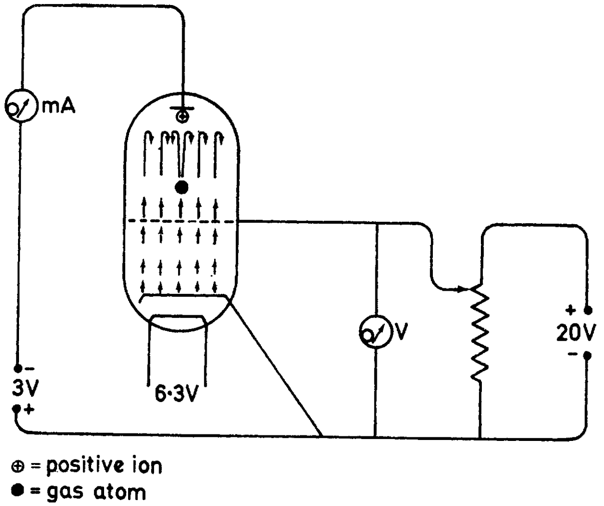


**Figure 6** *Circuit for use of triode in measuring ionization energy of argon*

emphasized, and Planck's constant introduced to provide the link between energy and frequency, $\Delta E = h\nu$.

This discussion is centred on the simplest line emission spectrum, that of atomic hydrogen, using a plot of $\nu$ against $1/n^2$ ($n = 2 + 1, 2 + 2, 2 + 3$, *etc.* for successive lines) to show that there is a recognizable pattern amongst the frequencies in the Balmer series of the visible region (Figure 7). Using an energy-level diagram to aid discussion, the probable complete ejection of an electron from a hydrogen atom when $1/n^2 = 0$ ($n = \infty$) can be deduced. For the Balmer series the datum energy level is $n = 2$; to study transitions to and from the $n = 1$ level we need to provide more energy; hence the u.v. spectrum, forming the Lyman series, becomes of interest. By this time, the problem has been recognized as that of finding the energy corresponding to the convergence limit of the spectrum lines. This is found by plotting $\Delta\nu$ against $\nu$ for the Lyman series (Figure 8); two curves can be plotted, using the higher or lower values of $\nu$ against a given value of $\Delta\nu$. They converge at a value for $\nu$ of $3.27 \times 10^{15}$ Hz when $\Delta\nu = 0$. From this, the ionization energy of hydrogen is 1300 kJ $mol^{-1}$.

When students appreciate that ionization energies can be measured and have some idea of how this can be done, the information obtainable from a table of successive ionization energies for a variety of elements can be explored. This leads to a refinement of the previous model for an atom into a nucleus plus electrons in specific energy levels (*s*, *p*, *d*, and *f*) and to a correlation between the atomic structure of an element and its position in the Periodic Table.

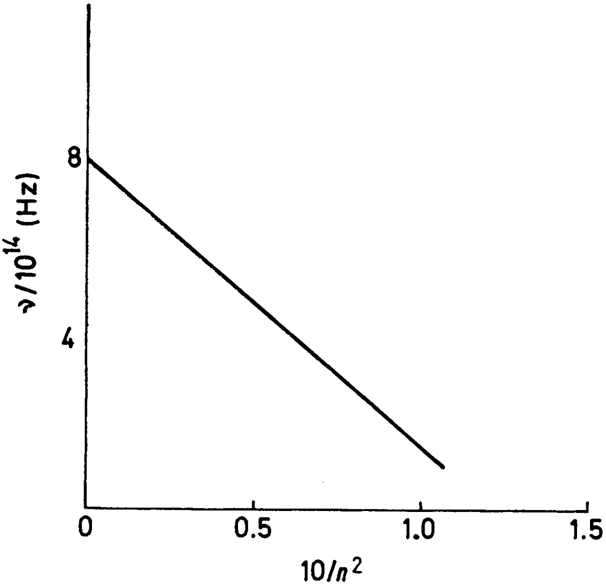


Figure 7

| $\nu/10^{15}$(Hz) | $\Delta\nu/10^{15}$(Hz) |
|---|---|
| 2.466 | |
| | 0.457 |
| 2.923 | |
| | 0.160 |
| 3.083 | |
| | 0.074 |
| 3.157 | |
| | 0.040 |
| 3.197 | |
| | 0.024 |
| 3.221 | |
| | 0.016 |
| 3.237 | |
| | 0.011 |
| 3.248 | |

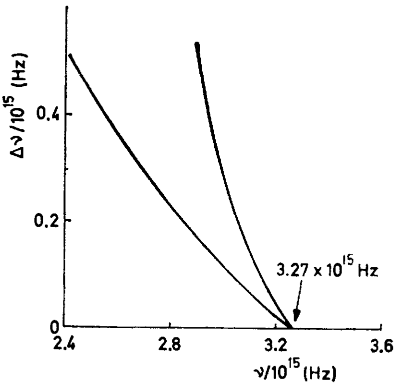


**Figure 8** *Convergence of spectrum lines in the Lyman series*

In this Topic of the course not much individual practical work is possible; in spite of this it is not difficult for students to 'get the feel' of the treatment by working on data obtained by others. There are opportunities for introducing a good deal of historical material, such as the work of Moseley, Rutherford, Geiger and Marsden, and Aston. Technological applications of the ideas and principles which emerge, such as those involved in mass spectrometry, can also be discussed; the Nuffield Student's Book contains a description of the use of the Polyvac atomic emission spectrometer in the rapid analysis of steel.

## 6 Problem of Integration

The desirability of integration within a chemistry course has been mentioned earlier. In this country there has been no real problem in the past at the pre-O-level stage; the major part of all courses at this level consisted of descriptive inorganic chemistry. It was after O-level that chemistry became sub-divided for teaching purposes, generally into the four main branches of inorganic, organic, physical, and analytical chemistry. With the tendency nowadays to regard factual information as part of an overall pattern of properties and behaviour, these sub-divisions are no longer very helpful to an understanding of the subject, especially at sixth form level. There are, of course, occasions in any teaching scheme where it is profitable to concentrate on study in some depth over a small area of the subject; the modern tendency is for the course structure to be so framed that each such study will be illuminated by what has gone before. An integrated presentation of chemistry does pose some problems, particularly in the field of practical work. Conventional treatment of qualitative and quantitative analysis becomes difficult and often unhelpful. This does not mean that analytical techniques are not used; they are regarded as tools which can be employed to assist the investigational process, rather than as ends in themselves.

There are other aspects to integration within the subject. It is desirable obviously, in a course which is to be alive, to integrate theoretical principles with practical work. The need for concepts and models for explanatory purposes should arise from experimental situations. As the second extract given in the preceding section shows, direct experimental experience is not always possible and observation at second hand must sometimes suffice.

Another area of integration is that between principles and social and industrial applications, to link chemical science with chemical technology as closely as possible. In the past, attention has been often confined to manufacturing processes in the heavy chemical industry, accompanied by lists of uses of the products. More recently, there have been attempts to give students some idea of the aims of technology, of some of its achievements in a variety of fields, and of the social, political, and economic consequences of advances in technology. There are major contributions to education for citizenship possible here, but, again, a sense of balance is required; it is easy to let matters sociological and economic swamp the chemistry. The Nuffield Advanced Chemistry course illustrates what is practicable in this kind of integration. The Students' Book contains a number of snippets of information about technological matters, varying from the use of halogen compounds in fire fighting and prevention to a discussion of equilibrium systems with reference to heart and lung surgery. These are intended to provide foci of interest for class discussion and to open windows into the world outside the school laboratory. For deeper treatment a special publication for students' use, 'The Chemist in Action', has been produced. Extensive collaboration with scientists in industry and government departments was undertaken during its preparation. It contains nine case histories of technological ventures in which chemists have played crucial roles, in fields such as the aerospace industry, anaesthetics, the petroleum industry, microelectronics, high polymers, and crop protection. Finally, during the second year of the course, each set of students spends four to six weeks on a Special Study of technological importance, chosen from five at present available: Biochemistry, Chemical Engineering, Food Science, Ion Exchange, or Metallurgy. These provide valuable revision opportunities, since they are firmly based on principles encountered earlier in the course, give experience of experimental work unusual in schools in the past, and involve a great deal of discussion of the merits of technological advances. A question must be answered on the Special Study followed by each candidate in the A-level examination. No attempt is made to test familiarity with specific parts of 'The Chemist in Action' by external assessment; it will, however, often provide candidates with material useful in answering open-ended questions.

At the present time, a good deal of attention is being give to integration between different disciplines, as well as within them. There are obvious advantages, in the school situation, in taking certain areas common to physics and chemistry on a 'combined operations' basis with contributions from staff experienced in one or the other discipline, instead of the chemistry teacher and the physics teacher dealing with them separately and, often, repetitively. Atomic structure, energy transfers, electrochemistry, and radiation are examples of topics that can be dealt with in this way, with a considerable saving of time and effort by all concerned. Chemistry and biology are open to similar treatment but here collaboration is often hampered by the need of the biologists to discuss complex molecules early in the course opposing the wish of the chemist to delay investigation in this area of common interest until a solid foundation of facts and principles has been laid. The craft subjects offer opportunities of mutually profitable interchange of ideas with chemistry, as does geography. There would seem no reason, also, why set books in language subjects should not be scientific in nature, or why essays in the mother tongue should not occasionally involve some degree of popularization of science. The Reviewer realizes that such crossing of borders is easier to commend than to achieve; interdepartmental co-operation on a fairly massive scale is essential to success, as is sympathetic support from those responsible for the curriculum as a whole. This, above all, is an area in which caution is needed. It is distressingly easy to frame a teaching scheme which delights teachers but plunges students into dire confusion by trying to encourage them to learn everything at once. Before knowledge and experience in different fields of endeavour can be integrated they must be acquired.

## 7 Problems of Assessment

Any radically new teaching scheme can be rendered sterile by an unsympathetic examination system. This has been realized by those responsible for the various exercises in curriculum development during the past ten years, with the result that methods of assessment have been given considerable attention. The problem is to devise methods of assessing attainment and ability both in theory and in practical work which involve the minimum disturbance of the work done in a given course, have a reasonable degree of validity, and are acceptable to individuals and organizations outside the school system. The solution lies in preparing a detailed specification of the objectives of the examination, and hence of the course, in advance of the choice of suitable instruments of assessment. The abilities which it is intended that the course shall foster must then be identified, together with the activities that can be used to achieve these objectives. An assessor, whether internal or external, must obviously know the content of the course and the major themes which give coherence to the subject matter. He can then consider the instruments of assessment suited to meeting the needs outlined above.

To use again the Nuffield Advanced Chemistry Project as an example, the information needed by an assessor can be shown (Table 8). The assessor will also need to have in mind the relative weighting that should be attached to the

**Table 8**

| | | |
|---|---|---|
| Intellectual abilities | 1 | Knowledge |
| | 2 | Comprehension |
| | 3 | Application (in both familiar and unfamiliar situations) |
| | 4 | Analysis/evaluation |
| | 5 | Synthesis |
| Students activities | 1 | Consideration of the behaviour of specific substances |
| | 2 | Practical work |
| | 3 | Using patterns in behaviour and structure |
| | 4 | Making measurements and calculations |
| | 5 | Using concepts |
| Major themes of the course | 1 | Materials exhibit specific behaviour and composition |
| | 2 | Materials exhibit patterns in behaviour and composition |
| | 3 | The explanation of behaviour and composition in terms of structure and bonding |
| | 4 | Kinetics |
| | 5 | Equilibria |
| | 6 | Energetics |
| | 7 | The applications of chemistry |

various items in the categories shown. An examination designed to foster the acquisition of knowledge by memorization, for example, would be framed quite differently from one intended to encourage the abilities to analyse and synthesize fairly complex communications.

Where practical work is considered an important element of a course, thought must be given to how it is to be assessed, which presupposes an awareness of the objectives of practical work. These might be:

(*i*) Skill in observation.
(*ii*) Ability to interpret observations.
(*iii*) Ability to plan experiments.
(*iv*) Manipulative skills.
(*v*) Attitude to practical work.

The areas of subject matter which candidates might be expected to cover and the types of practical work (qualitative, quantitative, and preparative) which should be involved must also be known before assessment can become really effective.

During recent years some relatively novel instruments of assessment have been introduced into schools, to supplement the question paper that demands essay-type answers and the practical examination that consists mainly of exercises in volumetric and qualitative analysis. Fixed response questions (of multiple choice and related kinds) are being used increasingly at all levels in the educational system; they can be used to test ability in recall, comprehension, application in familiar and unfamiliar situations, evaluation, and analysis, but are not suited to assessment of ability to marshal a complex argument. 'Yes/no' and short answer questions are similarly useful in that they can involve the candidate in a good deal of creative thinking without demanding a lot of writing. Also valuable is the so-called structured question, where a situation, or a collection of data, or some other fairly lengthy statement is presented to the candidate followed by a number of questions relating to it, which can be answered in a few sentences. The types of question mentioned so far demand fairly specific responses from the candidate. Papers compiled from them can be made to fit in with a predetermined specification, so that the weighting it is desired to attach to particular abilities, or activities, or themes, can be achieved. Marking such questions is also relatively easy. The fixed-response type can be marked by machine.

In some countries all assessment is done by fixed-response questions. The wisdom of this is very doubtful since students are thereby encouraged to give little attention to descriptive writing, which must form a major part of communication between scientists. It is desirable to include in any examination a proportion of questions which can only be answered by a candidate capable of presenting a fairly complex description or argument. These questions can be very open-ended and allow candidates to display evidence of wide reading, originality of thought, and power of critical appraisal. At their best no mark scheme can be applied to them; they must be marked by impression.

Ability in practical work has customarily been assessed by a single practical examination. At best this is an imperfect instrument, being limited in scope when it needs to be applied to large numbers of candidates. Intermittent assessment at intervals throughout the course is much more effective, and, if done during practical lessons, can cover abilities not amenable to written expression (the usual outcome of a practical examination) such as persistence, resourcefulness, compliance with safety precautions, and enthusiasm. Assessment of this kind can only be carried out internally, since the cost of visiting examiners for several sessions is prohibitive. It is very encouraging to find that teachers are being increasingly involved in assessment of their students' practical work. Another growing practice is to use project work by students as part of the evidence of ability in experimentation.

In the field of assessment in general there is much to be done and much to learn. Here space forbids more than a very sketchy survey; more detailed accounts can be found elsewhere.[21,22]

## 8 The Interface between School and University Chemistry Courses

Every teacher, at whatever level of the educational system he or she operates, would like nothing better than to receive students who have mastered all the dull bits of a subject, and all the ancillary requirements, and to be able to concentrate on the exciting and intellectually-rewarding matters. This, alas, is never possible, and if we tried to make it so the likelihood of significant numbers of students having sufficient powers of endurance to reach us eventually would be remote. So we must be prepared to give and take over course content and learning methods. Teachers in secondary schools are just becoming exposed to this kind of situation, from the recent introduction of informal work in science into the primary schools. Properly handled, this can lead to a marked improvement in the attitude towards chemistry of boys and girls reaching the secondary schools, but teachers in these schools must be willing to accept the opinions of their colleagues at the earlier stage about what is taught and how it is taught.

A similar situation has existed for many years between the sixth form courses in schools and the first year of a university course. Co-operation between teachers at the two levels has increased at a most encouraging rate recently and this growth of confidence and mutual respect must continue. The newer ideas in chemistry teaching for sixth forms will undoubtedly pose problems for university teachers but, provided both sides refrain from taking up fixed positions, solutions to them will be found. With the increasing spread of ability amongst sixth form students and the rise in the number of different careers open to them, chemistry must inevitably provide more of a contribution to a general education than has been the case in the past. As a result, sixth form courses will show greater variation amongst themselves and therefore make a smaller direct-contribution to the training of future specialists. On the credit side, if the inten-

[21] Ref. 7, Teachers' Guide II, Appendix 5.

[22] Ref. 7. Examinations and Assessment.

tions of those framing the new school courses are fulfilled, students entering universities and technical colleges will be more enthusiastic, eager to participate in critical discussions, and more expectant of personal involvement in their courses of study. These are attributes which universities will disregard at their peril.

## 9 Future Prospects

Prediction in the educational field is notably more difficult than it is in the realm of science. One always operates on incomplete and often conflicting information. The remark of one contributor to a teachers' discussion—'Whatever we think about the merits of the Nuffield O-level Chemistry Scheme, one thing is certain, chemistry teaching will never be the same again'—probably represents a fairly realistic appraisal of the fascinating possibilities. Curriculum changes will continue. The developing countries are especially active at present, seeing their needs in terms of production of trained technologists. From the U.S.A. one hears rumours of a resurgence of activity in curriculum development. In the U.K. the public examination boards are showing more interest than ever in bringing their syllabuses into line with current thinking; the Association for Science Education is again active in formulating revised policies, as it did in 1957; the first major revision of the Nuffield O-level proposals is under way; and our friends in Scotland are still active in their pioneering efforts. To those of us whose first and abiding intellectual delight lies in unravelling the mysteries of the 'idiosyncrasies of stuff', all this is as it should be.