Teaching AS Chemistry Practical Skills

Your attention is drawn to the Risk Assessment section on page 15 of the Introduction to this booklet, and to the hazards indicated in Appendices 1 and 2. While every effort has been made to ensure that appropriate safety indications are given, CIE accepts no responsibility for the safety of these experiments and it is the responsibility of the teacher to carry out a full risk assessment for each experiment undertaken, in accordance with local rules and regulations. Hazard data sheets should be available from your suppliers.

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Introduction

You may have been teaching AS and A level chemistry for many years or this may be a new experience. In either case, you will be keen to ensure that you prepare your students as effectively as possible for their examinations. Using a well-structured scheme of practical work will certainly help you to achieve this, but it can do so much more. Scientists who are thoroughly trained and experienced in practical skills will have a 'feel' for the subject and be much more confident in their own abilities than those with a purely theoretical background. While it is true that there are branches of chemistry that could be described as purely theoretical, these are in the minority. Essentially, chemistry is a practical subject and we owe it to our students to ensure that those who pursue science further have the necessary basic practical skills to take forward into their future careers. Furthermore, the basic skills of planning, analysis and evaluation will be of great value to those who pursue non-scientific careers.

Why should I read this booklet?

Some of you may be wondering why you need a booklet like this. If you have highly developed practical skills and you feel confident teaching these skills to others, you probably don't, but you might find some of the exercises described in the appendices useful. However, most of us appreciate a little help and support. This booklet aims to provide at least some of this support.

It is designed for the teacher rather than for the student. Its objective is to provide a framework within which your practical skills can develop and grow. Experience shows that as the teacher's practical skills develop, their confidence in teaching such skills increases, as does the amount of time that they will be prepared to spend on teaching practical work.

How much teaching time should I allocate to practical work?

The syllabus stipulates that 20% of teaching time should be allocated to practical work. This is in addition to any time you choose to spend on practical demonstrations to illustrate the theory syllabus. This emphasis on practical work is not misplaced. Consider the weighting given to assessment objectives in the syllabus: 24% of the award is allocated to experimental skills and investigations and 30% is allocated to handling, applying and evaluating information. Taken together, almost 55% of the total award is related to the student's ability to interpret data, understand how it has been obtained, recognise limitations and suggest explanations. All of these objectives lend themselves to investigative work involving practical experience. Even if you consider the specific practical papers in isolation, they still represent 23% of the AS or 24% of the A2 award.

In planning a curriculum, you should therefore expect to build in time for developing practical skills. If, for example, the total time allowed for this syllabus is 5 hours per week over 35 weeks, then a minimum of 1 hour per week should be built into the plan for practical work, so that over the year a minimum of 35 hours is made available – 20% of the total. Bearing in mind the emphasis on assessment objectives that relate to information handling and problem solving, a minimum of 2 hours per week might be more appropriate, which at 40% of the total time is still less than the overall weighting for these assessment objectives.

Can I use the practicals in these booklets in a different order?

It is assumed that for A level candidates, the AS work will be taught in the first year of the course and the A2 work will be covered in the second year. If you take this linear A level assessment route, you need to give careful consideration to the order in which you use the practical exercises, as the skills practised in these booklets are hierarchical in nature, i.e. the basic skills established in the AS booklet are extended and developed in the A2 booklet. Thus, students will need to have practised basic skills from the AS exercises before using these skills to tackle more demanding A2 exercises.

The exercises in the booklets are given in syllabus order. You may, of course, decide to use a different teaching sequence, but the above point regarding AS/A2 exercises still applies.

What resources will I need?

For a practical course in A level chemistry to be successful, it is not necessary to provide sophisticated equipment. The vast majority of the practicals in these booklets can be performed using the basic equipment and materials already in the laboratory. However, some of the more advanced practicals may require less easily obtainable equipment. Alternative, ‘low-tech’ exercises are also provided where possible.

A list of the basic resources required for assessment can be found in the syllabus. A more detailed list can be found in the booklet *CIE Planning for Practical Science in Secondary Schools,* Appendix B.

Is there a limit to the class size?

There is a limit to the number of students that you can manage in a laboratory situation, particularly when students may be moving about. Your particular class size may, of course, be determined by the size of the room. As a general guide, however, 15 to 20 students is the maximum number that one person can reasonably be expected to manage, both for safety reasons and so that adequate support can be given to each student. Larger numbers will require either input from another person with appropriate qualifications or splitting the class into two groups for practical lessons.

Why should I teach my students practical skills?

Although teachers are likely to read this section only once, it is arguably the most important. If it convinces the ‘non-practical’ chemistry teacher that practical work is an essential part of chemistry and that it underpins the whole teaching programme, the aim of publishing this booklet will have been achieved.

Points to consider

- It’s fun! The majority of students thoroughly enjoy practical work. The passion that many scientists have for their subject grew out of their experiences in practical classes. Students who enjoy what they are doing are likely to carry this enthusiasm over into other areas of their work and so will be better motivated.

- Learning is enhanced by participation. Students tend to find it easier to remember activities they have performed, which benefits their long-term understanding of the subject. Students who simply memorise and recall facts find it difficult to apply their knowledge to an unfamiliar context. Experiencing and using practical skills helps to develop people’s ability to use information in a variety of ways, thus practical work also enables students to apply their knowledge and understanding more readily.

- Integrating practical work into the teaching programme quite simply brings the theory to life. Teachers often hear students making comments like ‘I’m glad we did that practical because I can see what the book means now’ and ‘It’s much better doing it than talking about it.’

- Chemistry, physics and biology are, by their very nature, practical subjects – both historically and in the modern world. The majority of students who enter careers in science will need to employ at least basic practical skills at some time in their career. Those who pursue non-scientific careers will also benefit from acquiring transferable practical skills and safety awareness.

- A practical course develops many cross-curricular skills, including literacy, numeracy, ICT and communication skills. It develops the ability to work both in groups and independently, and with confidence. It enhances critical thinking skills and it requires students to make judgements and decisions based on evidence, some of which may well be incomplete or flawed. It helps to make students more self-reliant and less dependent on information provided by the teacher.

- The skills developed are of continuous use in a changing scientific world. While technological advances have changed the nature of practical procedures, the investigative nature of practical science remains unchanged. The processes of observation, hypothesis formation, testing, analysing results and drawing conclusions will always be the processes used in investigative science. The ability to keep an open mind in the interpretation of data and to develop an appreciation of scientific integrity is of great value in both science and non-science careers.

- Practical work is not always easy, and persistence is required for skills to develop and for confidence to grow. Students often relish this challenge and develop a certain pride in a job well done.

- The more experience students have of using a variety of practical skills, the better equipped they will be to perform well in the practical exams, both in terms of skills and confidence. While it could be argued that the required skills could be developed for paper 3 simply by practising past examination papers, the all-round confidence in practical ability will be greatly enhanced by wider experience. Similarly for paper 5, while it could be argued that planning, analysis and evaluation can be taught theoretically, without hands-on experience of manipulating their own data, putting their plans into action and evaluating their own procedures and results, students will find this section difficult and will be at a distinct disadvantage in the examination. Those students who can draw on personal experience, and so are able to picture themselves performing the procedure they are describing or recall analysing their own results from a similar experiment, are much more likely to perform well than those with limited practical skills.

What are the practical skills required by this course?

This course addresses seven practical skills that contribute to the overall understanding of scientific methodology. In a scientific investigation these would be applied in this sequence:

1. **Planning the experiment**
2. **Setting up/manipulating apparatus**
3. **Making measurements and observations**
4. **Recording and presenting observations and data**
5. **Analysing data and drawing conclusions**
6. **Evaluating procedures**
7. **Evaluating conclusions**

The syllabus shows how these seven skills are assessed, and the structure is common to all three sciences. The emphasis of the AS level syllabus is on developing an understanding of, and practice in, scientific procedures, data collection, analysis and drawing conclusions. It also starts to develop students' skills in critical evaluation of experimental procedures by asking them to suggest improvements to the procedures. In general, students find performing practical procedures and collecting data more accessible than analysis, while evaluation is the skill that is least readily accessible. To enable access to these more demanding skills, students need to understand why an experimental procedure is carried out in a particular way so that they can recognise sources of error or limitations that could affect the reliability of their results. Students will not be able to evaluate until they can critically review a practical procedure.

The A2 syllabus builds upon the skills developed at AS level. Its emphasis is on the higher-level skills of planning, analysis and evaluation. In order to plan effectively, students need to be able to evaluate procedures and critically assess results. This is best achieved by performing practical exercises, starting at AS level with relatively straightforward and familiar contexts and developing at A2 level by using more complex procedures and less familiar contexts. Data analysis also develops from AS level into more complex treatments, so students need to be provided with opportunities to gather suitable data and perform the appropriate manipulations. Evaluating conclusions and assessing procedures are very high-order skills. Students who have not had sufficient opportunity to plan and trial their own investigations will find these skills difficult. While students are not expected to be able to plan perfectly, they are expected to recognise weaknesses and make reasonable suggestions for improvement. The best learning tool for developing these skills is to devise a plan, carry out the investigation and then assess how well the planned procedure worked. The syllabus gives detailed guidance on the expected skills and learning outcomes.

In summary, Skills 2 to 6 listed above will be assessed at AS level. The first and last will only be assessed at A2 level, and A2 will also take Skills 5 and 6 to a higher level.

The above list shows the seven skills in the order in which they would be used in an extended investigation. It is not suggested that you teach these skills in this order, nor would it be wise. Students who are new to practical work will initially lack the basic manipulative skills, and the confidence to use them. It would seem sensible, therefore, to start practical training with Skill 2, initially with very simple tasks, paying attention to establishing safe working practices.

Once a measure of confidence in AS students' manual dexterity has been established, they can move on to exercises that require Skills 3 and 4 to be included. Extensive experience in carrying out practical procedures allows students to gain awareness of appropriate quantities and to become more organised in time management and recording data as it is collected.

It is likely that Skill 6, evaluating procedures, will be the most difficult to learn at AS level. Critical self-analysis does not come easily to many people. 'My experiment worked well' is a frequent response. If students are to master this skill, they need to develop an appreciation of the reliability and accuracy inherent in the equipment and procedure they are using. Only then will they be able to identify anomalous results, or results that fall outside the 'range of uncertainty' intrinsic in the apparatus they chose to use and which must therefore be considered inaccurate. Exercises with less reliable/accurate outcomes can be used to provide more scope for evaluating errors that result from procedure, technique or apparatus.

Planning is arguably the most demanding of the seven skills. For planning to be effective, students need to be very well grounded in Skills 2 to 6 so that they can anticipate the different stages involved in the task and can provide the level of detail required. It is for this reason that planning skills are not assessed at AS level but form part of the A2 assessment in paper 5. Students do not develop an understanding of how apparatus works and the sort of measurements that can be made using particular types of apparatus unless they use it. They cannot be taught to plan experiments effectively unless, on a number of occasions, they are required to:

- plan an experiment;
- perform the experiment according to their plan;
- evaluate what they have done.

Skill 7, evaluating conclusions, is achieved by comparing the outcome of an exercise with the predicted outcome, and so is also an A2 skill. It should be taught and practised as part of the planning exercises.

Summary of each of the seven skills

Full details of the requirements for each of these skills can be found on pages 34 to 41 of the syllabus. The following is a brief summary of the skills involved.

1. Planning the experiment

- **Defining the problem**
  Students should be able to use information provided about the aims of the investigation, or experiment, to identify the key variables. They should use their knowledge and understanding of the topic under consideration to make a quantitative, testable prediction of the likely outcome of the experiment.

- **Methods**
  The proposed experimental procedure should be workable. Given that the apparatus has been assembled appropriately, the procedure should allow data to be collected without undue difficulty. There should be a description, including diagrams, of how the experiment should be performed and how the key variables will be controlled. Equipment, of a level of precision appropriate for the measurements to be made, and quantities of materials to be used should be specified. The use of control experiments should be considered.

- **Risk assessment**
  Students should be able to carry out a simple risk assessment of their plan, identifying areas of risk and suggesting suitable safety precautions.

- **Planning for analysis, conclusions and evaluation**
  Students should be able to describe the main steps by which their results will be analysed in order for valid conclusions to be drawn. This may well include generating a results table and proposing graphical methods for analysing data. They should also propose a scheme for interpreting and evaluating the results and the experimental procedure employed to obtain those results. They should indicate how the outcomes of the experiment will be compared with the original hypothesis.

2. Setting up/manipulating apparatus
It is important that students are allowed sufficient time and opportunity to develop their manipulative skills to the point where they are confident in their approach to experimental science. They must be able to follow instructions, whether given verbally, in writing or diagrammatically, and so be able to set up and use the apparatus for experiments correctly.

3. Making measurements and observations

- **Measuring/observing**
  While successfully manipulating the experimental apparatus, it is crucial that students are able to take measurements with accuracy and/or to make observations with clarity and discrimination. Accurate meter or burette readings and precise descriptions of colour changes and precipitates will make it much easier for students to draw valid conclusions, and to attain a higher score in the test.

- **Deciding on what measurements/observations to make**
  Time management is important, so students should be able to make simple decisions on the number and range of tests, measurements and observations that can be made in the time available. For example, if the results of the first two titrations were in good agreement, there would be no need to carry out a third.

  Students need to be able to make informed decisions regarding the appropriate distribution of measurements within the selected range, which may not always be uniform, and the timing of measurements made within the experimental cycle. They should also be able to identify when repeated measurements or observations are appropriate.

  They should practise the strategies required for identifying and dealing with results that appear anomalous.

4. Recording and presenting observations and data

An essential, but frequently undervalued, aspect of any experimental procedure is communicating the results to others in a manner that is clear, complete and unambiguous. It is vital that students are well practised in this area.

- **The contents of a results table**
  The layout and contents of a results table, whether for recording numerical data or observations, should be decided before the experiment is performed. 'Making it up as you go along' often results in tables that are difficult to follow and do not make the best use of space. Space should be allocated within the table for any data manipulation that will be required.

- **The column headings in a results table**
  The heading of each column must be clear and unambiguous. In columns that will contain numerical data, the heading must include both the quantity being measured and the units in which the measurement is made. The manner in which this information is given should conform to 'accepted practice'.

- **The level of precision of recorded data**
  It is important that all data in a given column is recorded to the same level of precision, and that the level of precision is appropriate for the measuring instrument used.

- **Display of calculations and reasoning**
  Where students use calculations as part of the analysis, all steps of the calculations must be displayed so that thought processes involved in reaching the conclusion are clear to a reader. Similarly, where students draw conclusions from observational data, the key steps in reaching the conclusions should be reported and should be clear, sequential and easy to follow.

- **Significant figures**
  Students should be aware that the number of significant figures to which the answer is expressed shows the precision of a measured quantity. Therefore, they should take great care with regard to the number of significant figures quoted in a calculated value. The general rule is to use the same number of significant figures as (or, at most, one more than) that of the least precisely measured quantity.

- **Data layout**
  Students should be able to make simple decisions concerning how best to present the data they have obtained, whether this is in the form of tabulated data or as a graph. When drawing tables, they should be able to construct the table to give adequate space for recording data or observations. When plotting graphs, they should be able to follow best practice guidelines for choosing suitable axis scales, plotting points and drawing curves or lines of best fit.

5. Analysing data and drawing conclusions
This skill requires students to apply their understanding of underlying theory to an experimental situation. It is a higher-level skill and so makes a greater demand on the student's basic understanding of the chemistry involved. Even when that understanding is present, however, many students still struggle. Presenting a clear, lucid, watertight argument does not come naturally to most people and it is therefore recommended that students have a lot of practice in this area.

- **Interpreting data or observations**
  Once data has been presented in the best form for analysis of the results of the experiment, students should be able to describe and summarise any patterns or trends shown and the key points of a set of observations. Further values, such as the gradient of a graph, may be calculated or an unknown value may be found, for example from the intercept of a graph.

- **Errors**
  Students should be used to looking at an experiment, assessing the relative importance of errors and, where appropriate, expressing these numerically. They should be aware of two kinds of error:
  (i) The 'error' that is intrinsic in the use of a particular piece of equipment. Although we refer to this as an equipment error, we really mean that there is a 'range of uncertainty' associated with measurements made with that piece of equipment. This uncertainty will be present no matter how skilled the operator might be.
  (ii) Experimental error, which is a direct consequence of the level of competence of the operator or of the effectiveness of the experimental procedure.

- **Conclusions**
  Students should learn to use evidence to support a given hypothesis, to draw conclusions from the interpretation of observations, data or calculated values, and to make scientific explanations of their data, observations and conclusions. Whatever conclusions are drawn, they must be based firmly on the evidence obtained from the experiment. At the highest level, students should be able to make further predictions and ask appropriate questions based on their conclusions.

6. Evaluating procedures
Arguably, this is one of the most important, and probably one of the most difficult, skills for students to develop. In order for the evaluation to be effective, students must have a clear understanding of the aims and objectives of the exercise, otherwise they will not be able to judge the effectiveness of the procedures used. They must be able to evaluate whether any errors in the data obtained exceed those expected due to the equipment

used. If this is the case, they then need to identify those parts of the procedure that have generated these excess errors and suggest realistic changes to the procedure that would result in a more accurate outcome. They should also be able to suggest modifications to a procedure to answer a new question.

The evaluation procedure may include:

(i) the identification of anomalous values, a deduction of possible causes of these anomalies and suggestions for appropriate means of avoiding them;
(ii) an assessment of the adequacy of the range of data obtained;
(iii) an assessment of the effectiveness of the measures taken to control variables;
(iv) an informed judgement on the confidence with which conclusions may be drawn.

7. Evaluating conclusions

This is also a higher-level skill, which demands that students have a thorough understanding of the basic theory that underpins the science involved.

The conclusions drawn from a set of data may be judged on the basis of the strength or weakness of any support for, or against, the original hypothesis. Students should be able to use the detailed scientific knowledge and understanding they have gained in theory classes to make judgements about the reliability of the investigation and the validity of the conclusions they have drawn.

Without practice in this area, students are likely to struggle. To increase their confidence in drawing conclusions, it is recommended that practical exercises, set within familiar contexts, are used to allow students the opportunity to draw conclusions, make evaluations of procedures and assess the validity of their conclusions.

In the examination, students may be required to demonstrate their scientific knowledge and understanding by using it to justify their conclusions.

Ways of doing practical work

Science teachers should expect to use practical experiences as a way to enhance learning. Practical activities should form the basis on which knowledge and understanding are built. They should be integrated with the related theory, offering opportunities for concrete, hands-on learning rather than treated as stand-alone experiences. In planning a scheme of work, it is important to consider a mosaic of approaches that include those that allow students to participate in their own learning.

- Some practical activities should follow a well-established structure that includes a detailed protocol for students to follow. Such well-structured learning opportunities have a vital role to play in introducing new techniques, particularly in rapidly developing fields such as biotechnology. In these new areas of science, teachers often find themselves leading practical work that they did not have the chance to experience themselves as students.

- Other practical activities should offer students the opportunity to devise their own methods or to apply the methods that they have been taught to solving a problem. The excitement generated by exposure to ‘new’ and unfamiliar techniques provides a stimulus that will engage students’ interest and challenge their thinking.

Practical activities may be used as a tool to introduce new concepts – for example, introducing catalysis by experimentation, followed up by theoretical consideration of the reasons for the unexpected results obtained. On other occasions, practical work can be used to support and enhance the required knowledge and understanding – for example, in building upon a theoretical consideration of the limiting factors of photosynthesis with a series of practicals investigating the effect of light intensity and hydrogen carbonate concentration on photosynthesis in water weed. In all cases, learning will be enhanced most effectively by practical work that encourages students to be involved and to think, and to apply and use their knowledge, understanding and skills.

Practical work does not always have to be laboratory based. In classrooms, using models, role-play and paper cut-outs to simulate processes can be equally valuable. In biology, field studies also contribute greatly to a student's appreciation.

There are many strategies you can adopt to integrate practical work into a scheme of work. You should use a wide range of methods to enhance a variety of subject-specific skills and simultaneously develop a variety of transferable skills that will be useful throughout students' future professional lives. Some of the methods you can use to deliver practical work also enable you to interact on a one-to-one basis with individual students. This allows you to offer support at a more personal level and develop a greater awareness of an individual student's needs.

Your choice of a specific strategy will depend on issues such as class size, laboratory availability, availability of apparatus, level of competence of your students, availability and expertise of technical support, time available, your intended learning outcomes for the activity and safety considerations. The following are some possible strategies for delivering practical work:

- **Teacher demonstrations**
  These require less time than a whole-class practical, but give little opportunity for students to develop manipulative skills or to become familiar with equipment. Careful planning can provide an opportunity for limited student participation. Teacher demonstrations are a valuable way of showing an unfamiliar procedure at the start of a practical session, during which students go on to use the method.

  Considerations in choosing to do a demonstration **might include** the following:

  (i) **Safety** – some exercises carry too high a risk factor to be performed in groups.
  (ii) **Apparatus** – you may need to show complicated procedures or you may have limited resources.
  (iii) **Time** – demonstrations usually take less time.
  (iv) **Outcome** – some results are difficult to achieve and may be beyond the skill level of most students. A failed experiment may be seen as a waste of time.
  (v) **Students' attention** – a danger is that the attention of some students will drift.
  (vi) **Manipulative experience** – remember that with this strategy, the teacher gets experience, the students don't.

  There are many good reasons for the teacher to perform a demonstration, but do be aware that most students have a strong preference for hands-on experimentation. So, where possible, let them do it!

- **Group work**

  Whole-class practical sessions. These have an advantage in terms of management as all the students do the same thing. Students may work individually, in pairs or in small groups. Integrating this type of practical is straightforward as earlier lessons can be used to introduce the context and subsequent lessons can be used to draw any conclusions and develop evaluation. However, this approach may not be feasible where specialised equipment or expensive materials are in short supply.

  Small-group work. This can provide a means of utilising limited resources or managing investigations that test a range of variables and require that a lot of measurements are collected. Although the same procedure may be performed, each student group collects only one or a few sets of data, which are then pooled. For example, if five concentrations of the independent variable are being tested, each of which needs to be measured at 2-minute intervals for 30 minutes, then a group of five students can each test one concentration. In biology, field studies also lend themselves to group activities as a lot of data has to be collected in a short period of time. The individual student has the opportunity to develop their subject-specific skills. Part of the teacher's role is to monitor and maintain safety and to enable and persuade reluctant learners to take part. Group work aids personal development as students must interact and work co-operatively.

  Considerations might include:

  (i) **Learning** – successful hands-on work will reinforce understanding and students will also learn from each other.
  (ii) **Confidence** – this will grow with experience.
  (iii) **Awareness/insight** – this should grow with experience.
  (iv) **Team building** – this is a very desirable outcome.
  (v) **Setting out** – as all students are doing the same thing, it is easier for the technicians.
  (vi) **Confusion** – incomplete, ambiguous or confusing instruction by the teacher will result in wasted time while the instructions are clarified, and may also compromise safety and restrict learning.
  (vii) **Opting out** – some students will leave others to do the procedure and so learn very little.
  (viii) **Safety** – this could be a serious issue and constant vigilance is essential.
  (ix) **DIY** – the urge to adapt their experiments, to see 'what would happen if', must be dealt with strictly.
  (x) **Discipline** – practical time must not be allowed to become 'play time'.

  Working in groups, whether as part of a whole-class situation or where groups are working on parts of a whole, is probably the preferred option for many students. At A level, however, it is highly desirable to include opportunities for students to work on their own, thus developing individual skills and independence. In paper 3, students' practical skills will be assessed on an individual basis, so each student's experience, competence and confidence are of considerable importance.

- **Circus of experiments**
  A circus comprises a number of different exercises that run alongside each other. Individuals or groups of students work on the different exercises and as they complete each exercise, they move on to the next. These are a means by which limited resources can be used effectively.

There are two basic approaches. Most commonly, during a lesson a number of short activities are targeted at a specific skill. Alternatively, a number of longer practical activities are undertaken over a series of lessons, to address a variety of skills. The circus arrangement may be more difficult for the teacher to manage as the students are not all doing the same activity. This puts more pressure on the teacher as they have to cope with advising and answering questions from a variety of investigations. With circuses spread over a number of sessions, careful planning is needed to enable the teacher to engage each group of students and to maintain a safe environment. In these situations, it is useful to include at least two activities that do not involve hands-on practical work – using data response based simulations or other activities – so that the teacher can interact with the groups that need a verbal introduction or short demonstration and can monitor their activities more effectively.

Considerations might include:

(i) **Apparatus** – if the amount of apparatus needed for an exercise is limited, students are able to use it in rotation.

(ii) **Awareness** – by observing their peers, students will become more aware of the pitfalls of the exercise and so will learn from the experience of others.

(iii) **Safety** – different exercises may well carry different safety risks, all of which need to be covered.

(iv) **Setting out** – students doing different exercises will make it more difficult for the technicians.

(v) **Opting out** – some students may be tempted to 'borrow' the results obtained by earlier groups.

- **Within theory lessons**
  This option should be considered whenever it is viable. It is likely that the practical work will be demonstrated, as this takes less time. Given the power of visual images, including a short practical to illustrate a theoretical point will reinforce the point and so aid the learning process. It is critical, however, that the practical works correctly, otherwise the flow of the lesson will be disrupted and confidence in the theory may be undermined. The teacher should therefore practise the exercise beforehand.

- **Project work**
  Projects are a means by which a student's interest in a particular topic, which is not always directly on the syllabus, can be used to develop investigative skills. It can also be used to access parts of the syllabus that have little laboratory-based investigation. For example, in gene technology students might use internet-based research to find examples of genetic modification and present a poster display showing the implications. This sort of investigative work can be undertaken as either an individual or a group activity. Once the project is underway, much of the work can be student-based, outside the classroom. Care is needed in selecting the topics and setting a timescale so that relevance to the syllabus context is maintained. The work can be directed towards producing posters, giving a presentation to the group or producing group or individual reports.

- **Extra-curricular clubs**
  These can play a role in stimulating scientific enquiry methods. There are a number of ways of using clubs. One is to hold the club session during the teaching day so that all students can attend. In effect, this becomes additional lesson time in which students can practise investigative skills, including laboratory work. Such laboratory work involves materials that have a cost, which must be taken into consideration. Another way is to hold a club outside the teaching day, in which case it may be voluntary. Syllabus-specific activities should therefore be limited, but such clubs offer

valuable opportunities for exciting work unrelated to syllabuses. After-school clubs could be used as a vehicle for project work that is related to science and that is of social or economic importance, for example, endangered species or local mineral resources. Students who do attend the club could be used as a teacher resource by reporting their findings in a classroom session.

Keeping records

Students often have a problem integrating the practical work with the theory. This is particularly true when a series of experiments or a long-term investigation or project is undertaken. Potential issues include the following:

- Some students use odd scraps of paper in the laboratory, which get lost or become illegible as chemicals are spilled on them. One important criterion is that students are trained to record results immediately and accurately.

- Practical procedures may be provided by the teacher, or students may write their own notes from a teacher demonstration. These notes may get lost, so students end up with results but no procedure or context.

- When results are collected over a period of time, analysis becomes isolated from the context of the investigation and may not be completed.

The key to minimising these issues is to train students into good work practices. This is particularly important in colleges where students join at the start of their A levels from a variety of feeder schools. It is also vital for students with specific learning difficulties that affect their ability to organise their work, such as dyslexia and Asperger's syndrome.

Students may be encouraged to integrate their practical notes with their theory notes and keep them all in one file. Alternatively, they may be encouraged to keep an entirely separate practical book or file. Loose-leaf files make it easy to add to their notes, but also make it easier to lose items. Exercise books can be used, but students should be encouraged to glue any protocols provided and their laboratory records into the book so that they do not get lost. Students can adopt whichever method they prefer, depending on how they learn. Whichever option they choose, they need to be encouraged to relate their investigations to the appropriate theory and to regard it as something that needs to be thoroughly assimilated.

- Integrating the materials generated by practical work with the notes from their learning of theory can be achieved by interspersing the records of investigations with the relevant section of theory. This may still require cross-referencing where work targets several learning outcomes and assessment objectives.

- Keeping a separate practical book enables students to keep records of all the practical investigations in one place. Students need training to manage practical files effectively, particularly in keeping the contexts and cross-referencing to the theory. If care is not taken to develop and maintain these skills, students may perceive practical work as something different from theory.

- An intermediate between the two extremes is to have a separate section for practical investigations within each syllabus section in the student's file, cross-referenced to the relevant theory.

How is a practical activity organised?

Preparing for practical work needs thought and organisation. The practical work may be an activity that forms part of a lesson, it may comprise an entire lesson or it may be an investigation designed to last for several lessons, but in every case, thorough preparation is a key prerequisite for success.

Practical and investigative work should be integrated into the programme of study. The scheme of work should identify appropriate practical investigative experiences for use at the most suitable time. In designing the scheme of work, you need to do the following:

- Consider the resource implications in terms of equipment and materials in stock.

- Think about the seasonal availability of materials such as organisms and the shelf-life of thermo-sensitive or hygroscopic substances, which is sometimes short.

- Consider the time taken from order to delivery of resources, the potential for damage during dispatch and the cost of materials to be obtained from local, national or international suppliers.

- In centres with a large number of students, you may need to schedule carefully. It may be possible to permit several groups to do the work simultaneously or in quick succession, or it may be essential to re-order the scheme of work for different groups so that scarce resources can be used effectively.

- Take note of national or local health and safety regulations relating to chemicals, electricity, growing micro-organisms, etc. There may also be regulations controlling use of controversial materials such as genetically modified organisms.

Once the scheme of work has been established, the next stage is to consider each practical activity or investigation. In an ideal course, you would go through each of the following stages when developing each practical exercise. In the real world, however, this is not always possible the first time you run a course, which is one of the reasons for producing this booklet. It is better to get going and do some practical work with students than to hold out for perfection before attempting anything. Obviously, all practical work should be subject to careful and rigorous risk assessment, no matter how provisional the rest of the supporting thinking and documentation.

- Decide on the aims of the work – the broad educational goals, in terms of the broad skill areas involved (e.g. planning), and the key topic areas.

- Consider the investigative skills to be developed. You should refer to the syllabus, which in the practical skills section includes learning outcomes relating to practical skill. For example, if the intended practical work is to be a planning exercise, which of the specific skills identified in the learning outcomes will be developed?

- With reference to the topics included, decide on the intended learning outcomes of the practical activity or investigation, again referring to the syllabus. For example, which of the transport learning outcomes will be achieved? In a few cases during the course, the material on which the practical is based may be unfamiliar, in which case there may be no topic-related intended learning outcomes. Thus, A2 contexts may be used for AS practicals, and topic areas not on the syllabus may be used for AS or A2 practicals.

- In addition, it is useful to assess any other context of the practical investigation. For example, is it intended as part of the introduction to a concept, to support a theory or to demonstrate a process?

- Produce a provisional lesson plan, allocating approximate amounts of time for the introduction, student activities and summarising.

- Produce and trial a student worksheet. You can use published procedures or those produced by other teachers, or you can produce your own. As a rule, schedules produced by others need to be modified to suit individual groups of students or the available equipment. It is helpful to ask students or another teacher to read worksheets before they are finalised to identify instructions that are ambiguous or use inaccessible terminology.

- Refine the lesson plan in relation to the number of students for which the investigation is intended (whole class or a small group) and the available equipment (does some have to be shared?) and materials. There are examples of lesson plans and student worksheets in Appendix 2.

- Carry out a detailed and careful risk assessment (see below) before any preparatory practical work is done, and certainly well before students do any of the practical work. You should consider:
    - the likelihood that any foreseeable accident might occur – for example, when pupils are putting glass tube through bungs, they are quite likely to break the tube and push it though their hand;
    - the potential severity of the consequences of any such accident – for example dropping a plastic dropper bottle of 0.01 mol dm^{-3} hydrochloric acid onto a desk would cause much less severe eye injuries than the same accident with a glass bottle containing 5.0 mol dm^{-3} hydrochloric acid;
    - the measures that can be taken to reduce the severity of the effect of any accident – for example, the teacher or technician preparing bungs with glass tubes before the lesson, or using eye protection such as safety spectacles during all practical work.

- Make an equipment and materials list. This may need to be in sections and should include the following information:
    - materials and apparatus per student or per group (chemicals and glassware);
    - shared equipment per laboratory (water baths, microscopes, pH meters);
    - any chemicals should include concentrations and quantities needed;
    - any equipment should include number required;
    - any hazard associated with specific chemicals or equipment should also be noted and cross-referenced to the risk assessment – sources of information about safety may be found in the syllabus (and are reproduced below);
    - the location of storage areas for equipment and chemicals, which may be cross-referenced to the equipment and materials in the list.

- Set up and maintain a filing system where master copies of the worksheets, lesson plans and equipment lists can be stored. It is helpful to have these organised, or at least indexed, by both their syllabus context and skills developed.

- Once an investigation has been used by a group of students, it should be evaluated in relation to intended outcomes and the lesson plan. It is important to obtain feedback from the students about their perceptions of the work. For example:
    - was the time allocation appropriate;
    - were the outcomes as expected;

- o did they enjoy the work;
- o did they understand the instructions;
- o was the point of the work clear to them?

If necessary, the worksheet and lesson plan should be revised.

Risk assessment

All practical work should be carried out in accordance with the health and safety legislation of the country in which it is done. You should not attempt any activities that conflict with this legislation.

Hands-on practical work can be carried out safely in schools. However, to ensure that it is safe, you must identify the hazards and reduce any associated risks to insignificant levels by adopting suitable control measures. You should carry out these risk assessments for all the activities involved in running practical science classes, including storage of materials, preparatory work undertaken by the teacher and any technical support staff, and practical activities carried out in the classroom, whether demonstrations by the teacher or practical activities undertaken by the students. Such risk assessments should also be carried out in accordance with the health and safety legislation of the country in which you are working.

Risk assessment involves answering two basic questions:

1. **How likely is it that something will go wrong?** For example, pupils using a double-sided razor blade to cut up carrots are quite likely to cut themselves.
2. **How serious would it be if it did go wrong?** For example, the consequences of a spark from an experiment landing in an open bottle of magnesium powder are likely to be serious, and include spraying burning magnesium all over the laboratory, burning many pupils and setting the laboratory ceiling on fire (this scenario is based on a real accident).

Once you have the answers to these questions, it is possible to plan the practical activity to minimise the risk of an accident occurring and, if it does, to minimise its possible severity. In our first example, this could include cutting up the carrot before giving it to young pupils or providing older pupils with an appropriate sharp knife rather than a razor blade; in the second, it could include bringing only the amount of magnesium powder required for the activity into the laboratory.

The likelihood that something will go wrong depends on who is carrying out the activity and what sort of training and experience they have had. Obviously you would not ask 11-year-old students to heat concentrated sulphuric acid with sodium bromide or to transfer *Bacillus subtilis* cultures from one Petri dish to another, simply because their inexperience and lack of practical skills would make a serious accident all too likely. However, by the time they reach post-16, they should have acquired the skills and maturity to carry such activities out safely.

Decisions need to be made as to whether an activity should only be carried out as a teacher demonstration or whether it could be performed by students. Clearly, some experiments should normally only be done as a teacher demonstration or by older students. Well-motivated and able students may be able to carry out such an experiment at a younger age, but any deviation from the model risk assessment needs to be discussed and a written justification must be prepared beforehand.

There are some activities that are intrinsically dangerous and, if included in the suggested procedure, should always be changed to include safer modes of practice. For example, there are **no** circumstances under which mouth pipetting is acceptable – pipette fillers of some sort should **always** be used.

Teachers tend to think of eye protection as the main control measure for preventing injury. In fact, personal protective equipment, such as goggles or safety spectacles, is meant to protect from the unexpected. If you expect a problem, more stringent controls are needed. A range of control measures may be adopted, the following being the most common. Use:

- a less hazardous (substitute) chemical;
- as small a quantity as possible;
- as low a concentration as possible;
- a fume cupboard; and
- safety screens (more than one is usually needed, to protect both teacher and students).

The importance of using the lowest possible concentrations is not always appreciated, but the following examples, showing the hazard classification of a range of common solutions, should make the point.

ammonia (aqueous)	irritant if ≥ 3 mol dm^{-3}	corrosive if ≥ 6 mol dm^{-3}
sodium hydroxide	irritant if ≥ 0.05 mol dm^{-3}	corrosive if ≥ 0.5 mol dm^{-3}
hydrochloric acid	irritant if ≥ 2 mol dm^{-3}	corrosive if ≥ 6.5 mol dm^{-3}
nitric acid	irritant if ≥ 0.1 mol dm^{-3}	corrosive if ≥ 0.5 mol dm^{-3}
sulphuric acid	irritant if ≥ 0.5 mol dm^{-3}	corrosive if ≥ 1.5 mol dm^{-3}
barium chloride	harmful if ≥ 0.02 mol dm^{-3}	toxic if ≥ 0.2 mol dm^{-3} (or if solid)

Reference to the above table shows, therefore, that if sodium hydroxide is in common use, it should be more dilute than 0.5 mol dm^{-3}. Using more concentrated solutions requires measures to be taken to reduce the potential risk.

Material Safety Data Sheets (MSDS)
Your risk analysis should consider the hazards associated with the materials you propose to use. These risks are best assessed by reference to MSDS's appropriate to the chemical(s) in use. These are generally supplied by the chemical manufacturer and supplied with the chemical. If this is not the case then there are many internet sites that have this information freely available. These sheets also provide useful information on the actions to take following an accident, including first aid measures, and should therefore be considered essential for all practical experiments involving chemicals, as part of the risk assessment process.

Your risk assessment should not be restricted simply to the materials, procedures and equipment that will be used, but should have a wider remit that covers the time from when the students enter the room until they leave it.

Eye protection

Clearly students will need to wear eye protection. Undoubtedly, chemical splash goggles give the best protection but students are often reluctant to wear goggles. Safety spectacles give less protection, but may be adequate if nothing classed as corrosive or toxic is in use.

Practical science can be – and should be – fun. It must also be safe. The two are not incompatible.

Further relevant information on health and safety can be obtained from the following publications:

Safeguards in the School Laboratory, 10th edition, ASE, 1996
Topics in Safety, 2nd edition, ASE, 1988
Hazcards, CLEAPSS, 1998 (or 1995)
Laboratory Handbook, CLEAPSS, 1997
Safety in Science Education, DfEE, HMSO, 1996
Hazardous Chemicals Manual, SSERC2, 1997

AS skills

Teaching students to manipulate apparatus

Students gain the necessary skills of manipulating apparatus through becoming familiar with various techniques during the practical part of the course. However, skills do need to be taught and demonstrated. Manipulating some pieces of apparatus is quite complicated and it is sometimes advisable to provide short exercises to build student confidence in using certain techniques. A particular example is the skills needed to perform accurate titrations. In Appendix 2, Experiment 1 provides a simple titration to build these skills. Prior to students performing this particular experiment, you may wish to provide short exercises in using the burette and pipette, depending on their previous experience.

A useful way of showing students the different degrees of precision in volume measurement is to use a pipette and burette to deliver volumes of water into measuring cylinders. This also provides several short exercises to give students confidence in using pipettes and burettes. For example, a 10 cm^3 pipette could be used to check out the accuracy of a 10 cm^3 measuring cylinder. Another experiment may involve running exactly 20 cm^3 of water from a burette into a 25 cm^3 measuring cylinder and a 50 cm^3 measuring cylinder to demonstrate the greater accuracy of a 25 cm^3 measuring cylinder.

Experiment 2 extends the opportunity to perform volumetric analyses, while Experiment 3 also introduces students to the technique of using a volumetric flask to make up solutions accurately.

Teaching students to make observations and measurements

These skills are fundamental to practical work and many experiments and investigations require students to use both. As experienced scientists, we may forget that students do not automatically acquire these skills. The best way to teach students to make observations and measurements is by getting them to practise using these techniques in the context of their practical work. In this way, students come to understand that the techniques they are learning are not just necessary for examinations, but are important skills, without which chemistry could not progress.

Observational skills involve noting the detail of something. It may be a colour change or the production of bubbles of gas. Even making simple observations, a skill we, as teachers, may take for granted, needs to be developed through opportunities in a practical course.

Making measurements and understanding their accuracy is also something that students need to practise throughout their course. Students need to consider to how many decimal places a particular piece of apparatus can measure and how appropriate such measurements are. For example in Experiment 15, which concerns measuring rates of reaction, students may have access to stop watches that measure to the nearest hundredth of a second, but accuracy to the nearest second is more appropriate. Thus students should be encouraged to consider what number of decimal places to use when recording their data. This does not mean that results should arbitrarily be rounded up or down, as this will affect their reliability.

In the previous section we mentioned the techniques required for titration and suggested short exercises you could ask students to perform prior to doing Experiment 1. These short exercises could also be used to teach students how to make accurate measurements using a burette, measuring cylinder and pipette. Reading the scale with the eye level with the bottom of the meniscus is something you will need to reinforce. Fig. 1.3 in Experiment 1 provides a good illustration of why this is essential.

Burettes should be read to the nearest 0.05 cm^3. It is possible to determine whether the bottom of the meniscus is nearer to a graduated mark or nearer to the middle of two 0.1 cm^3 marks, hence reading to the nearest 0.05 cm^3. However, it is not possible to say precisely that a reading is, for example, 20.01 cm^3 because the closeness of the 0.1 cm^3 marks does not allow this degree of accuracy. In addition, the smallest drop that a burette can deliver is approximately 0.05 cm^3.

The thermometer is another measuring instrument where accuracy depends on the scale. A thermometer calibrated in 1ºC intervals can be read to the nearest 0.5ºC, whereas another calibrated in 0.2ºC intervals can be read to the nearest 0.1ºC. A good experiment for exploring this is Experiment 8 in Appendix 2, where the thermometer we suggest you use is calibrated from –5ºC to +50ºC, and the graduations are 0.2ºC. You can ask students why this choice is preferable to a thermometer measuring from –10ºC to +110ºC in 1ºC intervals.

Many measurements require a judgement to be made. This is very clear in Experiment 15, where the reaction rate between sodium thiosulphate solution and dilute hydrochloric acid is measured by timing the disappearance of a cross drawn on a piece of paper. The stopwatch is stopped when the student judges that the cross has disappeared. No matter how accurate the stopwatch, the student's judgement will affect the reliability of the data. If you ask different groups what measurements they made at the same temperature, there is likely to be a wide variation. In this case, the measurements should be made by the same individual to make them more reliable. If there is time, experiments should be repeated until they do not show too much variation to ensure reliability. In a titration with a sharp end-point, titres should be within 0.10 cm^3.

Teaching students to record and present data and observations

There is little point in doing experiments if the results are not recorded in a systematic way. This is a skill to which students need to be introduced. Our experience, and probably yours, is that students need to be convinced that they should record results so that they can use them to draw conclusions when the experiment is over. Too often students make unintelligible scribblings, the meaning of which they think they will remember accurately for the next lesson. Getting students into the habit of recording their results is probably something that will require persistence and patience, but it is worth it.

Tables are a very good way to organise results, provided that some thought has gone into their construction, for example thinking about how many columns will be needed. Columns should be correctly labelled, with appropriate headings that describe what the data is and the units used if a measurement is involved. This also makes drawing graphs easier, since column headings can then be transferred onto axes.

In the previous section we discussed the number of decimal places that should be used. In a column of results, all the raw data should be expressed to the same number of decimal places, as this indicates that the accuracy is consistent. This is something that students need to be reminded about, quite frequently, as it is fundamental to experimental work. When data in a column is calculated, then the number of significant figures needs to be considered; this should be appropriate to the degree of accuracy of the apparatus used. This is decided by determining which of the measurements is least accurate and to what number of significant figures it is accurate. The appropriate number of significant figures to be recorded is this number, or one more than this number.

In the very first experiment in Appendix 2, students are introduced to putting their titration results in a table. In Experiments 2 and 3, they are expected to produce similar tables for their data. Check on this as you go round to different students and ensure that their tables of results are neat. This is important because neatly recording results saves time – it prevents students needlessly having to copy out data, which could result in them copying incorrectly.

An exercise that you may wish to develop is to give students a range of different tables that have errors in them or that are constructed in an inappropriate fashion. Ask them to work in groups and suggest ways in which the tables could be improved.

Graphs are often an effective way of presenting data and demonstrating relationships and trends. Again, getting students into the right habits from the outset will pay dividends for them later. Some of the key features of drawing a graph are:

- having a title that describes what the graph represents;
- labelling the axes and including the correct units;
- plotting the independent variable on the *x*-axis and the dependent variable on the *y*-axis;
- using a sharp pencil;
- choosing a sensible scale for axes – use most of the graph paper (at least half in both dimensions) but ensure the graph is still convenient to plot;
- where data varies continuously, drawing the line of best fit;
- identifying anomalous results and not giving these undue weight.

You can really emphasise this in the rate experiments suggested in Appendix 1: Experiments 14 to 16.

Many experiments involve presenting qualitative data. This also needs to be accurately recorded in such a way that makes it easy to understand the results. If a particular experiment has several stages, then any changes, or lack of them, should be clearly identified at each stage.

Teaching students to analyse data and draw conclusions

Drawing conclusions is a skill that involves analysing the results of a practical and stating and explaining what they show.

Some conclusions are drawn from qualitative observations. In Experiment 21, the relative oxidising powers of the halogens are seen through their displacement reactions. The results are then drawn together to show a trend in oxidising power from chlorine to iodine.

Before drawing a conclusion, it may be necessary to do a calculation. It is essential to show the key steps in the working so that a competent scientist can follow the process and check the accuracy. In Experiment 1, titration readings are duplicated to ensure accuracy and to identify anomalous results. This means that an average must be calculated and the working should be shown. If there is an anomalous result, then this should not be included in the calculated average.

Processed results are often shown in graphical form. In Experiment 14 of Appendix 1, gradients can be calculated to give initial rates at time zero. These are then plotted on axes of rate (*y*-axis) versus concentration (*x*-axis). Explain to students that when calculating gradients, large triangles should be used to give a more accurate calculation.

Graphs are an excellent way of showing trends and relationships. A straight-line graph shows that there is a directly proportional relationship between the dependent and independent variables. A conclusion should always be supported by evidence from the data and in the case of the directly proportional relationship, the graph should be referred to as providing the evidence. Sometimes graphs are used to find unknown values by using co-ordinates or extrapolation. Students need to practise this skill to gain confidence in it.

Students should be encouraged to consider why data is analysed in the way that it is. For example, what is the advantage of drawing a graph over just presenting results in a table?

Teaching students to evaluate procedures

Evaluation is a skill that students do find difficult to develop. They need to think critically about the reliability of their data and the validity of their conclusions. When developing students' skills in this area, a good place to begin is to consider errors.

There are two types of error that affect results. Random errors cause results to fluctuate around a mean value and data is made more reliable by averaging repeated readings. Systematic errors affect all measurements in the same way, producing lower or higher values than the true result. These cannot be averaged out. Sometimes they are due to the particular experimental procedure that has been adopted. For example, when one person performs a rate experiment it may take time to mix the reagents and start the stop clock. This error can be minimised, or even eliminated, by using two people, one to do the timing and one to mix the reagents. Another source of systematic error may be the measuring device itself. This can be checked by seeing if two different instruments give the same values. In Experiment 8, there will be unavoidable heat losses when trying to assess enthalpy change and this causes a systematic error.

Students should be looking at experiments and assessing the relative importance of errors in measurement, or in making observations, so that they can judge which sources of error are most important. They should be able to express these errors in a standard format. For example, the measurement of volume from a burette may be $20.00\ cm^3 \pm 0.05\ cm^3$, while that from an electronic balance may be $\pm$ 0.01 g.

Experiment 4 provides a good opportunity to compare values obtained for the formula of magnesium oxide by different groups of students. The loss of magnesium oxide during flare-ups is probably the most significant source of error. If students have only one value, how can they tell how accurate their results and conclusions are?

In evaluating experiments, students should be able to do the following:

- Suggest improvements to the procedures they adopt.
- Compare repeated results to consider their similarity and thus how reliable they are.
- Identify results that are clearly anomalous.
- Identify variables that they need to control. In some experiments, students need to keep variables constant. For example in Experiment 13, 'Determining the value of K_c for an equilibrium reaction', temperature changes have a significant effect on the results, yet it is very difficult to control temperature variation over a few days without the use of a constant temperature water bath.
- Estimate uncertainty in measurement.
- Distinguish between random and systematic errors.

The above points need to be discussed at the end of experiments. Get students to suggest a checklist they could use to evaluate experiments that incorporates these ideas. Also point out to them that perfect experiments make for poor evaluation.

Designing a practical course for the AS year

We have already expounded the essential place of practical work in any chemistry course. Students develop their practical skills through being taught how to use them and then practising them.

The course we have suggested in Appendix 1 is simply that, a suggestion. There may be other experiments that you think work better or demonstrate a concept more effectively. In building our practical course we have gone through the theoretical and practical learning outcomes that need to be achieved and linked them to the syllabus. We have tried to provide a variety of approaches and to suggest practicals, where possible, with a ‘real world’ context. You will notice that certain skills are practised in several different experiments. For example, titration work occurs in three experiments at the outset of the course to build the necessary skills and these are reinforced in Experiments 13 and 23.

It is very tempting to drill students in the skills they need by endlessly practising past examination papers, but this provides an arid experience for them and does not relate the concepts they meet in theory to observations made through experiment. Yes, there is a place for doing past-paper work, but this should be limited to the very end of the course to reinforce the skills developed from all the varied practical work we recommend that students should carry out.

Of the 30 experiments in Appendix 1, 10 are fully worked up in Appendix 2 with Student Sheets and Teachers’ Notes. The other 20 are presented in outline, in the hope that you will develop them to suit your own students and ways of working. Sometimes local circumstances mean that you cannot perform some of the experiments we suggest. In these instances, it may be possible to substitute other practicals that cover the same learning outcomes. There are several good practical textbooks that can support your course. We have featured some experiments from the Royal Society of Chemistry’s books, *Classic Chemistry Experiments: One hundred tried and tested experiments* and *Classic Chemistry Demonstrations: One hundred tried and tested experiments*. What we hope comes across is how important we feel a well-constructed AS chemistry course is in developing a love of the subject and in furnishing students with the practical skills they will need to be successful both in the examination and in future practical work.

Sources

Many of the experiments listed in Appendix 1 can be found in the following books:

Classic Chemistry Experiments: One hundred tried and tested experiments, complied by Kevin Hutchings, published by the Royal Society of Chemistry, www.rsc.org
(ISBN 0 85404 9193)

Classic Chemistry Demonstrations: One hundred tried and tested experiments, complied by Ted Lister, published by the Royal Society of Chemistry, www.rsc.org
(ISBN 1 870 343 38 7)

Appendix 1

Syllabus section	Skills/Learning Outcomes	Notes	Sources
1g, 1h	**1. Making salt – an introduction to some basic techniques**		
	• Acquire skills in manipulating apparatus • Acquire skills in reading a burette and using a pipette • Revise use of Bunsen burner • Introduction to titration • Use and understand molecular and ionic equations • Use the mole concept	Approximately 0.1 mol dm^{-3} solutions of hydrochloric acid **(Corrosive)** and sodium hydroxide **(Corrosive)** are used in a titration experiment to produce sodium chloride solution. The water is then evaporated to concentrate the salt solution and produce sodium chloride crystals. **Timing**: 1.5 hours if salt solution is to be evaporated	**Appendix 2**
1h	**2. Which is the best indigestion tablet?**		
	• Acquire skills in manipulating apparatus • Acquire skills in reading a burette and using a pipette • Make decisions relating to measurements and observations • Draw conclusions • Identify sources of error and suggest improvements	This experiment reinforces the techniques of titration and can be used to give students an opportunity to develop some of the skills they will need for the Practical Assessment. In addition to the apparatus listed in Practical 1, you will need different brands of indigestion tablet, mortars and pestles, 0.1 mol dm^{-3} HCl and methyl orange indicator. If the cost of each packet of tablets is known, this experiment could be used to determine which tablet represents best value. If pestles and mortars are not available, indigestion powders can be made up in advance using $NaHCO_3(s)$ and $NaCl(s)$. **Timing:** 1.5 hours to plan, carry out the investigation, process results and draw conclusions. This could include homework time	*Classic Chemistry Experiments*, The Royal Society of Chemistry – Experiment 60

Appendix 1

Syllabus section	Skills/Learning Outcomes	Notes	Sources
1h	**3. Determining the mass of iron in iron tablets**		
	• Perform a titration involving potassium manganate(VII) • Develop skills in reading a burette and using a pipette • Record results appropriately • Use and understand an ionic equation • Use the mole concept to perform calculations	This volumetric analysis is intended to further develop skills of accurate titration. It introduces a potassium manganate(VII) **(Oxidising, Harmful, Dangerous to the environment)** titration in an interesting context. **Timing:** One lesson for the practical and another lesson to explain the processing of the results. Approximately 1.5 hours	**Appendix 2**
1f, 1h	**4. Finding the formula of magnesium in magnesium oxide**		
	• Acquire skills in manipulating apparatus • Acquire skills in accurate measurement • Calculate the empirical formula of magnesium oxide from reacting masses	This is a simple experiment to perform but there is much scope for experimental error. Do not worry about this, as there is a great deal of learning to be gained. Weigh a crucible and lid to at least two decimal places. Clean about 15 cm of magnesium with an emery cloth. Coil it round a pencil and place the loose coil in the crucible, then weigh this together with the lid. Place on a pipe-clay triangle on a tripod and heat. Lift the lid very slightly to let more oxygen in but immediately replace it to prevent magnesium oxide escaping. Do this until the magnesium no longer flares up. Remove the lid and heat strongly for 5 minutes. Allow to cool and re-weigh. The increase in mass of the magnesium is due to the oxygen that combines with it. **Note:** A typical porcelain crucible will itself react with the magnesium, leaving black 'stains'. This can be used in the discussion of results. Magnesium nitride (Mg_2N_3) may also be formed. **Timing:** 1 hour, which includes discussing the calculation	*Classic Chemistry Experiments*, The Royal Society of Chemistry – Experiment 67

Appendix 1

Syllabus section	Skills/Learning Outcomes	Notes	Sources
1g, 1h, 4c	**5. What is the volume of 1 mole of hydrogen gas?**		
	• Further develop skills in manipulating apparatus and accurate measurement • Use the mole concept • Calculate the molar volume at room temperature and pressure	This experiment allows students to perform a procedure to calculate the molar volume. It gives practice in calculations involving the mole concept. **Timing**: 1 hour, which includes discussing the calculation	**Appendix 2** Also in *Classic Chemistry Experiments*, The Royal Society of Chemistry – Experiment 68
4c	**6. Determining the relative molecular masses of a gas**		
	• Use the general gas equation $PV=nRT$ to determine M_r	This experiment provides a simple, quick method for finding the relative molecular mass of butane. You will need a can of butane, used for re-filling cigarette lighters. Weigh the can before the experiment and then attach a length of flexible tubing to enable 1 dm^3 of the gas to be collected over water. Then dry and weigh the can again. Another possibility is to use a cigarette lighter, in which case you will not need the delivery tube – simply hold the lighter in the water trough below the measuring cylinder. This is slower and it is better to collect 250 cm^3 gas – which still gives a mass loss of approximately 0.4 g. $PV=nRT$ can be used to calculate the number of moles in the known mass of gas. If you cannot measure the pressure accurately, it is worth making an educated guess. **Timing:** 30 minutes for the practical	*Classic Chemistry Demonstrations*, The Royal Society of Chemistry – Experiment 7

Appendix 1

Syllabus section	Skills/Learning Outcomes	Notes	Sources
4e	**7. The effect of heat on different substances**		
	• Relationship between lattice structure and melting points • Sodium chloride and magnesium oxide are ionic lattices • Silicon(IV) oxide and graphite are giant molecular • Iodine and sulphur are simple molecular • Copper is a metallic lattice	This is a very simple set of experiments. Heating one or two crystals of iodine, placed in a conical flask, should be an opening demonstration as iodine is harmful and will stain skin and clothing. The iodine sublimes to give a purple vapour that turns back to crystals on cooling. Students can perform the other experiments, noting down their observations. $NaCl$, MgO, graphite powder and sand (which is mainly SiO_2) can be heated in hard glass test tubes. A small piece of copper can be heated with tongs and a small quantity of sulphur can be heated on a tin lid or bottle top. **Timing:** 30 minutes. This practical could be arranged as a circus	Most A level practical textbooks will cover something similar
5b, 5c, 1h	**8. Measuring the enthalpy changes of exothermic and endothermic reactions**		
	• Further develop skills in manipulating apparatus and accurate measurement of temperature • Know that some chemical reactions are accompanied by energy changes in the form of heat energy • Know that energy changes can be exothermic (ΔH, negative) or endothermic (ΔH, positive) • Calculate enthalpy changes from your experimental results using enthalpy change = $mc\Delta T$	This is a good experiment for introducing some of the main concepts of chemical energetics. Students do two experiments using polystyrene cups as calorimeters. Enthalpy change = $mc\Delta T$ is used to calculate the enthalpy changes of two reactions. **Timing**: 1 hour that includes discussing the calculation and a homework for completion	**Appendix 2** Most A level practical textbooks will cover something similar

Appendix 1

Syllabus section	Skills/Learning Outcomes	Notes	Sources
5b, 5c, 1h	**9. Measuring the enthalpy change of neutralisation**		
	• Determine the enthalpy change of neutralisation through experiment and calculation • Explore the reason for similar values obtained for different neutralisation reactions per mole of water formed	25 cm^3 of 1 mol dm^{-3} HCl is used to neutralise solutions of 25 cm^3 of 1 mol dm^{-3} NaOH **(Corrosive)** and KOH **(Corrosive)** separately, using the apparatus described in Experiment 8 (Appendix 2). Following the calculation, similar values for enthalpy changes should be obtained (actual value is approximately 58 kJ mol^{-1}). As an extension, 50 cm^3 of 1 mol dm^{-3} H_2SO_4 **(Corrosive)** could be used. This would give double the value of the above neutralisation reactions as there are 2 moles of H^+ for every mole of H_2SO_4. **Timing**: 1 hour	Most A level practical textbooks will cover something similar
6b	**10. Experiments to show which ions move to the anode and cathode**		
	• Greater awareness of the properties of ions as charged particles • Introduce the terms anode and cathode • Explain what is happening in the electrolysis of sodium chloride solution	This is a useful introduction to electrochemistry. Cut filter paper to fit a microscope slide or watch glass. Draw a faint pencil line in the middle of the paper. Moisten it with tap water and place a crystal of potassium manganate(VII) **(Oxidising, Harmful, Dangerous to the environment)** on the pencil line. Connect two wires to a 6 V DC supply and attach the crocodile clips at the end of the wires on either side of the pencil line, holding the filter paper to the glass. After 10 minutes, the purple-coloured band due to the MnO_4^- ion moves to the anode. A similar experiment can now be done with a saturated solution of sodium chloride. This time use universal indicator paper soaked with the salt solution. The paper goes blue at the anode (due to OH^-) and red at the cathode (due to H^+). **Timing:** 30 minutes	A similar sort of experiment is found in *Classic Chemistry Experiments*, The Royal Society of Chemistry – Experiment 15

Appendix 1

Syllabus section	Skills/Learning Outcomes	Notes	Sources
6b	**11. Electrolysing sodium chloride and copper(II) sulphate solution**		
	• Understand the electrode reactions occurring when brine (concentrated sodium chloride solution) and aqueous copper(II) sulphate are electrolysed • Understand how the experiments relate to the industrial processes of the diaphragm cell and the electrolytic purification of copper	If you have access to low voltage DC sources, this is a worthwhile experiment for students to perform or for you to demonstrate. Use graphite electrodes to electrolyse a concentrated solution of sodium chloride and a copper(II) sulphate solution **(Harmful, Dangerous to the environment).** Also electrolyse Copper(II) sulphate using copper electrodes. The different gaseous products can be tested. **Timing:** 40 minutes	*Classic Chemistry Experiments*, The Royal Society of Chemistry – Experiments 82 and 92 Most A level practical textbooks will also include this experiment
7a, 7b	**12. Introducing equilibria through two demonstrations**		
	• Understand what is meant by a reversible reaction and a dynamic equilibrium • Introduce and use Le Chatelier's Principle • Observe the effects of changes of concentration and temperature on the equilibrium position	Two experiments are suggested: **1.** The equilibrium between $Co(H_2O)_6^{2+}$ and $CoCl_4^{2-}$ **2.** The equilibrium between bismuth oxide chloride and bismuth trichloride Conditions are altered and are found to be as predicted by Le Chatelier's Principle. **Timing:** Each demonstration takes about 5 minutes but securing the learning outcomes from the demonstrations will require 1 hour	**Appendix 2** *Classic Chemistry Experiments*, The Royal Society of Chemistry – Experiments 8 and 87
7d, 7e, 7f	**13. Determining the value of K_c for an equilibrium reaction**		
	• Deduce an expression for the equilibrium constant, K_c • Calculate a value for K_c from the concentrations of substances at equilibrium • Further develop skills in titration techniques	This experiment allows students to use skills they have gained from volumetric analysis to measure equilibrium concentrations for $CH_3COOH + C_2H_5OH \rightleftharpoons CH_3COOC_2H_5 + H_2O$ They can then determine a value for the equilibrium constant. **Timing:** 20 minutes to set up the equilibrium mixtures, which are left for a week, and 1 hour to analyse them	**Appendix 2**

Appendix 1

Syllabus section	Skills/Learning Outcomes	Notes	Sources
8a, 8b	**14. The effect of concentration on the rate of a chemical reaction**		
	• Explain and use the term *rate of reaction* • Follow the rate of reaction of calcium carbonate and hydrochloric acid using loss of mass of carbon dioxide • Measure the effect of different concentrations on the reaction • Explain the results obtained in terms of collisions • Determine the gradient of a straight line graph • Identify the most significant errors in this experiment	Measuring the rate of reaction using marble chips and dilute hydrochloric acid is a really good introduction to reaction kinetics. The rate can be followed using a top balance, weighing to 0.01 g. Weigh out about 10 g of large marble chips into a conical flask. Quickly add 20 cm^3 of 1 mol dm^{-3} hydrochloric acid **(Corrosive)** and record the mass loss every 15 seconds. From this experiment, a rate curve can be drawn by plotting mass of carbon dioxide lost against time. The experiment can be repeated using other concentrations and these rate curves plotted on the same sheet of graph paper. The gradients of the graphs at time zero can be calculated. These are usually straight line graphs for the first 30 seconds at least. A graph of concentration against time can then be plotted, giving a straight line. This shows that for this reaction a straight line should be obtained. **Timing:** 1 to 2 hours	Most A level practical texts will have some reference to this or a similar experiment
8c, 8d	**15. The effect of temperature on reaction rate**		
	• Measure the effect of temperature on a reaction rate • Represent results graphically and draw conclusions • Explain, in terms of the collision theory, why temperature change affects the reaction rate	This experiment investigates the effect of temperature on the rate of reaction between sodium thiosulphate and dilute hydrochloric acid. **Timing:** 1 to 1.5 hours	**Appendix 2** *Classic Chemistry Experiments*, The Royal Society of Chemistry – Experiment 64

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Syllabus section	Skills/Learning Outcomes	Notes	Sources
8e	**16. Effect of catalysts on the reaction rate**		
	• Catalysts alter the reaction rate • Catalysts are unchanged chemically at the end of the reaction • Catalysts work by providing a different mechanism for the reaction	This demonstration is an effective way to introduce the role of catalysts in speeding up reactions. It shows clearly that catalysts do take part in the reaction and are unchanged chemically at the end. Hydrogen peroxide oxidises potassium sodium tartrate (Rochelle salt) to carbon dioxide. The reaction is slow. Adding cobalt(II) chloride **(Toxic, Dangerous to the environment)** causes the reaction to froth. The colour of the cobalt(II) chloride changes from pink to green to pink, showing that the reaction proceeds by an alternative mechanism. **Timing:** 5 minutes for the demonstration	*Classic Chemistry Demonstrations*, The Royal Society of Chemistry – Demonstration 1
9.1e, 9.1g	**17. The reaction of oxygen with some elements in the third period**		
	• Describe the reactions of third period elements with oxygen	This demonstration examines the reactions of sodium **(Corrosive, Highly flammable)**, magnesium, **(Highly Flammable)** aluminium, phosphorus (red) **(Highly Flammable, Dangerous to the environment)** and sulphur. Fill gas jars or boiling tubes with oxygen. Use a combustion spoon to heat very small samples of the elements. Then plunge these into the oxygen. After cooling, add water and test the pH of resulting solutions using universal indicator. Oxygen can be prepared using hydrogen peroxide **(Caustic)** and manganese(IV) oxide **(Harmful)** and collecting the gas over water. **Timing:** 30 minutes for the demonstration	Some A level practical texts will have reference to this or a similar experiment

Appendix 1

Syllabus section	Skills/Learning Outcomes	Notes	Sources
9.1e	**18. The reaction of sodium and magnesium with water**		
	• Describe the reaction of sodium and magnesium with water	You should do these experiments as demonstrations. Place a very small piece of sodium **(Corrosive, Highly Flammable)**, the size of a rice grain, in a glass trough that is a third filled with water. Cover the trough with a perspex sheet. Test the resulting solution with universal indicator. In a second experiment, trap the sodium on a piece of floating filter paper in the trough. This time the hydrogen produced catches fire. You can show the reaction of magnesium with cold water by trapping some pieces of cleaned magnesium under water in an upturned funnel feeding into a boiling tube full of water. Leave this set up for a week, which will produce 2 or 3 cm^3 of hydrogen. Show the reaction of magnesium with steam by soaking mineral wool with water at the bottom of a test tube. Then push a coil of magnesium into the centre of the tube. Attach a delivery tube and strongly heat the magnesium. The resulting gas, collected over water, is hydrogen, which can be tested with a lighted spill. **Timing:** 30 minutes	*Classic Chemistry Demonstrations*, The Royal Society of Chemistry – Demonstrations 72 and 75

Appendix 1

Syllabus section	Skills/Learning Outcomes	Notes	Sources
9.1e	**19. Reaction of sodium with chlorine**		
	• Describe the reaction of sodium with chlorine	If you have access to a fume cupboard, this is a useful demonstration to show the formation of sodium chloride from its elements. Chlorine gas **(Toxic, Irritant)** can be generated from solid potassium manganate(VII)) **(Oxidising, Harmful, Dangerous to the environment)** , covered with water, onto which some concentrated hydrochloric acid **(Corrosive)** is added from a tap funnel in a typical gas generation apparatus. A gas jar is filled by downward displacement of air. Heat a very small piece of sodium **(Corrosive, Highly Flammable)** (the size of a rice grain) on a combustion spoon and plunge it into the gas jar of chlorine. Clouds of white smoke show that sodium chloride has formed. **Timing**: 15 minutes	*Classic Chemistry Demonstrations*, The Royal Society of Chemistry – Demonstration 72

Appendix 1

Syllabus section	Skills/Learning Outcomes	Notes	Sources
9.2a, 9.2b, 9.2c	**20. Group II practical work**		
	• Describe the reactions of the elements with oxygen and water • Describe the behaviour of the oxides with water • Describe the thermal decomposition of the nitrates and carbonates	Remind students of the reaction of magnesium with oxygen and water/steam (Experiments 17 and 18). **Experiment 1.** Students can perform an experiment with a small calcium **(Highly Flammable)** granule in a large beaker of water and devise a method for collecting and testing the hydrogen gas produced. **Experiment 2.** Heat a lump of limestone, or marble chip, suspended from a tripod by nichrome wire, for 15 minutes. Allow to cool on a watch glass. Add one drop of cold water to the previously heated section using a thermometer and note the exothermic reaction. Add more water, drop by drop, from a dropping pipette until no further reaction occurs. Test the pH. **Experiment 3.** Warm a little solid magnesium oxide with water, filter and test the pH. **Experiment 4.** Investigate the relative stabilities to heat of magnesium carbonate, calcium carbonate and strontium carbonate. Test for carbon dioxide. **Experiment 5.** Investigate the relative stabilities of the nitrates of magnesium, calcium and strontium – this must be carried out **in a fume cupboard** as one of the potential products is **poisonous**. In all cases, get students to write up equations for the reactions they observe. **Timing:** 1 hour	Many practical texts contain references to these activities

Appendix 1

Syllabus section	Skills/Learning Outcomes	Notes	Sources
9.4f, 6a	**21. Some redox reactions of halogens and halides**		
	• Describe the relative reactivity of the elements as oxidising agents • Describe and explain the reactions of halide ions with concentrated sulphuric acid • Describe and explain redox processes in terms of electron transfer and/or changes of oxidation number	Students perform two experiments. The first looks at the displacement reactions of the halogens and the second involves the reactions of the halogens with concentrated sulphuric acid. **Timing:** This depends on the approach taken. The actual experimental work takes 30 minutes for each experiment	**Appendix 2** *Classic Chemistry Experiments*, The Royal Society of Chemistry – Experiment 19 for the first experiment. Some practical texts contain references to these activities
9.4f and Practical Assess-ment	**22. Reactions of the aqueous halide ions – testing for halides**		
	• Describe and explain the reactions of halide ions with aqueous silver ions followed by aqueous ammonia • Have performed the test for silver halides detailed in the Practical Assessment	These test-tube experiments give qualitative tests for halide ions. **Experiment 1.** Add five drops of silver nitrate solution **(Corrosive, Dangerous to the environment)** separately to solutions of sodium chloride, sodium bromide and sodium iodide. Note the appearance of the precipitates. Now add fairly concentrated ammonia solution (about 8 mol dm^{-3}) **(Corrosive, Dangerous to the environment)**. Note what happens to each precipitate. **Experiment 2.** Repeat Experiment 1 to obtain a second set of silver halide precipitates. This time leave them to stand in the light and note their appearance. **Experiment 3.** Add five drops of the three halide solutions used in Experiment 1 separately to lead nitrate solution **(Toxic, Dangerous to the environment)**. Note the colours of the precipitates. **Timing:** 45 minutes	*Classic Chemistry Experiments*, The Royal Society of Chemistry – Experiment 89

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Syllabus section	Skills/Learning Outcomes	Notes	Sources
6a, 1h and Practical Assess-ment	**23. Reaction of iodine with sodium thiosulphate**		
	• Carry out a titration using iodine and sodium thiosulphate • Use the results gained to verify the balanced equation for the reaction • Work out the oxidation numbers of sulphur in the sodium compounds used and produced in the reaction	This is a good place to introduce this titration. In this experiment, 10 cm^3 samples of 0.010 mol dm^{-3} iodine solution are titrated with 0.010 mol dm^{-3} sodium thiosulphate solution, which is delivered from a burette. The end point can be made clearer by adding starch solution when the iodine is a pale straw colour. Students could be asked to see if their results are consistent with the equation for the reaction $2Na_2S_2O_3(aq) + I_2(aq) \rightarrow 2NaI(aq) + Na_2S_4O_6(aq)$ It is also a useful exercise to ask students to work out the oxidation numbers of sulphur in the sodium compounds in the equation. **Timing:** 1 hour	Most A level practical texts will contain reference to this volumetric analysis
10.2a, 10.2b, 10.2c, 10.2h	**24. Experimenting with alkanes**		
	• Awareness of unreactivity of alkanes • Combustion reaction of alkanes • Substitution reactions of bromine	This is very useful as an introduction to organic compounds and it is worth spending time going through the safety aspects, such as what the various hazard-warning symbols mean. Small samples of hexane **(Highly Flammable, Harmful, Dangerous to the environment)** are used. **Experiment 1.** Dip a combustion spoon into 2 cm^3 hexane in a boiling tube and stopper the tube. Burn this in a Bunsen flame, well away from the stoppered boiling tube. **Experiments 2 to 6.** These investigate the reaction of hexane with (i) bromine water **(Highly Toxic, Corrosive, Dangerous to the environment)** in the dark (ii) bromine water in sunlight (iii) dilute acidified aqueous potassium manganate(VII) **(Oxidising, Harmful, Dangerous to the environment)** (iv) two drops of concentrated sulphuric acid **(Corrosive)** (iv) 1 cm^3 dilute potassium hydroxide **(Corrosive).** **Timing:** 45 minutes	Many A level practical books contain references to these experiments

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Syllabus section	Skills/Learning Outcomes	Notes	Sources
10.2g	**25. Cracking hydrocarbons**		
	• Understand the importance of cracking large hydrocarbon molecules to produce more useful alkanes and alkenes of smaller M_r • Have continued to develop manipulative and observational skills	In this experiment, the molecules to be cracked are vaporised over a heated catalyst. The gas produced is collected over water. The experiment is a good test of manipulation and observation. **Timing:** 1 hour	**Appendix 2** *Classic Chemistry Experiments*, The Royal Society of Chemistry – Experiment 96
10.2d	**26. Experimenting with alkenes**		
	• Combustion reaction • Addition of halogens • Oxidation by cold, dilute manganate(VII) to form the diol	Cyclohexene **(Highly Flammable, Harmful, Dangerous to the environment)** is a convenient alkene to use. Experiments similar to the ones carried out with alkanes in Experiment 24 can be performed, omitting the experiment with potassium hydroxide solution. If desired, the potassium manganate(VII) can be made alkaline using aqueous sodium carbonate. In this case, the diol is still formed but a green coloration followed by a brown precipitate will be seen. **Timing:** 45 minutes	Many A level practical books contain references to these experiments

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Syllabus section	Skills/Learning Outcomes	Notes	Sources
10.3a, 10.3b, 10.3c	**27. Some reactions of the halogenoalkanes**		
	• Understand that the rate of hydrolysis depends on the strength of the C-Hal bond • Understand that the rate of hydrolysis also depends on whether the halogenoalkane is primary, secondary or tertiary • Describe the mechanism of nucleophilic substitution as S_N1 or S_N2	These experiments are designed to show the different rates of hydrolysis caused by different halogen atoms and different carbon structures. A further experiment shows that alcoholic alkali causes elimination. **Experiment 1.** Add three drops each of 1-chlorobutane, **(Highly Flammable)** 1-bromobutane **(Irritant, Highly Flammable, Dangerous to the Environment)** and 1-iodobutane **(Harmful)** to 1 cm^3 ethanol **(Highly Flammable)** in three test tubes. Then react the solutions with 0.02 mol dm^{-3} aqueous silver nitrate. Immediately put the test tubes in hot water. Note the rate of appearance of silver halide precipitates. **Experiment 2.** Repeat the method used in Experiment 1, only this time change the carbon skeleton by using three drops each of 1-chlorobutane (primary), 2-chlorobutane (secondary) and 2-chloro-2-methylpropane **(Highly Flammable)** (tertiary). Note the rate of appearance of silver chloride precipitate. **These three halogenoalkanes are highly flammable.** **Experiment 3.** Show elimination by using 2 cm^3 20% potassium hydroxide **(Corrosive)** in ethanol **(Highly Flammable)** soaked into mineral wool using the apparatus in Experiment 25 (without the aluminium oxide). Ethene gas is collected which can be tested using dilute (pale yellow) bromine water. **Timing:** 1 hour	Many A level practical texts will contain references to these experiments

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Syllabus section	Skills/Learning Outcomes	Notes	Sources
10.4a, 10.4b	**28. Some reactions of alcohols**		
	• Combustion reaction of alcohols • Reaction of alcohols with sodium • Oxidation of ethanol to ethanal and ethanoic acid • Dehydration of alcohols to alkenes • Reaction of alcohols with carboxylic acids to form esters	These experiments introduce students to some reactions of the alcohol functional group. **Timing:** At least 1 hour. This is likely to be spread over two 1-hour practical sessions	**Appendix 2** *Classic Chemistry Experiments*, The Royal Society of Chemistry – Experiment 79 for Experiments 1 and 3 Most A level practical texts
10.5c, 10.5d	**29. Testing for, and deducing the nature of, carbonyl compounds**		
	• Describe the use of 2,4-dinitrophenylhydrazine (2,4-DNPH) to detect the presence of carbonyl compounds • Deduce the nature of an unknown carbonyl compound using Fehling's and Tollen's reagents	**Experiment 1.** Test 3 drops of proponane (H**ighly Flammable**) and 3 drops of propanal **(Highly Flammable Harmful)** separately with 5 cm^3 2,4-DNPH (**Corrosive, Toxic and Highly Flammable**). **Experiment 2.** Test 10 drops of propanone and 10 drops propanal separately with 3 cm^3 Fehling's solution **(Corrosive and Toxic)**. **Experiment 3.** Test 10 drops of the aldehyde and ketone with 3 cm^3 freshly prepared Tollen's reagent. **Timing:** 45 minutes	Many A level practical books provide information about how to make up Tollen's solution and Fehling's solution
10.6b	**30. Some reactions of ethanoic acid to form salts**		
	• Describe the reactions of carboxylic acids in the formation of salts	Show the reactions of the weak acid, ethanoic acid **(Corrosive)** (0.05 mol dm^{-3}). Use universal indicator paper to show neutralisation with (i) sodium carbonate solution (0.4 mol dm^{-3}) (ii) sodium hydroxide solution (0.4 mol dm^{-3}) **(Corrosive).** Add a small piece of magnesium ribbon **(Highly Flammable)** to 2 cm^3 of the above acid and test the gas evolved for hydrogen. **Timing:** 30 minutes	*Classic Chemistry Experiments*, The Royal Society of Chemistry – Experiment 78