

THE EFFECT OF EXAMINATIONS IN
DETERMINING THE CHEMISTRY
CURRICULUM UP TO THE
LEVEL OF UNIVERSITY
ENTRANCE

*A Report Prepared for the International Union of Pure
and Applied Chemistry*

*by the
Committee on the Teaching of Chemistry*

FOREWORD

Following the 22nd Conference of the International Union of Pure and Applied Chemistry held in London in 1963 (Minute 19), it was decided to set up a Committee on the Teaching of Chemistry. This committee has now had several meetings and its objects have been outlined in Information Bulletin No. 23 (1965). From the outset, the committee adopted the view that it should not make pronouncements on facets of chemical education unless and until it had at least some of the relevant factual information on the subject. Towards this objective, it has arranged for investigations to be made and reports prepared on a variety of topics. The first two of these investigations were commissioned in 1965.

We were fortunate in obtaining the services of Mr. J. C. Mathews to prepare a report on the importance of examinations at the Secondary School level and this is published in full herewith. Given the choice of an exhaustive report covering all countries associated with the I.U.P.A.C., or a more limited report which could be produced quickly dealing with a smaller number of countries from which data were readily available, we decided upon the latter. Mr Mathews was invited to prepare a report concerning Britain, the United States, some of the European countries, and several British Commonwealth countries for consideration by our committee. This report was discussed at a meeting of the Teaching of Chemistry Committee held in London on February 14th, 1966. The committee was delighted to obtain such a lucid and informative statement concerning the position in the countries mentioned above, and it was decided that the report should be published as presented by Mr. Mathews for dissemination to all members of I.U.P.A.C. It was felt, however, that a useful purpose would be served by adding in due course a further and complementary report dealing with examinations in countries where a different procedure was adopted, namely the Latin members of I.U.P.A.C. such as France, Italy, the South American countries, *etc.* We are glad to say that arrangements are being made to provide this in the near future.

In the meantime we felt that Mr. Mathews' report should be published as it stood and forwarded to all member countries so that they might have the opportunity of seeing the results of our first investigation as quickly as possible.

Member countries will naturally view the report from different angles, but the overall impression of the committee was that in the countries which had been surveyed there was an excessive demand in examinations for the mere recapitulation of factual material. The committee were unanimous in the view that the teaching of chemistry, the stimulation of pre-university students towards the study of our subject, and indeed the future of the study of chemistry in general would be greatly helped if the understanding and use of factual material was emphasized rather than merely learning by rote. This report is disseminated to our member countries in the hopes that it will serve a useful purpose in emphasizing the importance of this modern approach to the teaching of chemistry.

March, 1966

R. S. NYHOLM
Chairman

I.U.P.A.C. Committee on the Teaching of Chemistry

CONTENTS

	Page
Foreword	587
Preface	589
Introduction	591
1. The Setting and Administration of Chemistry Examinations	591
2. The Form of Chemistry Examinations	592
3. The Purpose of a Chemistry Examination and its Effect on Pupils and Teachers	594
4. The Questions—What do They Test?	596
5. What do the Teachers Need to Know from Examiners to Help Them to Devise the Chemistry Curriculum in Schools?	598
6. Some Difficulties of the Examiners	600
7. Summary and Suggestions	602
 <i>Appendices</i>	
A. Questionnaire	605
B. Correspondents and Sources of Information	605
C. Who Sets the Papers?	607
D. The Form of Chemistry Examinations	608
E. Sample Questions With Comments	610
F. Practical Examinations	621
G. The Use of Multiple Choice Questions to Test Particular Abilities	623
H. Extract from “Recent Developments in Science Teaching in Scotland” by A. J. Mee	631

PREFACE

The purpose of this report is to provide information on chemistry examinations and to review the effect of these examinations on the chemistry curriculum in schools.

The committee of the I.U.P.A.C. thought it better to gather information from a small number of countries, provided that these countries gave a reasonable cross-section of examining methods, rather than attempt to review the examinations of a large number of countries; for this reason both the good and bad features of the examinations under review will certainly be found in examinations elsewhere.

Information was obtained by sending a questionnaire (Appendix A) to individuals and to some of the examining authorities in Australia, England, Japan, Northern Ireland, Scotland, U.S.A., and West Germany. More information was obtained by subsequent correspondence with people in these countries. A full list of sources of information is given in Appendix B. Without the generous assistance given by correspondents in these countries this report would not have been possible; I am greatly indebted to them all.

November, 1965

J. C. MATHEWS
*Head of Science, King Edward VII School,
Lytham, Lancashire, England*

THE EFFECT OF EXAMINATIONS IN DETERMINING THE CHEMISTRY CURRICULUM UP TO THE LEVEL OF UNIVERSITY ENTRANCE

INTRODUCTION

For the purpose of this report, the term "curriculum" is extended to include the methods and general approach to the teaching and study of chemistry, in addition to the material and conceptual content of chemistry courses. In other words, the report reviews the impact of examinations on *all* aspects of chemistry teaching in schools.

The influence of examinations on the curriculum is only one of many others. The relative effect of these influences would be difficult to measure and must vary from country to country, school to school, and teacher to teacher; but in considering any one of them it is useful to keep the others in mind. It is suggested that the following influence a teacher's decision on what to teach and the manner in which it is to be taught.

- (i) The teacher's own study of chemistry at school and university.
- (ii) His training as a teacher and discussion with colleagues.
- (iii) Publications: (a) teachers' guides such as CHEM study, Chemical Bond Approach, the Nuffield Science Teaching Project, *etc.*; (b) text-books and courses published by individuals; (c) education journals, and publications by education authorities.
- (iv) Conferences, courses, and participation in trial schemes.
- (v) Examination syllabuses.
- (vi) Specimen examination papers and past examination papers.
- (vii) Other information from examiners.
- (viii) The intellectual level of his pupils.

It is with item (vi) and some aspects of (v) and (vii) that this report is mainly concerned, but they can only be properly considered in relation to the others. Comments from experienced teachers in the countries under review show that although examination pressure varies widely it is usually present in some degree and is often the major influence on the curriculum. This report seeks to show how this influence operates, its effect on the curriculum, and—assuming the necessity for examinations—how it can be put to good use.

1. THE SETTING AND ADMINISTRATION OF CHEMISTRY EXAMINATIONS

The authorities which set and administer pre-university chemistry examinations in the countries under review may be one or more of the following: Education Ministries, Universities, Educational Testing Services, Regional Committees, Professional Organizations (A.C.S. *etc.*), Study

Groups (CHEM Study, *etc.*). Examination papers are usually set by one or more of the following: university teachers, school teachers, professional educational testers, education officials, (Appendix C). It is clear that chemistry examinations are firmly in the hands of teachers (university and school) and those closely connected with teaching.

It is apparent that industrial chemists have little representation in the groups which control the form of the examination and the setting of questions, and examining may well be the poorer for this. Ultimately, industrial chemists will employ many of the candidates; one would expect them to have constructive opinions on the content of questions and, even more important, on the attitudes of mind which the questions encourage.

Amongst those who set examination questions the *proportion* of school teachers is high, but, in general, their *number* is small. The setting of *good* examination questions is arduous, time-consuming work, and difficult for one or two men to maintain without running short of ideas. While the final selection and revision of questions is probably best done by a small group of experienced examiners, there is no reason why they should not invite questions from a much larger group of people: other university and school teachers, industrial chemists, and—indirectly—the pupils themselves. Most of the questions which came in would require revision, but they would frequently contain the germ of a good question which an experienced examiner could put to good use. Some examining authorities, for example in the United States and the Nuffield Project Examinations in England, already draw their questions from teachers not directly concerned with the examining.

In all countries there are a number of examining authorities and often an even greater number of examinations. Sometimes, but not always, this is the result of different States within the countries. In England, where the examining authorities originate from a university or group of universities, there are eight different examining boards, some setting more than one examination at university entrance level (the number is much higher if Entrance Scholarship Examinations of individual universities and the Ordinary National Certificate Examinations are included). Whatever the reason, the great number of examinations in a subject in which one would expect some agreement on basic facts, concepts, and educational abilities, is difficult to justify. While some variety in syllabuses and examinations is to be welcomed, it is difficult to escape the conclusion that there is much duplication of work and waste of resources in the present multiplicity of chemistry examinations. A greater pooling of resources and experienced examiners could well lead to better examinations and hence to better teaching.

2. THE FORM OF CHEMISTRY EXAMINATIONS

Details of the form of the examinations under review are given in Appendix D. For the purpose of this report, questions are classified into four main types: multiple choice, short answer, extended answer, and problem (practical tests are discussed in Sections 6 and 7). All these questions could be further subdivided, but the report would lose clarity by so doing.

Discussion on the form of chemistry papers frequently concerns multiple choice and extended answer questions; it may be worthwhile to set out concisely some of their merits and demerits—no doubt others can be found.

Multiple choice questions

The merits of multiple choice questions include the following:

- (i) They can be objectively marked.
- (ii) They can be marked by machine.
- (iii) They can be adapted to test certain abilities such as judgement, understanding, and application of knowledge, without relying too heavily on other abilities such as a good memory and the ability to write well.
- (iv) They are readily pre-tested for reliability.
- (v) In a given time they allow a greater and more systematic coverage of both syllabus content and abilities than would be possible with extended answer questions.
- (vi) They resemble questions frequently used as a teaching technique.

The limitations of multiple choice questions include the following:

- (i) They do not test fluency in written and verbal expression, creativity, or divergent thinking.
- (ii) In a completely multiple choice type of paper there is no opportunity for a candidate to say *why* he made a choice.
- (iii) The questions are frequently kept secret after the examination.

Unless teachers are provided with adequate specimen papers and other information from the examiners, they may well claim that they are working in the dark (*see* Section 5). On the other hand, the secrecy of the paper plus the wide range of syllabus coverage could well discourage the lamentable practice of “question spotting”, which does much to distort the curriculum.

Extended answer questions

Extended answer questions include many types in which a piece of continuous writing is required by way of answer; their merits include the following:

- (i) They test ability in writing.
- (ii) They test ability to assemble a description or an argument with free choice of facts.
- (iii) They can indicate divergent thinking in a candidate.

Objections to extended answer questions include the following:

- (i) It is difficult to get adequate syllabus coverage with them and this can lead to “question spotting”.
- (ii) They penalize too heavily those candidates of low writing ability.
- (iii) They are not easily pre-tested.
- (iv) The marking of these questions is more subjective than that of others.
- (v) Although the question may aim to test one particular ability, it may fail to do this because of a candidate’s lack of another, *e.g.*, lack of fluency in writing.

The examination papers listed in Appendix D range from some which are completely multiple choice to some which are completely extended answer and problems. In recent years it is interesting to see the growth of a form of chemistry examining which seeks to make use of the merits of all four types of questions; such examinations include: the New South Wales (Australia) Leaving Certificate Examination, the Advanced Placement Examination (U.S.A.), and the Nuffield General Certificate of Education Examination (U.K.). Typical questions from some of these papers are set out in Appendix E.

3. THE PURPOSE OF A CHEMISTRY EXAMINATION AND ITS EFFECT ON PUPILS AND TEACHERS

A chemistry examination may be used to:

- (i) test achievement;
- (ii) indicate a student's potential in the subject;
- (iii) select for further education;
- (iv) select for employment;
- (v) select for monetary or scholastic award;
- (vi) test the effectiveness of the teaching;
- (vii) guide teaching methods;
- (viii) guide pupils and diagnose their difficulties.

To ask an examiner to produce a single examination instrument which will measure all these things could rightly be regarded as unreasonable; but the examiner himself has little control over how or by whom the results of his examination will be used. It is not uncommon for a single examination to be used for all these purposes and each one can add to the pressure of the examination on the curriculum.

Chemistry is usually only one of a number of subject examinations which a candidate for university entrance may have to sit at about the same time. In West Germany the number may be eight for would-be teachers of chemistry (though only three for would-be chemists), in Japan six, and in England as few as three. It follows that in countries such as England a greater depth of chemistry may be expected—although not necessarily achieved—possibly at the expense of a broader education.

The pressure of success in examinations

The *amount* of examination pressure on pupils and teachers depends largely on the extent to which both employers and establishments of further education use examination results in their methods of selection, and it is probably not measurable. Some useful information might arise from an investigation of the selection methods, but it is outside the scope of this report and, even if it were done, it is unlikely to give a quantitative estimation of this pressure. Opinions of experienced teachers could be useful in indicating the amount of examination pressure which exists, but they would remain opinions not measurements. For example, the author would say that in the U.K. examinations are the greatest single pressure on the school curriculum, despite the fact that some university selection methods rely

increasingly on interviews and headmasters' reports; from the U.S.A. Professor J. A. Young says: "The examinations administered on anything like a national level do not have a major impact upon the curriculum at any level, though the small effect is probably most noticeable in the pre-university area . . . I suspect that, by far, the textbooks play a major role in determining the chemistry curriculum here . . ."

The degree to which the use of examination results for selection procedures is allowed to put pressure on the curriculum depends on the social and educational climate of each country, and the reforms to alter this pressure must remain a domestic matter; but the value of studying other examinations in other countries is that it can help those concerned to decide how this pressure can be harnessed and put to good use in influencing the curriculum.

The effect of pressure on the pupil

- (a) He may work harder in order to do well in the examination.
- (b) He may work less hard because he thinks that his chances of passing are slight therefore he might as well not try.
- (c) He might think that the purpose of studying chemistry is to pass examinations.
- (d) He might think that only those things which appear in examinations are important.
- (e) His interest may be increased, particularly if he is anxious to please.
- (f) His interest may be decreased, particularly if he is a divergent thinker faced with an examination, and hence a course, in which everything is said to be either right or wrong.

The pupil who likes examinations is a rarity, if not an oddity. It is surely safe to say that, however necessary they may be, examinations are more likely to decrease rather than increase the enjoyment of chemistry. If the balance between studying because the subject itself is worthwhile and studying to pass examinations swings too far to the latter, the ultimate quality of work is likely to suffer. This is particularly so in chemistry: physics can be applied and enjoyed in the home, biology in something as simple as a walk in the country, but chemistry is more dependent on laboratories. If the pupil does not enjoy his chemistry at school, he is unlikely to enjoy it anywhere or pursue it later in life.

Pressure on the teacher

The pressure of examination success is no less on the teacher. Teachers naturally want to see their pupils do well and their own promotion and esteem may well depend on it. In England it is not unknown for the examination results of a teacher's classes to be quoted when he seeks another post. If a teacher sees his work in terms of examination success—and who can blame him—past examination papers are vital to this end. This is one reason why examination papers which are kept secret after the examination are not popular with teachers.

Passing and failing

Some examination authorities publish their examination results in pass/fail form; they may also grade the candidates both above and below the

pass/fail dividing line. Other authorities publish results simply as grades, leaving those who use the results to decide which grade will divide those they want from those they do not want. The idea of passing, and still more of failing, must exert still more pressure on pupil and teacher and it would appear to be a very crude method of measuring what may be five years work in chemistry. What have the failures failed to do? They may well have failed to do as well as others, but is this failure in any absolute sense?

The constructive pressure of examinations

To say that examinations influence the curriculum by exerting pressure on teachers and pupils is not to say that this influence is necessarily bad. If a chemistry examination is devised, at least partly, with the intent to encourage and guide good teaching methods (see (vii) above), examination pressure can be used to guide the curriculum to what is educationally desirable. An example of how this can be done reasonably quickly is given by the Scottish Education Department (Appendix H).

Questions asked during the chemistry course

A good teacher teaches more by asking than by telling. Throughout the course, the situations encountered in the laboratory become meaningful to pupils as a result of innumerable questions posed by the teacher. If an examination is to encourage good teaching, it must to some extent pose questions which are similar in form and purpose to those which good teaching demands. It is noted that in West Germany the chemistry examination in the Abitur is an oral one, just as most of the teacher's questions are oral. The difficulties of oral examining will be apparent, but, even in written form, a good examination should be regarded as an extension to good teaching.

4. THE QUESTIONS—WHAT DO THEY TEST?

It was implied in the last section that examinations can be used as a positive instrument for good in guiding teaching methods, methods of study, and the syllabus content. To do so requires an exposition of those *educational qualities* which the examination intends to encourage and assess, and not solely the subject matter of the course.

Educational qualities to be tested by the questions

It is necessary before constructing questions for an examination to define these qualities, to ensure that each question is designed specifically to test one or more of these qualities, and to ensure that the examination as a whole is so constructed as to give the desired weight to each quality. Perhaps the best known definition of these qualities is Professor B. S. Bloom's "Classification of Educational Objectives: knowledge, comprehension, application, analysis, synthesis, evaluation". However, opinion must differ as to the best definitions of these educational qualities and the relative weight to be given to

them in the examination. For purposes of example, the qualities set out in the chemistry scheme of the Nuffield Project (U.K.) are quoted:

- (i) the ability to recall information and experience;
- (ii) the ability to devise an appropriate scheme and apparatus for solving a practical problem;
- (iii) the ability to classify and use information, including quantitative results;
- (iv) the ability to interpret information with evidence of judgement and assessment;
- (v) the ability to apply previous understanding to new situations;
- (vi) the ability to report and comment on matters of chemical interest;
- (vii) an awareness of the place of chemistry amongst the other school subjects and the world at large.

The specification of the examination questions

The traditional way of expressing the subject matter has been in the form of an examination syllabus, usually a list of substances and concepts. An examination should be constructed in accordance with a predetermined specification of the subject matter and *abilities* to be tested. In multiple choice questioning the specification can be shown in the form of a two-way grid in which the relative weighting of both subject matter and abilities is set out in terms of the number of questions allocated to each portion of the subject matter and each ability. If an examination specification is to be given to the teachers (an argument in favour of this will be given in Section 5), it could be misleading to show the subject matter as a list of substances and concepts. Both teacher and examiner should know how the subject matter of an examination will be weighted in terms of the *major activities* in Chemistry. For example:

- (i) the study of the composition and changes in materials;
- (ii) the use of practical techniques;
- (iii) the essential measurements in chemistry: how much, how fast, how far, and energy changes;
- (iv) the study of patterns in the behaviour of materials;
- (v) the origin of concepts in chemistry and the use to which they can be put.

Such a detailed specification as that of the multiple choice two-way grid is not so easy, or even possible, in other forms of questioning, but, to quote from Examination Bulletin No. 3 (London, H.M. Stationery Office)—“ . . . an analysis in some form of the objectives and content of the written paper cannot fail to illuminate both the scope and the purpose of the paper. It will ensure that the whole of the course studied is given consideration when questions and marking schemes are constructed . . . ”. In some of the sample questions which were received for this report it was clear that this sort of analysis had been done before and during the constructing of questions, in others it was equally clear that no such analysis had been attempted.

5. WHAT DO TEACHERS NEED TO KNOW FROM EXAMINERS TO HELP THEM DEVISE THE CHEMISTRY CURRICULUM?

If teachers and pupils have examination success as a main objective, teachers will wish to know as much as possible from the examiners before devising the chemistry curriculum in their schools. Furthermore, they would prefer that the information came direct from the examination authority rather than they should guess the examiners' intentions from past papers. Information from examiners may include the following:

- (i) copies of past papers and an examination syllabus;
- (ii) marking schemes for the past papers, examiners' reports on past papers, and meetings with examiners;
- (iii) some indication of the educational qualities and the major areas of the study of chemistry and their relative weighting in the examination (an examination specification), together with specimen papers;
- (iv) a sample teaching scheme or detailed memoranda which suggest a *teaching approach* to the topics listed in the syllabus.

Past papers and examination syllabuses

Examining authorities which publish past papers are shown in Appendix D; it is common practice to do so in all except the multiple choice papers. Some authorities deliberately do not publish a syllabus in the form of a list of topics, seeking rather to give detailed guidance to the teacher (for example, CHEM Study and the Nuffield Project), others do both (Scottish Examination Board).

Teachers can use past papers in three ways: to decide the subject matter of the curriculum, to decide their approach to chemistry teaching, and to spot questions for the next examination. This last use will not be discussed save to say that it is a sorry, usually futile, but understandable activity.

One of the harmful effects of using past papers to determine the subject matter of the curriculum is that it can lead to the inclusion of topics for no better reason than that they were *once* asked in an examination. The examiners may not want to use them ever again, but these topics accumulate on the chemistry curriculum like barnacles on a ship. This is so even when an examination syllabus is available: suppose a syllabus asks for a study of carbon monoxide and that the examiners have asked, at different times, questions on the preparation of carbon monoxide from oxalic acid, from formic acid, and from carbon dioxide. There is nothing to tell the teacher which of the preparations may or may not be asked again so he asks his pupils to learn them all; and, furthermore, he may ask his pupils to learn how carbon monoxide may be prepared by the water gas process, the producer gas process, and from hydrocarbons, just in case the examiner *might* ask them next time. Questions set thoughtlessly by examiners, such as those which begin "Write short notes on . . ." either have the effect of trivial treatment in the curriculum or of overloading it by the more conscientious teacher, who has nothing to tell him where lies the dividing line between "Write short notes on . . ." and "Write an account of . . .".

A teacher has a still more difficult problem if his pupils face an examination for which no syllabus is published, his only information being the past papers. This is so with some of the university scholarship papers set in England, in which guidance for the teacher and candidate appears to be withheld so that there is no limit to the breadth and depth to which the subject may be studied. The high standard of the questions and the competitive nature of the examination are well designed to find out which are the most able and hard working candidates (and teachers), but one must ask whether the discovery of a few very able chemists while still at school is worth the curriculum load such an examination imposes on them, on the unsuccessful candidates, and on the school as a whole.

The effect of past papers on teaching *methods* is straightforward: if the questions ask for recall of information, so will the teachers; if the questions demand judgement, understanding, application, and originality, so will the teachers.

Marking schemes, examiners' reports and meetings

Few would say that in the past, communication between examiners and the whole body of teachers has been either free or fruitful. It is common practice for examiners to give a report after an examination and some examples are given in Appendix E. Too frequently, however, the comments of the examiners are negative in that they tell the teachers what the pupils have done wrong. Teachers are usually only too well aware of what their pupils can do wrong.

Constructive guidance to teachers would be available in the detailed marking schemes. Of the examinations under review no detailed marking schemes are available to the teachers, although in some [Scotland, New South Wales and the Advanced Placement Examination (U.S.)] the mark allocation is shown on the papers. In some cases the detailed marking schemes were not available to the author of this report. One can understand an examiner's reluctance to divulge his marking scheme: when so much may depend on a candidate achieving a certain grade, the examiner may lay himself open to endless disputes with disappointed candidates or with teachers on the candidates' behalf. However, the idea that the examiner is always hidden and omnipotent is not a healthy one for the teaching of chemistry in schools. It is encouraging to discover that some authorities allow more cooperation between teachers and examiners. In New South Wales the Chief Examiner meets teachers, through the Science Teachers' Association, for an exchange of ideas, which are subsequently published. It is worthwhile quoting the Chief Examiner: "This is, I feel, a fruitful meeting, because it helps the teachers to see the point of view of the Chief Examiner whilst he is in the middle of the marking job. It is also possible for the Chief Examiner to receive some helpful advice!"

Another example of positive cooperation of examiners with the examined is that of Professor J. A. Young (U.S.A. Advanced Placement Examination) who has written an article "How to write good answers in an essay examination" [*Chemistry*, **38**, 10 (1965)].

Examination specifications and specimen papers

The resistance of teachers to examination papers which are not published after the examination could be reduced if some examination authorities were more forthcoming with examination specifications and specimen papers. This would involve the examiners in a good deal more work, but not only would it help the teacher to discover what the examiner wants to encourage and assess, it would also make it easier for the examiner to change his specification and the form of his paper and give the teachers adequate and timely information about the changes.

Teaching schemes and teachers' guides

If the only information which a teacher receives from an examiner is in the form of past papers and a list of topics, he usually turns to a text-book to provide him with details for his curriculum. Some texts have been written without a particular examination in mind, but it has been common practice for an author to rely on past papers and examination syllabuses to decide the content of his book; this increases the "barnacle" effect of past papers and also slows down the speed with which changes, examiners may wish to make, can find their way into the school curriculum.

Recent years have seen the publication of schemes of work and teachers' guides in chemistry for use in schools: for example, CHEM Study, C.B.A., the Nuffield Project, and the publications of the Scottish Education Department. Furthermore, these schemes have been linked with public examinations and those responsible for setting the examinations have been closely associated with the development of the schemes so that the examinations have been designed to fit the courses and not the courses to fit the examination. In these circumstances the teacher has much less difficulty when drawing the bounds of his curriculum and deciding his teaching method, because he knows that the examiner will use the same subject matter and seek the same objectives as those of the published scheme. If the examiner wants to test the ability of a candidate to apply knowledge to a new situation, any information which has not been published in the scheme will be given in the question or in a book of data which the candidate can use in the examination. This sort of cooperation between examiners, published teachers' guides, examining authorities, and the teachers and schools, may well eliminate the work in the curriculum which is there simply because the teacher thinks it may be asked in the examination. It does not follow that every teacher is bound rigidly to the same syllabus: the "Options" in the Nuffield Scheme allows considerable choice and specialization; and, *provided the examiner matches it with an equally generous choice of questions*, the teacher and pupil will not be penalized.

6. SOME DIFFICULTIES OF THE EXAMINERS

What has been said so far puts a heavy responsibility and a seemingly impossible number of functions on the examining authorities and their examiners; they may well say, "It has long been known that examiners can

never do right" [Mr. J. A. Petch, Joint Matriculation Board (U.K.), "School Estimates and Examination Results Compared", December 1964]. In fairness, the difficulties which face examiners must be considered and some solutions to these difficulties—where a solution is possible—will be suggested in the final section.

The number of different objectives an examination is expected to achieve

Some of the objectives tend to exclude each other. The more an examination is designed to be objective and reliable in measuring achievement and grading candidates, the less can it be expected to assess those qualities, such as the ability to write a lucid discussion, which can only be marked subjectively.

The number of candidates

With a small number of candidates it is relatively easy to set open-ended questions in which candidates are free to discuss chemical topics without being burdened with the need always to be exactly correct in their conclusions. If such questions are marked by one or two examiners, who have probably set the questions, using a flexible marking scheme or marking purely by impression, it is possible to arrive at a reliable order of merit of the candidates; this is possible in the relatively small numbers of candidates who present themselves for the university scholarship examination in the U.K. Compared with the marking of objective tests, this subjective type of marking will always be more difficult to do reliably; and, if used in the grading or pass/fail type of examination system, it is difficult to get a reliable comparison of results from year to year. When the number of candidates grows to thousands, many more markers are needed and the standardization of the subjective marking becomes very difficult.

Multiple choice and other objective questions

The use of these forms of questioning is becoming more widespread but they too present difficulties. The construction of objective tests, particularly of the multiple choice type, is skilled work and requires much practice. At first deceptively easy to construct, multiple choice items frequently show hidden faults when scrutinized by experienced examiners or when pre-tested on a group of pupils. At the moment there is a shortage of teachers—at least outside the U.S.A.—who are able to devise good multiple choice items and who have the time to do so. Equally, there is a shortage of experienced examiners to assemble objective tests, people and equipment to handle the statistical procedure of the testing and pre-testing, and it may well be more expensive than other forms of examining.

Examining that which it is impossible to examine

Some examiners feel that it is so difficult as to be almost impossible to measure achievement in certain important aspects of chemical education by

I.U.P.A.C. REPORT ON THE TEACHING OF CHEMISTRY

any of the usual methods. Amongst the subject matter, the idea of three dimensional structure is important and should find a place in school chemistry, but it gives rise to a very few *good* questions which would test achievement in this aspect of chemistry and encourage a proper study of it in schools. Amongst the abilities, truly creative and original thought, although undoubtedly present in students at school, by its very nature excludes itself from the examination room.

Practical examinations

The ability to handle apparatus and materials and use them to solve a *real* problem is the hallmark of a chemist and it is not beyond the ability of students at school, but can this ability be measured in a practical *examination*? Over a limited range of technique and subject matter—usually analytical—it is possible to do something (some examples are given in Appendix F), but only at the expense of putting school practical work in a straight-jacket. There are so few forms of practical test, which are capable of being administered to thousands of candidates and of being objectively marked, that an inhibiting effect on school practical work is unavoidable if such examining is attempted.

How can an examiner know what subject matter and abilities he is to test?

In some respects the examiner is in the same difficulty as the teacher, having only a list of topics, past papers, and his own imagination to guide him; and a new examiner cannot suddenly change the test specification of his predecessor.

7. SUMMARY AND SUGGESTIONS

The education and examination systems of the member countries of I.U.P.A.C. are so diverse that the suggestions made here cannot equally apply to all of them; but there are some principles in chemistry examinations which could be common to all countries. It is hoped that this report has done something to analyse the pressures of examinations on the chemistry curriculum and to provide some suggestions which will at least form a basis for discussion when the need for examination reform arises.

(i) Much work on school examinations seems to have been done without a great deal of consultation between countries and sometimes without consultation between examining authorities within a country. A notable exception is the spread of multiple choice examinations from the U.S.A.

(ii) The question of who should control the general policy for the construction and administration of examinations is the private concern of each country; but some blend of university and school teachers, State or Country education officials, professional testing services, and industrialists, seems called for.

(iii) The element of competition in examinations and in the use to which

the results are put is inevitable, and can lead to a healthy pressure on the pupils and teachers to do well. But if universities and employers lean too heavily on the results of school examinations in their selection methods or if they devise competitive examinations in which there is no limit to the amount of work which the competitors and their teachers can do, this pressure may exceed the bounds of healthy pressure and result in young chemists who consider the subject as an examination paper to be passed rather than an intellectual and practical activity to be enjoyed. It would be difficult to determine where the boundary between healthy and unhealthy examination pressure lies and, ultimately, only teachers and pupils can determine it.

(iv) Those countries in which the examination pressure is greatest should not be too dismayed; this pressure can be used to improve both the subject matter and the educational objectives of the curriculum provided that there is a corresponding improvement in the examination. But such a use of examinations requires that much thought and work go into the construction of each question and part of a question, into the pre-testing of multiple choice questions, and into the assembly of the whole examination according to a specification which gives a predetermined weight to individual topics and to individual educational qualities.

In some countries much of the effort in examining seems to go into the marking. While a great deal of work remains to be done to find the best methods of subjective marking, particularly of large numbers of scripts, the use of machine marking can lighten the load of marking. Some of the effort which has previously gone into the marking could then be put into devising better questions.

(v) The final assembly of an examination is probably better in the hands of a small number of people who should be chemists, assisted, in the case of multiple choice examining, by some means of analysing the results of the pre-testing. In the writing of questions, however, the load could easily be spread over many more people: university and school teachers, industrial chemists, even pupils.

(vi) While variety in curricula is inevitable and to be welcomed, is there not a large area of school chemistry on which can be formulated a much smaller number of syllabuses and examinations than the bewildering number that exists at present? Optional syllabuses and optional topics within a syllabus could still be possible, but quantity of alternatives should not be at the expense of quality of the examinations; the latter could well be increased by more pooling of examining experience and resources.

(vii) If an examination is to become a good educational influence as well as an efficient measuring instrument, examiners, teachers, and pupils should know clearly the limits of the subject matter and educational abilities which are to be examined. These things are not clear if the only guides are a list of topics and examiners' reports (in their conventional form), backed by a variety of text books. If in any part of a paper the examiners do not put a limit on the depth of knowledge and understanding of the candidates and teachers (in other words, that part of the examination is strictly competitive) the examiners should say so.

It is a sign of progress in recent years that groups of educationists, (including teachers), administrators, and examiners have cooperated in

publishing schemes for the study of chemistry in schools, together with forms of examination which both assess and encourage the schemes. Accompanied by more information from the examiners in the form of examination specifications, specimen papers, and more constructive reports, these schemes of work could lead to a very fruitful cooperation between those who set and those who sit the examinations.

(viii) A chemistry teacher is rarely at a loss on what to put into his curriculum; his problem is usually what to leave out. The most harmful effects of chemistry examinations have been (a) to overload the curriculum with subject matter, and (b) to concentrate the educational objectives into one objective—the acquisition of knowledge. It seems likely that examination authorities are becoming aware of the dangers of the latter and intend to encourage other educational qualities; but the guiding of pupils to the qualities of understanding and judgement, and a spirit of investigation, is time-consuming. To enable these qualities to be fostered in schools, in which the whole curriculum may well be over-loaded, we must make it possible for teachers to discard all the accumulated material which is learned at present solely for the purpose of passing examinations.

(ix) There is no need for chemistry examinations to become a battleground in multiple choice/short answer/extended answer controversies. Why not make use of the best of all the forms of questioning in a single examination, choosing those which are best for the job in hand. A step in this direction has been taken in the Advanced Placement Examination (U.S.), the Leaving Certificate Examination in New South Wales (Australia), and Nuffield General Certificate of Education "O" level in England—there are probably others which were not reviewed for this report.

(x) If it becomes clear that some aspects of chemistry cannot be properly tested by the methods now in use, it is probably better not to try to do so until better methods of assessment are discovered. The assessment of practical skill is one such aspect. Could not practical work be assessed by the grading of course work by the teachers, together with visits by examiners to schools to examine the equipment, the course of practical work, some laboratory note-books, perhaps to see practical classes at their normal work, and to discuss and give advice to teachers?

(xi) A good examination is an extension of good teaching; it should have the same objectives and, in some respects, the same form of questioning; only thus can it reflect and encourage desirable teaching methods.

Finally, we should remember that experiments with curricula and examinations are, to some extent, experiments affecting the future of individual pupils. This is not an excuse to avoid change, but the first question which should be asked when discussing a change in examinations should be: how will it affect the pupils? The author, as both teacher and examiner, has had this much in mind while writing this report.

APPENDIX A

QUESTIONNAIRE

General information

(1) What public examinations are set and who sets them; *e.g.* Universities, Ministry of Education and Educational Testing Service, *etc.*

(2) The extent to which schoolteachers participate in setting the papers.

(3) The average age of the candidates and the period of study before taking the examination. The fraction of the population of this age who take the examination.

(4) The use which is made of the examination results; *e.g.*, selection for further education, selection for entrance to further examinations, selection for entrance to a career.

(5) The fraction of candidates who obtain a pass or better.

(6) The form in which the results are published; *e.g.*, grades, percentages, pass/fail.

(7) The general form of the syllabus; *e.g.*, the amount of detail in which the syllabus is given and whether any guidance is given on the approach to the teaching of the syllabus.

Particular information about examination papers

(8) The form of the papers; *e.g.*, all multiple choice questions, all short answers, all extended answer questions, a practical test, or combinations of these.

(9) The form of marking; *e.g.*, subjective, objective, machine, or combination of these.

(10) Whether candidates are allowed to take books into the examination.

(11) Whether past papers are available to candidates or teachers or both.

(12) A sample of typical questions from a paper which reflects the level of each public examination, preferably for 1965. The number of questions in the sample will depend on their type; as a rough guide, questions for about two hours of examination time would be sufficient.

(13) A marking scheme for each of the questions, indicating what marks would be awarded for and particularly the average depth of knowledge and conceptual ability which is expected.

(14) Some indication of what educational qualities each question is designed to test; *e.g.*, knowledge, comprehension, application to new situations, judgement, ability to write a report or comment on matters of chemical interest.

(15) Whether the questions are pre-tested on a sample of the age group to determine whether they are suitable for their purpose.

APPENDIX B

CORRESPONDENTS AND SOURCES OF INFORMATION

Professor G. A. Barclay. University of New South Wales, Australia.

Mr. E. N. Barker. Department of Education, Box 33, GPO Sydney, New South Wales, Australia.

I.U.P.A.C. REPORT ON THE TEACHING OF CHEMISTRY

- Dr. Erwin Baurmann. Formerly O.E.C.D., Paris, France.
Mr. N. Booth. H.M.I., Ministry of Education, England.
Professor J. A. Campbell. Harvey Mudd College, Claremont, California, U.S.A.
Mr. D. G. Chisman. Royal Institute of Chemistry, London (now Science Education Officer, British Council, London), England.
Dr. Frank Fornoff. Educational Testing Service, Princeton, U.S.A.
Mr. R. Ganef. Division of Science Teaching, Department of Advancement of Science, UNESCO, Place de Fontenoy, Paris 7^o, France.
Dr. Wolfgang Holbing. Arbeitskreis der Leiter und Lehrer öffentlicher Fachschulen für Chemotechnik, West Germany.
Dr. A. J. Harte. Chemistry School, University of Sydney, New South Wales, Australia.
Mr. J. McG. Jackson. H.M.I., Belfast, Northern Ireland.
Dr. A. J. Mee. H.M.I., Scottish Education Department, Scotland.
Dr. R. J. Merrill. CHEM Study, University of California, Berkeley, U.S.A.
Professor D. J. Millen. University College, London, England.
Professor Fr. Mutscheller. Deutscher Verein zur Forderung des Mathematischen und Naturwissenschaftlichen Unterrichts e.V., West Germany.
Professor R. S. Nyholm. University College, London, England.
Professor M. Oki. University of Tokyo, Japan.
Mr. Seizo Otsuka. Division of Primary and Secondary Education, Ministry of Education, Kasumygasaki, Tokyo, Japan.
Dr. P. J. Padley. Department of Physical Chemistry, University of Cambridge, England.
Dr. B. C. Saunders. University Chemical Laboratory, Cambridge, England.
Dr. A. G. Sharpe. Jesus College, Cambridge, England.
Dr. Peter Sykes. Department of Organic Chemistry, Cambridge, England.
Professor B. Tamamushi. Tokyo Women's Christian College, Iogi, Suginami-ku, Tokyo, Japan.
Mr. H. Templeton. State Education Department (Regents High School Examination), New York, U.S.A.
Professor J. A. Young. King's College, Wilkes Barre, U.S.A.

School Chemistry—Trends in Reform. O.E.C.D. (1963).

Memoranda and Publications of the Scottish Education Department.

Examinations and the Curriculum. Report No. 4, Ministry of Education, England.

Past Papers and Examination Syllabuses of the English Examining Boards.

ETS Builds a Test. Educational Testing Service, Princeton, U.S.A.

Course Work—Teacher Assessment. East Midland Regional Examination Board, Certificate of Secondary Education, England.

Examinations Bulletins. H.M. Stationery Office, London, England.

CHEM Study Publications.

Nuffield Foundation Science Teaching Project Publications.

“True or False?”. *Education in Chemistry* 2, No. 3 (1965).

B. S. Bloom. *Taxonomy of Educational Objectives.* Longmans, London (1956).

Publications of the Examining Authorities shown in Appendices C and D.

APPENDIX C

WHO SET THE PAPERS?

Australia

New South Wales, Leaving Certificate Examination

Set by a university teacher. Assessed by an education inspector and one other person.

England

General Certificate of Education

Set and moderated by university and school teachers in eight separate examining authorities.

Certificate of Secondary Education

Set and moderated by school teachers in Regional Boards.

University Scholarship Examinations

Set by university teachers.

General Certificate of Education (Nuffield Alternative)

Questions are invited from teachers with experience of the Nuffield Project. The examination is then devised by two school teachers with the assistance of an educational research team.

Japan

National Examination. (Equivalent to Upper Secondary School Graduation)

Set by two school teachers with the assistance of one official from the Ministry of Education.

Northern Ireland

General Certificate of Education

School teachers do not set the papers, but they have majority representation on the committee which draws up the syllabus.

Scotland

Scottish Certificate of Education

Set by the Inspectorate of the Scottish Education Department. From 1966 onwards the papers will be set by school teachers and these will be moderated by a panel of one Inspector, one university teacher, and one school teacher.

Germany

Abitur

Oral examination by an examination board consisting of two teachers and one person nominated by the education authorities.

U.S.A.

CHEM Study

Test designed by CHEM Study staff with the aid of questions submitted by teachers.

New York, Regents High School Examination. The Advanced Placement Examination. College Entrance Examination Board. American Chemical Society High School Chemistry Test

It appears that the common practice in all these examinations is to invite questions from teachers. The tests are then devised by a small committee.

APPENDIX D

THE FORM OF CHEMISTRY EXAMINATIONS

Australia

New South Wales, Leaving Certificate Examination

Paper A.—Sixty multiple choice questions. Pre-tested and confidential.

Paper B.—Short answer, extended answer, and simple problems.

Honours paper.—Short answer, extended answer, and problems. Paper is of a higher level than B.

Paper B and the Honours paper are available to teachers.

England

General Certificate of Education

Ordinary level.—Age is approximately 16 years. Short answer, extended answer, simple problems. Some authorities set practical examinations.

Advanced level.—Age is approximately 18 years. Mostly extended answer and problem questions. A practical examination. None of the papers is pre-tested. Papers are available to teachers.

University Scholarship Examinations

Usually extended answer and problem questions. There are some practical examinations. The papers are not pre-tested; they are usually available to teachers.

Certificate of Secondary Education

Not fully in operation. Examination varies from region to region. Age of candidates will be approximately 16 years.

I.U.P.A.C. REPORT ON THE TEACHING OF CHEMISTRY

General Certificate of Education (Nuffield Alternative)

Paper I.—Multiple choice, probably secret and pre-tested.

Paper II.—Section A: short answer (programmed questions).

Section B: extended answer.

Germany

Abitur

Oral examination. Five of the Landers also use a practical test.

Examination in schools for chemical technicians

Extended answer. Practical test. Papers available to teachers. Papers not pre-tested.

Japan

National Examination (Equivalent to Upper Secondary School Graduation)

Multiple choice and short answer. Papers are secret, and not pre-tested.

Northern Ireland

General Certificate of Education

Ordinary Level.—Short answer, extended answer, simple problems, practical test.

Advanced Level.—Extended answer, problems, practical test. Past papers available, not pre-tested.

Scotland

Scottish Certificate of Education

Short and extended answer. Past papers available, not pre-tested.

U.S.A.

CHEM Study

Multiple choice. Pre-tested. Papers available to teachers but not to students.

New York, Regents Examination

Part I.—Multiple choice. Pre-tested. Not secret.

Part II.—Short answer.

Advanced Placement Examination

Part I.—Multiple choice. Secret and pre-tested.

Part II.—Extended answer and problems.

College Entrance Examination Board

Multiple choice. Secret and pre-tested.

APPENDIX E

SAMPLE QUESTIONS WITH COMMENTS

The following questions are selected from the many examination papers which the author received. To have reproduced all these papers would have given rise to a very unwieldy document, so the author has chosen questions on which he can raise specific comments either about the question itself or about an examination as a whole. Those who would like to see the whole examination papers may find the source in Appendix C. There is no intention to single out particular examinations for recommendation or for adverse criticism—good and bad questions and examinations can be found in all countries. Ruthless criticism of questions is good for the examiners and for those who criticize; it, at least, makes all concerned think hard about what each question will do both as a means of assessment and as a formative influence on teaching. The author's comments themselves will be criticized and rightly so; the perfect question and the perfect comment have yet to be written.

England, General Certificate of Education "A" Level

The first three questions are taken from the General Certificate of Education "A" level, 1965. The age of the candidates is approximately 18 years, and the examination is used for university and employment selection.

Question 1

Describe the experimental determination of molecular weight by Victor Meyer's method. State the theoretical principles underlying this method and the types of substance for which the method is suitable.

How does Victor Meyer's method differ from that of Dumas, and what advantage does it possess over that of Dumas?

In a Victor Meyer's determination of the molecular weight of iodine (of normal boiling point 184°C), the heating vessel was maintained at 450°C . A mass of 0.500 g of iodine was used and the volume of displaced gas, collected over water at 15°C was 48.0 cc. The barometric pressure was 743 mm Hg (vapour pressure of water at $15^{\circ}\text{C} = 13$ mm Hg). Calculate the molecular weight of iodine and comment on the value found.

Examiner's report.—This was a popular question, with the experimental detail of Victor Meyer's method described at great length. Many candidates, however, cannot correct volumes correctly to S.T.P. or allow for the partial pressure of the water vapour. There was widespread confusion between the atomic and molecular weights of iodine and erroneously high values obtained for the molecular weight were generally attributed to dissociation.

Author's comments.—One wonders what educational value there is in being able to describe the experimental detail of Victor Meyer's method at great length. In the author's experience the best method of obtaining good

examination results in this type of question is to show the apparatus to the pupils and then give them concise notes to be learned nearer to the time of the examination. Candidates would have done better if they had had more mechanical practice on arithmetical problems with the Ideal Gas Law; but to what end? There is no *real* problem in this calculation, except in the comment asked for at the end.

Question 2

Name one important ore of zinc and describe how the pure metal is extracted from it. Indicate the chemical principles involved, but do not give details of industrial plant.

Compare and contrast the properties of zinc and magnesium by describing how and under what conditions they react with: (a) dry air; (b) sodium hydroxide; (c) nitric acid.

Examiner's report.—The extraction of zinc was answered well; the remainder of the question was answered badly. In the reactions with sodium hydroxide some alleged that sodium was precipitated. The action of nitric acid on the metals produced some wild guesses, including the allegation that nitric acid rendered one or other of the metals passive.

Author's comments.—This question demands nothing but recall; asking for a statement of "principles" should not be thought to be a test of understanding or judgement—"principles" can be *learned* equally as well as facts. How many pupils would have really *investigated* the reactions of zinc and magnesium? To have done so would have been time-consuming and a handicap in obtaining a good examination result. For good results: good teachers' notes or a concise revision book, coupled with a teacher of sufficiently forceful personality to make or persuade his pupils to learn the necessary information. Note that the teacher is given no help in deciding which extraction of zinc to teach; if the method in his text-book is obsolete will it matter to the examiner? A good chemist must know many facts, but only if they can be put to good use. Would not a better approach to this question have been to give the candidate a description of a modern process for extracting zinc followed by a series of short answer (or multiple choice) and extended answer questions posing problems or asking for comparisons and comments on the process. This is how this topic should have been taught. As it stands, the question implies that the teacher simply gives the information to the pupil and then asks for the same information back again in the same form.

Question 3

Three unsaturated dichloro-olefins exist having the molecular formula $C_2H_2Cl_2$ and two unsaturated dicarboxylic acids with the molecular formula $C_4H_4O_4$. How do you account for the existence of these isomers? Discuss, where appropriate, the stereochemical principles involved.

Describe two ways which would enable you to assign to each its structure if you were given specimens of the two unsaturated dicarboxylic acids.

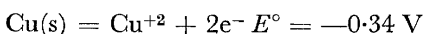
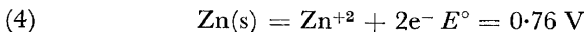
Examiner's report.—This was the least popular question, but answered well by the few. Restriction of free rotation as the basic reason for this form of isomerism was generally appreciated, but few know of the contingency that the end-groups must be different. The assignment of structure was well done *on paper*, but “easily forms an anhydride” left some doubt as to just how the anhydride formation was intended to be ascertained.

Author's comments.—One can well understand why this was “the least popular question”. It is a searching and difficult question, but a good one in the sense that it is likely to differentiate between those who understand and those who simply learn. But in this examination candidates had a choice of question; those who chose this type of question were being tested for something quite different from those who chose the same type as questions (1) and (2) above (all three of these questions came from the same paper). If on this paper two candidates both obtained the Grade B, one could be Grade B for his powers of memory, the other for quite different qualities; how are those who use the results to know?

U.S.A., Advanced Placement Examination

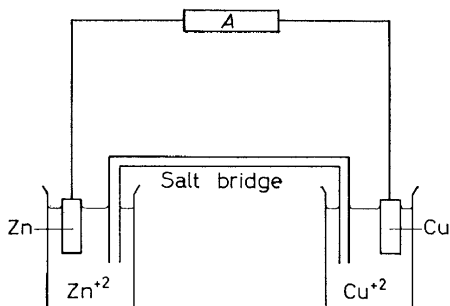
The following six questions are taken from the U.S.A., Advanced Placement Examination, Section II. The age of the candidates is 16–17 years. Comments are given after the last one.

Questions 4–9



$$2.3 \frac{RT}{F} = 0.059 \text{ at } 25^\circ\text{C}$$

A cell is set up to plate zinc onto a zinc electrode. The loss of weight of a copper electrode is used to determine the amount of current passed.

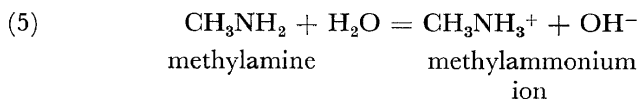


(a) Assuming box *A* to be a source of direct current, if 100 ml of a solution of Zn^{+2} , initially at a 1.00-molar concentration, is electrolyzed until 1.00 per cent of the original Zn^{+2} remains in solution, (i) how many coulombs are required (ii) how much weight does the copper electrode lose?

I.U.P.A.C. REPORT ON THE TEACHING OF CHEMISTRY

(b) Assuming box *A* to be a voltmeter, what is the standard potential of the cell?

(c) What is the minimum voltage to be applied to this cell if the electrolysis is to continue until the concentration of Zn^{+2} reaches 1.00 per cent of the original? (Assume that the concentration of Cu^{+2} reaches 1.00-molar and that the temperature is 25°C.)



The equilibrium constant for the reaction of methylamine, an organic base, with water is 4.4×10^{-4} mole/l. The solubility product constant for magnesium hydroxide is 1.2×10^{-11} . These data and the calculations below are for solutions at 25°C.

(a) Calculate the hydroxide ion concentration in a 0.10-molar solution of the amine.

(b) If equal volumes of this 0.10-molar solution and of a 0.020-molar magnesium chloride solution were mixed, would there be a precipitate of magnesium hydroxide? Show your calculations.

(c) Would a precipitate form if the final solution were also 0.025-molar in methylammonium chloride? Show your calculations.

(6) Give an explanation for each of the following observations.

- (a) The boiling point of CBr_4 is distinctly higher than that of CCl_4 .
- (b) The boiling point of CH_3OH is distinctly higher than that of CH_3Cl .

(7) In each of the following cases, a slight excess of dilute base is added to a 0.05-molar solution of acid. The resultant heats of neutralization per mole of acid reacting are indicated for each acid-base reaction.

	<i>Heat of neutralization</i>
(a) $HCl + NaOH$	13.7 kcal
(b) $HNO_3 + KOH$	13.7 kcal
(c) $HCl + NH_3$	12.6 kcal
(d) $CH_3COOH + NaOH$	13.4 kcal
(e) $HClO_4 + KOH$	13.7 kcal

Account for the fact that the heats are the same in (a), (b) and (e) but are different in (c) and (d).

(8) You are given a sample of ordinary chloride, some glassware, a crucible, a 3 V battery, an ammeter, wires, distilled water, carbon tetrachloride, a bunsen burner, a balance, equipment for supporting a crucible or beaker, and a selection of thermometers. Your problem is to obtain experimental evidence for the assertion that sodium chloride is electrovalently bonded. Describe a series of relevant observations and experiments. Explain how the concept of ionic bonding gives a consistent interpretation of all of the observations and experiments.

I.U.P.A.C. REPORT ON THE TEACHING OF CHEMISTRY

(9) Discuss a chemical and a physical method for the determination of atomic weights. State what experimental data are needed and show how the data may be employed to achieve the desired objective. Indicate any assumptions that are made in the use of each method.

Author's comments.—In all there were 21 questions in Section II, to be answered in two hours and the variety of *types* of questions was even greater than that indicated by this sample. Furthermore, Section I (kept secret) was a multiple choice paper, presumably with an equal variety of types of question.

The examiner's instructions for questions 6 and 7 were: "Brief and specific answers are preferable to broad diffuse responses". Each question seeks to test the candidates' understanding of carefully limited principles. It should be clear to the candidates what is expected of them and if they know the answers they are not likely to waste time with irrelevancies.

The examiner's instructions to questions 8 and 9 were: "Select one of the essay topics presented below and spend about 30 minutes on it. The essay question is included to give you an opportunity to demonstrate your ability to think clearly and to present your material in logical, convincing and coherent English. The essay will be judged on the basis of the accuracy and the importance of the detail cited, the appropriateness and the scope of the descriptive material used and its organization. The use of diagrams, equations or tables may help".

The impressive things about this examination are (a) the variety of types of questions which the examiner is prepared to devise in order to give adequate coverage of both subject matter and abilities; (b) that the examiner is prepared to help the candidates—and the teachers—by stating in the last two questions what abilities he was testing and the manner in which the candidates could best display these abilities.

U.S.A., CHEM Study Achievement Test

The following four questions are taken from a CHEM Study Achievement Test 1964–5. Comments are given after the last one.

Questions 10–13

Questions 10 through 13 refer to the following situation. A chemist working for a toothpaste firm wishes to prepare 250 ml of a 0.010 molar aqueous solution of stannous fluoride, SnF_2 . Fortunately for him, SnF_2 is soluble in water. One mole of SnF_2 weighs 156.7 g. Equipment available includes a 250 ml volumetric flask, a 10 ml pipet, a 0.01 g sensitivity balance, and a 400 ml beaker.

(10) The amount of solid SnF_2 that should be weighed out is:

- (1) 0.010 g
- (2) 0.39 g
- (3) 1.57 g
- (4) 39.20 g
- (5) 156.70 g

I.U.P.A.C. REPORT ON THE TEACHING OF CHEMISTRY

(11) Once the proper amount of SnF_2 is weighed, which one of the following procedures would be best?

- (1) Place the SnF_2 in the beaker and add exactly 250 ml of water from the volumetric flask.
- (2) Place the SnF_2 in the beaker and add exactly 250 ml of water from the pipet in 10 ml portions.
- (3) Place the SnF_2 in the volumetric flask, dissolve it in somewhat less than 250 ml of water, and then dilute to the 250 ml mark.
- (4) Using the beaker and balance, weigh out exactly 250 g of water and add the SnF_2 to it.
- (5) Dissolve the SnF_2 in somewhat more than 250 ml of water in the beaker, mix thoroughly, and then fill the volumetric flask to the line with the solution.

(12) Once the solution has been properly prepared it is placed in a 500 ml stoppered bottle, shaken thoroughly, and then allowed to stand for two weeks. At that time, all of the following statements would be true *except one*. Identify the statement that is *wrong*.

- (1) Equilibrium has been reached between the solution and the vapor above it.
- (2) Samples drawn with a pipet from near the top and from near the bottom of the bottle have significantly different concentrations of SnF_2 .
- (3) No crystals of solid SnF_2 are found in the flask.
- (4) The boiling point of a sample of the solution is found to be slightly higher than that of pure water.
- (5) The bottle contains only one liquid phase and one vapor phase.

(13) A sample of the solution is tested and found to be a good electrical conductor. Which one of the following statements is *wrong*?

- (1) The solution contains electrically charged particles called ions.
- (2) Although the conducting solution is mostly water, pure water is a very poor conductor of electricity.
- (3) The solution has no net electric charge.
- (4) When solid stannous fluoride dissolves in water, $\text{Sn}^{+2}(\text{aq})$ and $\text{F}^-(\text{aq})$ are formed.
- (5) Solid SnF_2 must also be a good electrical conductor.

Author's comments.—These questions are included to illustrate some of the uses to which multiple choice questions can be put. In addition to recall of knowledge, these four questions require other educational qualities: understanding and judgement are called for, coupled with the ability to apply them to new situations (candidates were allowed to take text-books, laboratory manuals, and notebooks into the examination).

The questions are also of the same type that might be used by a teacher in class as part of his teaching technique. In this group of questions there appears to be too high a proportion asking for a WRONG statement, but, in the paper as a whole, this was not so.

England, Nuffield General Certificate of Education, "O" Level

The following four questions are taken from a *specimen* paper, for the Nuffield "O" level General Certificate of Education, 1966. The age of the candidates is approximately 16 years. Results are used for selection for further education and employment.

Questions 14–17

(14) An atom of bromine weighs more than an atom of hydrogen. Which of the following contains the greatest number of molecules?

- (a) 1 g of methyl bromide, CH_3Br ;
- (b) 1 g of methylene dibromide, CH_2Br_2 ;
- (c) 1 g of bromoform, CHBr_3 ;
- (d) 1 g of carbon tetrabromide, CBr_4 .

(15) In the electrolysis of fused calcium bromide two g-atoms of bromine are formed for each g-atom of calcium. Which of the following is the most reasonable conclusion?

- (a) The atomic weight of bromine is twice that of calcium.
- (b) The charge on a calcium ion is opposite and double that on a bromide ion.
- (c) The radius of a bromide ion is twice that of a calcium ion.
- (d) The formula of calcium bromide is Ca_2Br .

(16) In an experiment to determine the approximate dimensions of a molecule of oleic acid, 1 ml of oleic acid was dissolved in 9 ml of ether to make 10 ml of Solution *A*. 1 ml of Solution *A* was dissolved in another 9 ml of ether to form 10 ml of Solution *B*. One drop of Solution *B* was allowed to fall on to water which had been dusted with talc. A thin film of 1,000 sq. cm of oleic acid was obtained on the surface of the water.

- (a) Calculate the volume of oleic acid in 1 ml of Solution *B*.
- (b) Calculate the volume of oleic acid in the one drop of solution which fell onto the water. Assume that there are 20 drops in 1 ml.
- (c) What is the size of an Angstrom unit in centimetres? Calculate the thickness of the film in Angstrom units.
- (d) For the experiment to be successful, the film must contain no ether. What happens to the ether?
- (e) How would you show that the ether does not affect the size of the film of oleic acid?

I.U.P.A.C. REPORT ON THE TEACHING OF CHEMISTRY

- (f) What assumption about the film must be made before you can say that its thickness represents the approximate dimensions of a molecule of oleic acid?
- (g) Suppose you had no ether. In choosing a substitute solvent, state one property it must have.

(17) "Chemical equations cannot be written until:

- (a) The composition and therefore the formula of each of the products and the reactants is known, and
- (b) the relative numbers of gram-molecules or gram-ions is known."

Illustrate this quotation by describing how you have determined by experiment the relative numbers of gram-particles which react and are produced in a reaction, in order to construct an equation for the reaction. (You may assume that the formulae of the reactants and products were known). You should describe what you did, and what measurements you made (do not quote actual quantities), and how you used these measurements to construct an equation. Do not give details of practical techniques; for example, how to use a pipette and burette.

Author's comment.—Questions (14) and (15) are part of the multiple choice section of the examination, containing between forty and sixty items. They illustrate how understanding and judgement can be tested by multiple choice questions. Teachers could devise many variations of both these questions and practice in them might be thought to be better for the pupils than practice in the recall type of question.

Question (16) was one of seven short answer questions of which the candidates had to do four. The main feature of this sort of question is that it presents a practical situation which the candidates should have met as part of the Nuffield Scheme; but, instead of simply asking "Describe an experiment to determine the approximate dimensions of a molecule of oleic acid", the experiment is described in outline and a series of programmed questions follow which resemble the sort of questions which the teacher would pose to his class while they were actually doing the experiment. This is one way in which an examination can reflect and encourage a teaching method.

Question (17) was one of seven extended answer questions of which the candidates had to do two. Not only is a wide choice of topic given, there is also a choice of experiment within the question. Of course, a detailed and rigid marking scheme is not possible and the question will probably be marked by impression, but this sort of question does give the candidate an opportunity to demonstrate those educational qualities which are not tested by the multiple choice and short answer questions.

These questions have been chosen to illustrate the three sections of the Nuffield examination and to show how variety in types of questions can be used to test a variety of abilities within the same examination.

Australia, New South Wales Honours Leaving Certificate

The next question is taken from New South Wales, Honours Leaving Certificate, 1964. The age of the candidates is approximately 17 years.

Question 18

The following is an extract from a table of Standard Electrode (Reduction) Potentials:

	<i>Standard Electrode Potential (volts)</i>
$K^+ + e^- = K$	-2.92
$Zn^{2+} + 2e^- = Zn$	-0.76
$Cu^{2+} + e^- = Cu^+$	+0.15
$Cu^{2+} + 2e^- = Cu$	+0.34
$Cu^+ + e^- = Cu$	+0.52
$Fe^{3+} + e^- = Fe^{2+}$	+0.78
$Cl_2 + 2e^- = 2Cl^-$	+1.36
$MnO_4^- + 8H^+ + 5e^- = Mn^{2+} + 4H_2O$	+1.52
$F_2 + 2e^- = 2F^-$	+2.87

With the help of the table comment critically upon, and explain as far as possible, the following:

(i) The use of ammonium iron (II) sulphate 6-water as a suitable substance for the standardization of a potassium permanganate solution.

(ii) The suitability or otherwise of each of the following alternative iron compounds for the purpose indicated in (i):

(1) iron (II) sulphate 7-water;

(2) iron (II) chloride 4-water;

(3) iron (III) chloride 6-water.

(iii) The stability of simple copper (I) (cuprous) salts.

(iv) The relative strengths of chloride ion and iron (II) ion as (1) electron donors; (2) electron acceptors.

(v) The e.m.f. of, and terminal polarity of, the Daniell cell with electrolyte concentrations of 1 molar.

Author's comment.—This is a good example of the type of question which tests the ability to handle data and make judgements based on the data. This, however, was not a complete question and illustrates a common criticism of some of the newer types of examination—that the questions are too long (in this paper 10 minutes reading time was allowed). This is not sufficient reason for rejecting questions which ask candidates to comment on given information; such questions are an essential part of the formative influence which has been advocated in this report; but a partial solution to the difficulty would be to provide each pupil with a concise *book of data* which he can take into the examination and from which he can seek out such data as are necessary for answering the questions. In some respects this would be better than allowing a candidate to take a text-book into the

examination (see the CHEM Study examination)—too much information can be a handicap.

Japan, National Examination

The next question is from the Japan National Examination. The average age of the candidates is 19–20 years.

Question 19

This very long question described the estimation of acetic acid in vinegar by titration with standard sodium hydroxide using phenolphthalein indicator. There followed diagrams of (a) an Erlenmeyer flask, (b) a 100 ml graduated flask, (c) a measuring cylinder, (d) a pipette, (e) a burette.

(i) Which of these pieces of apparatus is unnecessary in the experiment which has been described?

(ii) Assuming that both the pipette and the burette have been rinsed with water, which of the following is the best technique before using them?

- (a) To dry both of them with heat.
- (b) To use them both as they are.
- (c) To use the burette wet, but the pipette after drying with heat.
- (d) To use the pipette wet, but the burette after drying with heat.
- (e) To use the burette after repeated rinsing with the standard sodium hydroxide solution, and the pipette after repeated rinsing with the vinegar.

(iii) Which of the following is most applicable to the use of the Erlenmeyer flask?

- (a) The flask should be thoroughly dried.
- (b) It does not matter if the flask is moist with water.
- (c) A little water should be added to the flask.
- (d) The flask should be rinsed with vinegar.
- (e) A volume of water equal to that of the vinegar should be added to the flask.

Author's comment.—This is an interesting attempt to assess laboratory work by means of written questions and answers. Similar questions have been used by the Scottish Education Board and the Nuffield Project. It would be difficult for a candidate to answer this type of question correctly if he had never handled apparatus for analysis. A good deal of variety can be introduced into this type of question, and, no doubt, these questions will encourage individual practical work by pupils. But there is a difference between testing a pupil's knowledge of practical techniques and his actual practical ability; the latter could only be assessed on his skill in the use of apparatus in *experiments which he actually does*. More will be said on the testing of practical skills in Appendix F.

England, Cambridge University Scholarship Examination

The next three questions are taken from scholarship examinations (1964) of Cambridge University. These examinations are very competitive, and the standard required from those who are awarded scholarships is probably as high, if not higher, than that required in any other school examination. The average age of the candidates is approximately 18 years; they are expected to attempt six questions in three hours. There is a practical examination. There are types of question in the examination other than the following three examples; these were chosen to illustrate their possible effect on the curriculum.

Questions 20–22

(20) A phenol U , C_7H_8O , is reduced by hydrogenation to V , $C_7H_{14}O$, which is oxidized in two stages, first to a ketone W , $C_7H_{12}O$, and then to an acid X , $C_7H_{12}O_3$. The acid on reduction with hydrogen and a catalyst forms Y , $C_7H_{14}O_3$, which on dehydration gives Z , $C_7H_{12}O_2$. Both X and Z may be oxidized to acetic acid and glutaric acid ($HOOC.(CH_2)_3.COOH$). Elucidate the reactions involved and write structural formulae for U , V , W , X , Y , and Z .

(21) Discuss the advantages and disadvantages for representing chemical bonds by single or multiple lines between symbols for atoms. Give examples from organic and inorganic chemistry where such a representation is appropriate.

(22) Write an essay on *Complex Ions*.

Author's comment.—These questions are well designed to fulfill their purpose, which is to choose from a small number (by national standards) of candidates those of the highest attainment to whom scholarships will be awarded. Questions, such as Question (20), demand a high level of deductive powers and are popular with able candidates because of the stimulation of a problem to be solved. Repeated practice in this type of question can improve a candidate's performance, so it may not be such a good test of deductive powers as at first seems. Furthermore the situation is an artificial one in school chemistry and one wonders if the time spent in practising this type of question may not have been better spent in attempting to solve practical problems which fall more within the scope of practical chemistry in schools.

The examiner says that he looked for "comprehension, logical argument, and judgement" in Question (21), and "ability to write a logical essay and to choose the important features of a subject" in Question (22). These questions clearly demand these abilities, and experience shows that some candidates can produce essays of a very high standard on these topics. The topics themselves are appropriate to the study of chemistry in schools, but from the teachers' and pupils' points of view the difficulty is to know where the study of these topics should stop in schools. This sort of question can result in much time being spent in learning facts and studying concepts which may well be

repeated in the subsequent university course. Furthermore, candidates will almost certainly have spent much time in writing essays of this type partly to obtain practice in so doing and partly in the hope that a question on a similar topic will arise in the examination. One wonders whether so much practice in writing essays on these topics bears much relationship to the functions of practising chemists. It is understandable that the chemistry of examinations is different from the chemistry of school, university and industrial laboratories; but just as chemistry examination questions could be brought closer to the work and questioning which goes on in school, so could they be brought closer to the work which candidates may meet in their careers. Unreal as they are, examinations should not be further from reality than needs be.

APPENDIX F

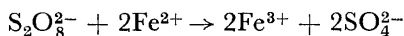
PRACTICAL EXAMINATIONS

With the exception of West Germany, the only practical examinations in the countries under review were those of England and Northern Ireland. The majority of practical examinations consist of volumetric or qualitative analysis, but it is apparent that in recent years attempts have been made to obtain a greater variety of question.

Questions 1-3

(1) Determine the number of grams of ammonium persulphate in 100 g of the specimen *A*.

- (a) Prepare without heating a standard solution containing about 3 g of *A* in 250 ml.
- (b) To 25.0 ml of the persulphate solution add 25.0 ml of the ferrous ammonium sulphate solution provided. Mix thoroughly and titrate with standard permanganate.



- (c) Standardize the ferrous solution against the permanganate. (Use 10 ml of the ferrous solution).

(2) To the chlorobenzene *B*, add 3 ml of concentrated nitric acid then 3 ml of concentrated sulphuric acid. Warm gently with continuous shaking for about 5 minutes. Pour into about 50 ml of water and stir until the oil solidifies. Boil the solid with a further 50 ml of water made just alkaline with sodium carbonate and again pour into cold water. Filter off the solid at the pump; recrystallize half of your yield (preferably twice) from methylated spirit, dry and determine the melting point (below 100°C). Suggest a name and structural formula of your product which is known to have a molecular weight of about 157.

(3) Identify the double salt *C*.

Author's comment.—This group of three questions formed a practical examination lasting three hours. It is worthy of note because it contains an

exercise in preparing and purifying a substance, and both this substance, and ammonium persulphate were probably unfamiliar to the candidates. One wonders how the questions were marked (the marks allocation was Question 1: 42 per cent, Question 2: 29 per cent, Question 3: 29 per cent): there are so many things including pure chance which could affect a candidate's score; for example, if credit in Question 2 was given for a good yield, what was to stop a candidate recrystallizing more than half his yield? Furthermore, would there not be a temptation for teachers to add questions 1 and 2 to the practical curriculum, and to continue to do so year after year until it became full of past examination questions?

Question 4

In this question, which is too long to reproduce in full, candidates were asked to determine by titration (hot) the formula weight of a substance Na_2XF_6 , given the equation for its reaction with sodium hydroxide. They were then asked to investigate the rate of reaction between this substance and sodium hydroxide at room temperature by a variation of the titration technique.

Author's comment.—This question was a rare example of the use of a physical chemistry problem in a practical examination. It was an excellent question, and much work—if not research—must have gone into its formulation. The difficulty is to find sufficient similar questions capable of being organized on a large scale in a school practical examination.

Questions 5 and 6

(5) You are supplied with a chloride S , of unknown composition, and exactly decinormal solution of silver nitrate. Determine the equivalent weight of S .

- (a) Weigh as accurately as possible about 1.6 g of S , dissolve in cold water and make up to 250 cc. Mix thoroughly.
- (b) Pipette 25 cc of the solution of S into a conical flask and titrate with the standard silver nitrate solution using either potassium chromate or an adsorption indicator.

(6) Analyse qualitatively the substance J which contains a total of four radicals (basic and acidic).

Author's comment.—These two questions formed a three hour practical examination. This particular examination has been in the same form for several years past, changing only the type of equivalent weight determination and the nature of the radicals, within a carefully prescribed syllabus. The positive results of this examination have been to bring some high quality balances into the schools and to raise the technique of the candidates in this type of titration and in qualitative analysis. The price by which these results are obtained is the frequent repetition of exactly these experiments throughout the two years of advanced study of chemistry.

APPENDIX G

THE USE OF MULTIPLE CHOICE QUESTIONS TO TEST PARTICULAR ABILITIES

This appendix gives samples of multiple choice questions arranged according to the abilities set out in the specification of the Admissions Achievement Test, constructed by the Educational Testing Service, Princeton, U.S.A. This sample illustrates the flexibility of this form of examining and can profitably be studied by those setting out for the first time to construct multiple choice questions in chemistry.

Chemistry test

The Chemistry Test includes questions selected from the following areas: kinetic-molecular theory and the three states of matter; atomic structure and the periodic table; quantitative relations as applied to chemical formulas and equations; chemical bonding and molecular structure, and their relations to properties; the nature of chemical reactions, including acid-base reactions, oxidation-reduction reactions, ionic reactions, and other chemical changes occurring in solution; energy changes accompanying chemical reactions; interpretation of chemical equilibria and reaction rates; solution phenomena; electrochemistry, nuclear chemistry and radiochemistry; physical and chemical properties of the more familiar metals, transition elements, and nonmetals and of the more familiar compounds; understanding and interpretation of laboratory procedure and observations.

Principles and concepts are tested in the context of factual material drawn largely from inorganic chemistry and to a much lesser extent from organic chemistry. Occasionally a question may be asked in which industrial or analytical chemistry provides the background.

A note concerning CBA and CHEMS courses

Members of the Committee of Examiners for the Chemistry Test are well informed with respect to the content of the Chemical Bond Approach course and of the Chemical Education Material Study course, and have been directing the evolution of the Chemistry Test so that it will be equally appropriate for candidates from either of these new courses and for candidates from the more conventional courses. All students may expect to find some questions that are not familiar to them, but any able chemistry student will be able to answer most of the questions on the test.

Ability to demonstrate an understanding of basic scientific concepts and principles*Questions 1 and 2*

Directions.—Each of the incomplete statements below is followed by five suggested answers or completions. Select the one which is best.

I.U.P.A.C. REPORT ON THE TEACHING OF CHEMISTRY

(1) If a certain element has an atomic number of 19, the element is:

- (A) an inert gas;
- (B) a metal with an oxidation number of +1;
- (C) a non-metal with an oxidation number of -1;
- (D) a metal with an oxidation number of +3;
- (E) a non-metal with an oxidation number of -3.

(2) The formula weight of $\text{Al}_2(\text{SO}_4)_3$ is 342. A solution of 342 grams of $\text{Al}_2(\text{SO}_4)_3$ in:

- (A) 1 liter of solution is 1 molar;
- (B) 1 liter of solution is 2 normal;
- (C) 1 liter of solution is 3 molar;
- (D) 1,000 grams of water is 3 normal;
- (E) 500 ml of solution is 0.5 molar.

Questions 3-5

This group of questions probes the same ability but uses a different type of question.

Directions.—For each of the questions below, *one* or *more* of the responses given are correct. Decide which of the responses is (are) correct. Then choose:

- A if only 1, 2, and 3 are correct;
- B if only 1 and 3 are correct;
- C if only 2 and 4 are correct;
- D if only 4 is correct;
- E if some other response, or combination of responses, of those given is correct.

Directions summarized

A	B	C	D	E
1, 2, 3 only	1, 3 only	2, 4 only	4 only	some other combination

(3) The theory of ionization is useful in explaining:

- (1) the conduction of electricity through water solutions of salts;
- (2) neutralization reactions;
- (3) gas pressure;
- (4) the existence of isotopes.

(4) Isotopes of a given element are related in that they have the same:

- (1) atomic weight;
- (2) position in the periodic table;
- (3) number of neutrons in the nucleus;
- (4) arrangement of electrons.

I.U.P.A.C. REPORT ON THE TEACHING OF CHEMISTRY

(5) The rate of reaction of iron filings with oxygen may be increased appreciably by:

- (1) adding a chunk of iron;
- (2) decreasing the pressure of the oxygen;
- (3) lowering the temperature of the iron;
- (4) increasing the concentration of the oxygen.

(6) In the gaseous equilibrium $\text{H}_2\text{X}_2 + \text{heat} \rightleftharpoons 2\text{HX}$, the conditions that favor formation of HX are:

- (1) high pressure and low temperature;
- (2) low temperature and low pressure;
- (3) high temperature and high pressure;
- (4) high temperature and low pressure;
- (5) high temperature regardless of the pressure.

Ability to apply scientific concepts and principles

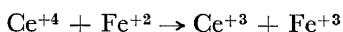
Questions 7 and 8

Some half-cell reactions, with the E° values are listed below:

	E° (volts)
$\text{Li} \rightarrow \text{Li}^+ + 1 e^-$	+3.05
$\text{Fe}^{+2} \rightarrow \text{Fe}^{+3} + 1 e^-$	-0.77
$\text{Ce}^{+3} \rightarrow \text{Ce}^{+4} + 1 e^-$	-1.70
$2\text{F}^- \rightarrow \text{F}_2 + 2 e^-$	-2.65

(7) At unit concentrations, the strongest oxidizing agent among the substances in the table above is:

- (A) Li^+
- (B) Fe^{+3}
- (C) Fe^{+2}
- (D) Ce^{+4}
- (E) F_2



(8) The potential of a cell with the reaction above, operating at unit concentration, is:

- (A) 2.47 volts
- (B) 0.93 volt
- (C) 0.87 volt
- (D) 0.34 volt
- (E) -2.47 volts

Questions 9-14

Directions.—The group of questions below consists of five lettered headings followed by a list of numbered questions. For each numbered question select

I.U.P.A.C. REPORT ON THE TEACHING OF CHEMISTRY

the one heading which is most closely related to it. Each heading may be used once, more than once, or not at all.

- (A) Pure covalent bond
- (B) Polar covalent bond (partial ionic bond)
- (C) Ionic bond
- (D) Metallic bond
- (E) Hydrogen bond

(9) The binding force between the atoms in a fluorine molecule.

(10) The binding force between the atoms in a molecule of hydrogen fluoride.

(11) The binding force between the phosphorus atoms in a molecule of P_4 .

(12) The binding force between water molecules in an ice crystal.

(13) The binding force between atoms of magnesium in a crystal of magnesium.

(14) The binding force between the unit particles in a crystal of potassium iodide.

Ability to handle quantitative relationships

Questions 15 and 16

(15) Analysis of a certain compound shows that it contains 14.4 per cent hydrogen and 85.6 per cent carbon. Which of the following is the most informative statement that can properly be made about the compound on the basis of these data? (Atomic weights: C = 12.0, H = 1.01).

- (A) It is a hydrocarbon.
- (B) Its empirical formula is CH_2 .
- (C) Its molecular formula is C_2H_4 .
- (D) Its molecular weight is 28.
- (E) It contains a triple bond.

(16) $CaCO_3$ (solid) + heat \rightarrow CaO (solid) + CO_2 (gas)

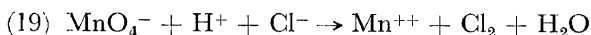
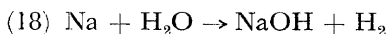
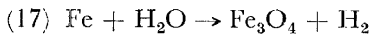
The equation above indicates that:

- (A) when $CaCO_3$ is converted to CaO and CO_2 heat is evolved;
- (B) when 1.0 mole of $CaCO_3$ is decomposed, 0.5 mole of CaO and 0.5 mole of CO_2 are produced;
- (C) 22.4 liters of CO_2 at S.T.P. is formed from 1.0 mole of $CaCO_3$;
- (D) the combined weight of CaO and CO_2 produced is less than the weight of $CaCO_3$ decomposed;
- (E) at S.T.P., 22.4 liters of $CaCO_3$ will form 44.8 liters of combined products.

Questions 17–19

Directions.—Balance each of the following equations, making sure that all coefficients are reduced to lowest whole-number terms. Select from the five suggested answers the one which is the coefficient of the substance whose formula is underlined.

- (a) 1
- (b) 2
- (c) 3
- (d) 4
- (e) 5



Ability to interpret cause-and-effect relationships

Questions 20–24

Directions.—Each question below consists of an *assertion* (statement) in the left-hand column and a *reason* in the right-hand column. Select:

- (A) if both assertion and reason are true statements and the reason is a *correct explanation* of the assertion;
- (B) if both assertion and reason are true statements but the reason is *NOT* a *correct explanation* of the assertion;
- (C) if the assertion is true but the reason is a false statement;
- (D) if the assertion is false but the reason is a true statement;
- (E) if both assertion and reason are false statements.

Directions summarized

A	True	True	Reason is a <i>correct explanation</i> Reason is <i>not</i> a <i>correct explanation</i>
B	True	True	
C	True	True	
D	False	True	
E	False	False	

Assertion

Reason

(20) Production of chlorine by electrolysis of brine is possible **BECAUSE** sodium chloride is an unstable compound

(21) A molar solution of sodium chloride conducts electricity **BECAUSE** such a solution contains a relatively high concentration of ions.

(22) Nitric acid and hydrochloric acid are called strong acids **BECAUSE** they can be prepared in concentrated form.

I.U.P.A.C. REPORT ON THE TEACHING OF CHEMISTRY

(23) Elements in the upper half of the periodic table cannot be made radioactive BECAUSE there must be a large number of protons in the nucleus of an atom in order to induce artificial radioactivity.

(24) In an equilibrium reaction if the forward reaction is exothermic, increasing the temperature will result in an increase in quantity of the product. BECAUSE when a stress is applied to a reaction in equilibrium, the position of the equilibrium is shifted in such a direction as to oppose the stress.

Ability to interpret experimental data

Questions 25 and 26

(25) A student made the following observations in the laboratory:

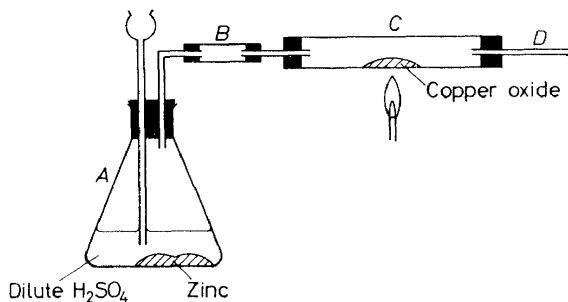
- (a) Clean copper metal did not react with 1-molar $\text{Pb}(\text{NO}_3)_2$ solution.
- (b) Clean lead metal dissolved in a 1-molar AgNO_3 solution and crystals of silver metal appeared.
- (c) Clean silver metal did not react with 1-molar $\text{Cu}(\text{NO}_3)_2$ solution.

The order of *decreasing* strength as reducing agents of the three metals is shown to be:

- (A) Cu, Pb, Ag
- (B) Cu, Ag, Pb
- (C) Pb, Ag, Cu
- (D) Pb, Cu, Ag
- (E) Ag, Pb, Cu

(26) What is the normal electronic formula of N_2 (atomic number 7)?

- (A) $:\ddot{\text{N}}::\ddot{\text{N}}:$
- (B) $\cdot\ddot{\text{N}}::\ddot{\text{N}}\cdot$
- (C) $:\ddot{\text{N}}:\ddot{\text{N}}:$
- (D) $:\text{N}:::\text{N}:$
- (E) $\cdot\ddot{\text{N}}::\ddot{\text{N}}\cdot$

Ability to apply laboratory procedures*Questions 27 and 28*

The equipment shown above is assembled to reduce copper oxide with hydrogen gas.

(27) Hydrogen gas produced in generator *A* is passed over hot copper oxide in tube *C*. Tiny droplets of a clear liquid collect on the inside of tubes *C* and *D*. To test whether the clear drops are water, the best of the following methods would be to:

- (A) add anhydrous copper sulfate and look for a color change;
- (B) smell the liquid;
- (C) taste the liquid;
- (D) add phenolphthalein and look for a color change;
- (E) moisten litmus paper with the solution.

(28) Assume that the liquid is definitely identified as water. Possibly water has been carried into tube *C* with the hydrogen from generator *A*. In order to test the validity of this explanation, it would be best to:

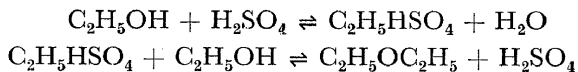
- (A) heat tube *C* further
- (B) heat generator *A*
- (C) add a calcium chloride drying tube at the right of tube *C*
- (D) add a calcium chloride drying tube in tube *B*
- (E) try to produce hydrogen by the reaction of zinc with a different acid.

Questions 29–33

In some cases a laboratory situation may be presented in such a fashion that you have not only to demonstrate your familiarity with laboratory apparatus and procedures but also to show that you can interpret the results of an experiment, even though it is one which you have not carried out yourself. The following experiment, for example, is one which few students are likely to do.

I.U.P.A.C. REPORT ON THE TEACHING OF CHEMISTRY

Diethyl ether ($C_2H_5OC_2H_5$) may be produced by the action of concentrated sulphuric acid on ethyl alcohol (C_2H_5OH) according to the equations:

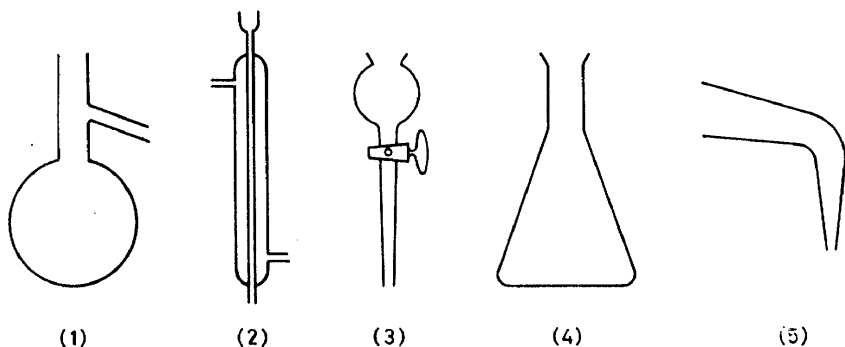


A small amount of ethyl alcohol is added up to the sulfuric acid. If the remaining ethyl alcohol is then added to the acid slowly and the temperature is maintained at $130-140^\circ C$, diethyl ether and water distill over, and the process can be made practically continuous. The diethyl ether-water mixture may be separated by pouring off the ether layer. The small amount of water remaining in the ether layer may be removed by adding a small amount of anhydrous $CaCl_2$, letting the mixture stand for a while, and filtering.

The glassware used in the laboratory preparation of diethyl ether is shown below. Glass and rubber tubing, Bunsen burners, stoppers, ringstands, *etc.*, are all available.

Boiling points: water = $100^\circ C$; ethyl alcohol = $78^\circ C$; diethyl ether = $35^\circ C$.

Molecular weights: ethyl alcohol = 46; diethyl ether = 74; water = 18; sulfuric acid = 98.



(29) Condensing gases to liquids is the function of the piece of glassware labeled:

- (A) 1
- (B) 2
- (C) 3
- (D) 4
- (E) 5

(30) The addition of controlled amounts of liquids to reaction mixtures is one use of the piece of glassware labeled:

- (A) 1
- (B) 2
- (C) 3
- (D) 4
- (E) 5

I.U.P.A.C. REPORT ON THE TEACHING OF CHEMISTRY

(31) The mixture produced in the experiment might be separated by distillation as well as by pouring off and drying the ether layer. Such distillation would best be carried out at a temperature of about:

- (A) 35°C
- (B) 73°C
- (C) 78°C
- (D) 100°C
- (E) 135°C

(32) Ethyl alcohol and sulfuric acid are mixed in a closed flask and heated to 140°C. The flask would then contain:

- (A) H₂O and C₂H₅OC₂H₅ only;
- (B) H₂O, C₂H₅OH, and C₂H₅HSO₄ only;
- (C) H₂O, C₂H₅OC₂H₅, and H₂SO₄ only;
- (D) H₂O, C₂H₅OC₂H₅, H₂SO₄, and C₂H₅HSO₄ only;
- (E) H₂O, C₂H₅OH, C₂H₅OC₂H₅, C₂H₅HSO₄, and H₂SO₄.

(33) Theoretically, the number of moles of ethyl alcohol necessary to produce 1 mole of diethyl ether is:

- (A) $\frac{46}{148}$
- (B) $\frac{46}{74}$
- (C) $\frac{92}{74}$
- (D) 1
- (E) 2

Answer key to chemistry test questions

- | | | | | |
|-------|--------|--------|--------|--------|
| (1) B | (8) B | (15) B | (22) B | (29) B |
| (2) A | (9) A | (16) C | (23) E | (30) C |
| (3) E | (10) B | (17) D | (24) D | (31) A |
| (4) C | (11) A | (18) B | (25) D | (32) E |
| (5) D | (12) E | (19) B | (26) D | (33) E |
| (6) D | (13) D | (20) C | (27) A | |
| (7) E | (14) C | (21) A | (28) D | |

APPENDIX H

EXTRACT FROM "RECENT DEVELOPMENTS IN SCIENCE TEACHING IN SCOTLAND" BY A. J. MEE

The examination system in Scotland differs fundamentally from that in England in that there are no examination boards. The examination for the

I.U.P.A.C. REPORT ON THE TEACHING OF CHEMISTRY

Scottish Certificate of Education is conducted by the *Scottish Education Department*, who are responsible both for the syllabuses and for the question papers. *No fees are charged, the whole cost being met from public funds.* The Secretary of State conducts the examination under authority derived from the Education (Scotland) Act, and he is answerable to Parliament for its proper administration. It might appear that this would make for rather rigid control, but although the Department are responsible for devising the syllabuses, the teachers' organizations and other interested bodies are always very fully consulted before any major change is made either in syllabuses or in organization. These bodies also comment on the papers after the examination and great regard is had to their comments in the composition of the papers for the next examination.

Whether the system is good or bad, however, it has one great advantage which has become apparent in the recent changes in respect of science. It has been possible to change the nature of the work done in the schools and to bring about the reform which many people felt to be desirable much more quickly than would otherwise have been likely, simply by offering a new examination based on the traditional syllabuses. This encouraged science teachers to modernize their teaching (which many were anxious to do) because they knew from the outset that their pupils would not be prejudiced at the examination. It should perhaps be mentioned that a Scottish Examination Board is shortly to be established to take over from the Department the duty of conducting the examination; but there will still be only one examining Authority and it should still be possible to make changes expeditiously.