triple science support programme

teaching triple science: GCSE chemistry

GCSE chemistry

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GCSE chemistry

This edition published by the
Learning and Skills Network in 2008

First edition published by the
Learning and Skills Network in 2007

www.lsnlearning.org.uk

Registered with the Charity Commissioners

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CIMS 080079GR/07/08
First edition CIMS 072840GR/11/07/5000
ISBN 9781845727307
First edition ISBN 9781845726492

Acknowledgements

The Learning and Skills Network wishes to thank the following for their work on this project: Catherine Aldridge, Ed Walsh, David Harrison, John Walker, Colin Osborne, Kay Stephenson, Maria Pack, Miranda Stephenson, Shân Oswald, Derek Bell and all those who participated in shaping and reviewing this publication.

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Contents

Preface

The Department for Children, Schools and Families (DCSF) has contracted with the Learning and Skills Network to support awareness and take-up of Triple Science GCSEs through the Triple Science Support Programme.

The programme aims to support the following policy objectives:

- to enable young people with level 6 or above in science at Key stage 3 that would benefit to study Triple Science GCSEs from September 2008
- to help specialist science schools offer Triple Science to their students that would benefit from September 2008.

The Triple Science Support Programme comprises the following:

- the programme website www.triplescience.org.uk
- the Triple Science community including a new section on e-learning
- a programme newsletter three times a year
- publications on: collaboration and partnership; raising attainment in Triple Science; curriculum modelling, timetabling and Triple Science, and three subject-specific resources on the separate sciences
- case studies that expand on the publication themes
- Triple Science networks of support for practitioners
- Triple Science collaborative projects
- an offer of small workshops or bespoke consultancy for up to 400 schools (around the topics above)
- a marketing campaign around Triple Science for schools.

This publication provides an introduction to teaching and learning approaches for the extension topics within GCSE Chemistry. It highlights some specific ideas that teachers can adopt and where to find further information. It also outlines issues for managing the change.

This programme has been funded by the DCSF. All publications, networks and newsletters will be delivered without charge to maintained secondary schools. The training and consultancy will be available to schools that either do not currently offer Triple Science GCSEs or are planning a substantial increase in the numbers in September 2009.

If you wish to register an interest in the programme, please contact the LSN helpline on 0845 071 0800 or e-mail triplescience@lsnlearning.org.uk

Alan Goulbourne

Executive Manager
Triple Science Support Programme
Learning and Skills Network


Sodium
Chloride

Section 1
The policy context

Background

Triple Science is a combination of three GCSEs in biology, chemistry and physics. It will normally be a course of study for students in Years 10 and 11. Triple Science provides the fullest coverage of these subjects at Key stage 4 – including all of the compulsory programme of study for science – provided all three are taken during the key stage.

A new non statutory 'entitlement' to Triple Science will be effective from September 2008 for students achieving at least level 6 at Key stage 3 that would benefit (see page 3). While around a quarter of maintained schools already offer Triple Science, there is still some way to go before the entitlement is available throughout the maintained sector.

Why Triple Science GCSEs?

Schools that have offered Triple Science GCSEs for a number of years report the following benefits.

- The course adds diversity to the curriculum.
- It satisfies parental demand.
- It is an excellent preparation for A-level.
- There is a 'halo' effect that improves the standard of science in the school.
- The staff enjoy teaching the course.

At the strategic level, the economic future of the country is dependent on a good supply of highly educated scientists. The Government has made commitments to encourage all schools to offer Triple Science to students who could benefit.

At the student level, Triple Science provides more opportunities to enjoy a more breadth of knowledge and understanding of science.

Why a Triple Science Support Programme?

The Triple Science Support Programme has been put in place to help schools, managers and teachers plan, prepare and implement the Triple Science GCSEs. At the systemic level, the support programme should create momentum for change that leads to the entitlement becoming a reality in maintained schools in England.

Section 2
About this publication

This is a subject-specific publication to support teachers in the delivery of the new Triple Science GCSEs. It focuses on GCSE Chemistry, and particularly on the content that extends Additional Science to the Triple Science GCSEs.

While this guide concentrates on the content and teaching and learning appropriate for GCSE Chemistry, there are also guides that explore:

- GCSE Biology
- GCSE Physics
- raising attainment
- curriculum modelling
- collaborative working
- resources for delivering Triple Science GCSEs.

The target audience is science teachers who are introducing Triple Science, including those teaching outside their specialism and subject leaders.

This guide provides an introduction to the extension topics for GCSE Chemistry and highlights some specific ideas that teachers can adopt. It is a starting point to provide support to teachers who will each have different needs, rather than a definitive guide. Further advice and support can be obtained from colleagues in school, the local authority, the Triple Science Support Programme or the organisations listed in this publication.

Section 3 outlines how Science, Additional Science and Extension Science (Chemistry) are structured and the related Annex 1 compares the chemistry content for each specification, outlining what is required for Science, Additional Science and Extension Science.

Section 4 outlines effective teaching and learning approaches relevant to the extension topics in GCSE Chemistry and introduces:

- teaching and learning models to encourage active learning
- approaches to teach and assess How Science Works
- using investigations and demonstrations
- enhancing science with ICT
- links to other subjects
- engagement and attainment in chemistry.

Section 5 provides specific ideas for teaching and learning the key topics in the extension specifications. Each topic is described in terms of the subject knowledge required, the challenging concepts that arise and the most relevant opportunities for How Science Works. A range of tried and tested teaching activities follows to exemplify the different teaching models introduced in Section 4. Ideas for investigations and demonstrations, additional activities and centre-marked assessment provide a taster of what other teachers recommend. There are also links to appropriate resources and organisations for each topic.

Section 6 outlines issues to consider when implementing GCSE Chemistry in a science department, such as staffing, continuing professional development, health and safety, and resource requirements.

Section 7 lists resources and organisations from where further information can be obtained.

Section 3
GCSE specifications for chemistry

Changes to the GCSE curriculum have provided schools – and students – with much greater choice and the opportunity to make GCSE Science more relevant.

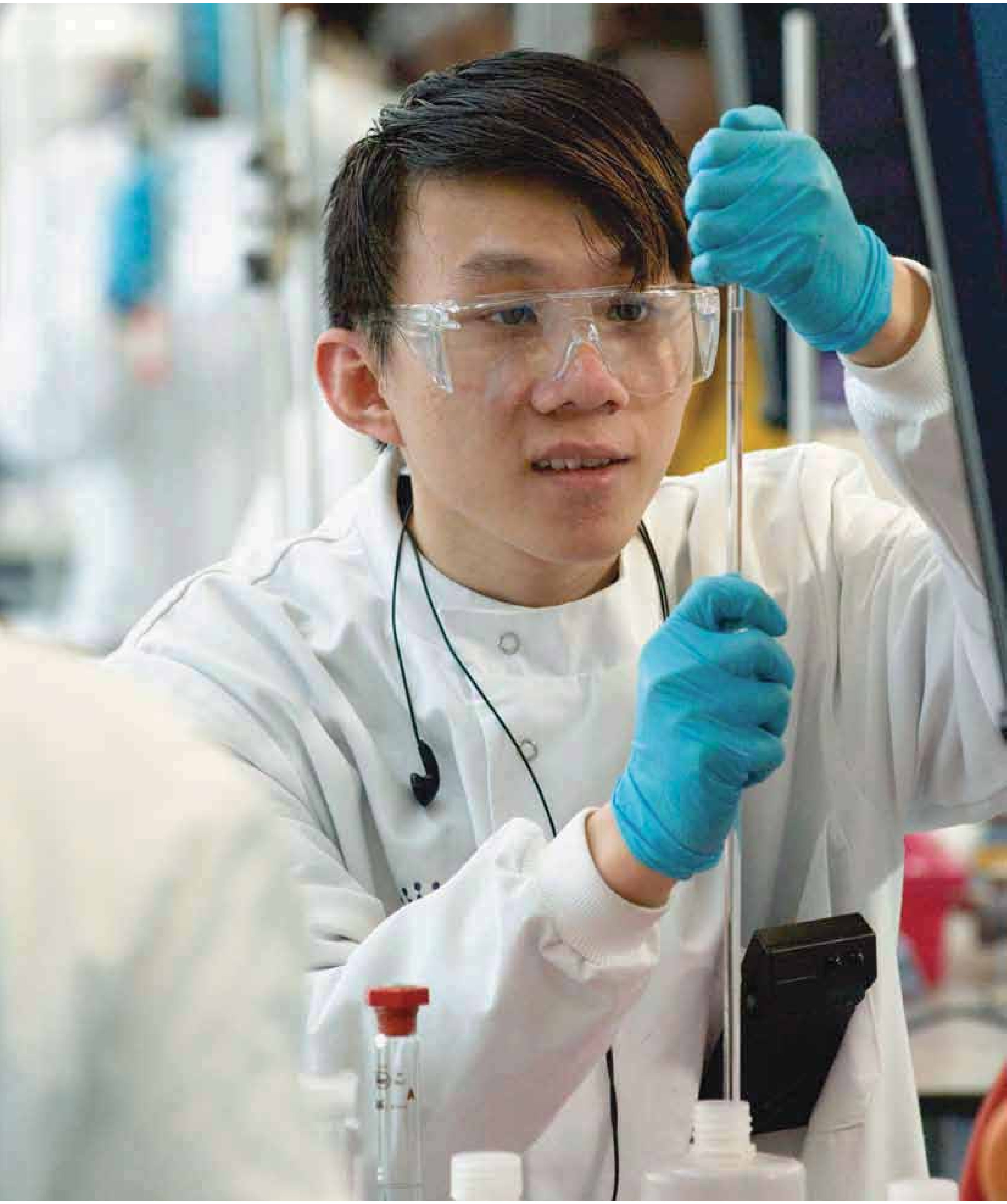
Schools introduced the new Programme of Study and associated specifications in September 2006.

The new GCSE Science and GCSE Additional Science, when taken together, are equivalent to the previous Double Science GCSEs. Specifications for GCSE Chemistry include the chemistry and 'How Science Works' content from GCSE Science and GCSE Additional Science. In addition, they include further extension topics in chemistry. Taken together, GCSE Biology, GCSE Chemistry and GCSE Physics cover the entire science Programme of Study, plus the additional subject-specific content.

This publication refers to the five main specifications for GCSE Science:

- AQA
- Edexcel 360Science
- OCR Gateway
- OCR Twenty First Century Science
- WJEC.

A summary of the chemistry content for each of the GCSE Science specifications can be found in Annex 1.



Section 4
Effective teaching and learning approaches for GCSE Chemistry

Effective teaching and learning is clearly critical to students' engagement, attainment and progression.

Ofsted's annual report 2005–06 summarises neatly some key elements of effective practice:

Many schools have given consideration to pupils' preferred learning styles, and across a range of subjects it is evident that higher achievement is associated with active forms of learning. For example, where science was well taught, not only were basic concepts effectively addressed, lessons were also stimulating and enjoyable. In thinking about How Science Works, pupils researched and exchanged information, often making effective use of ICT, debating ideas and displaying knowledge and understanding of issues very relevant to their own and others' lives.

This contrasted sharply with the low achievement in schools where pupils went through the motions of practical work as instructed, rather than engaging in genuine scientific investigation.

Triple Science offers significant potential in terms of a course that can be challenging, engaging and successful in inspiring more students to study science subjects post-16. It could, however, also become a dry and uninspiring delivery, only serving to discourage students. The challenge to the science education community is to identify the steps that will take it towards the former and away from the latter and to put those into practice.

Teaching and learning models

Teaching and learning are complex processes and often good teachers teach different aspects of the curriculum in different ways. When asked, teachers cannot always explain why they chose one particular process over another. These teachers are unconsciously using different teaching and learning models to best fit the students they are teaching.

By developing knowledge of different teaching and learning models, teachers are able to understand why some approaches are better than others in particular situations. The explicit consideration of which teaching and learning models to use and when to use them will not only enhance students' learning but also provide the vocabulary for teachers to discuss and share their experiences with others, and so help develop their practice.

Deciding which teaching and learning model(s) to use when planning is not intended to be time consuming; rather an opportunity to consciously adapt lessons to make them more effective for the students. Some teaching and learning models have been developed based on theories of learning and educational research. Each can be expressed as a tightly structured sequence of activities that is designed to elicit and develop a specific type of thinking or response from students.

The teacher's choice of approach should be determined by the learning objective and the needs of students, recognising that some subjects and topics will draw more heavily on some models than others and that different models will suit different learners and help develop different thinking skills. Consistent and explicit use, as well as carefully selecting and combining approaches, has significant potential for improving students' learning. Coupled with a metacognitive approach to teaching for learning, or 'thinking about thinking', it will support students' understanding further.

This publication explores five specific teaching and learning models appropriate for delivering different aspects of GCSE Chemistry. The five teaching and learning models considered here are ones that lend themselves particularly to science and include:[1]

- **direct interactive teaching**

  The teacher leads students through a variety of planned activities to introduce new knowledge or a skill. The class review what has been learned.

- **constructing meaning**

  The teacher introduces a concept and identifies prior knowledge. Students are provided with examples that do not fit their current understanding and discuss their ideas and restructure their understanding to include the new examples. The class review the changes in their understanding.

- **enquiry (inductive)**

  Students develop information-processing skills and gather, sort and classify data to suggest a hypothesis, similar to the process Darwin used to arrive at his theory of evolution. Data can be re-sorted to further test the hypothesis.

- **enquiry (deductive)**

  Students develop information-processing skills; they are provided with a hypothesis and determine the best way to collect data and draw conclusions. Students decide whether more data is needed to support or refute the hypothesis.

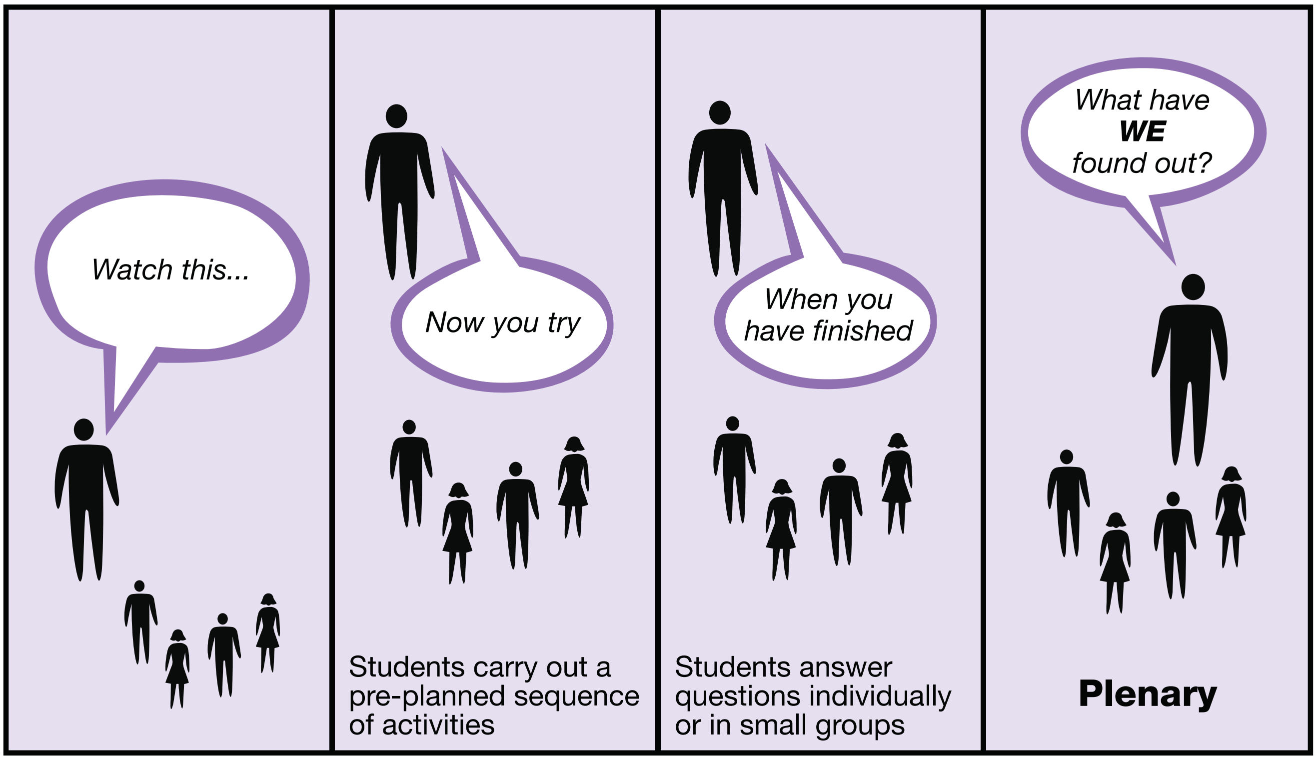
- **using models**

  Students are introduced to a model or idea. This is used initially to explain a phenomenon. Students begin to challenge the model and identify limitations. It is further refined to develop a 'better fit' model.

Each of these models is now described and exemplified in detail.

1
We gratefully acknowledge Gloucestershire Local Authority's work on teaching models, which is reproduced in this publication with the organisation's permission. A list of further publications given in Section 7 also informed this section.

Direct interactive teaching



Direct interactive teaching is effective in helping young people to learn new skills and procedures and acquire academic knowledge.

The sequence often begins with whole-class exploration of features of the skill or knowledge to be acquired, with modelling, demonstration or illustration. Students then work individually or in pairs to remember the new knowledge and fit it into existing ideas, or they apply and practise the new skill, perhaps with some new additional guidance. The learning ends with a whole-class review, attempting to move students from dependence to independence.

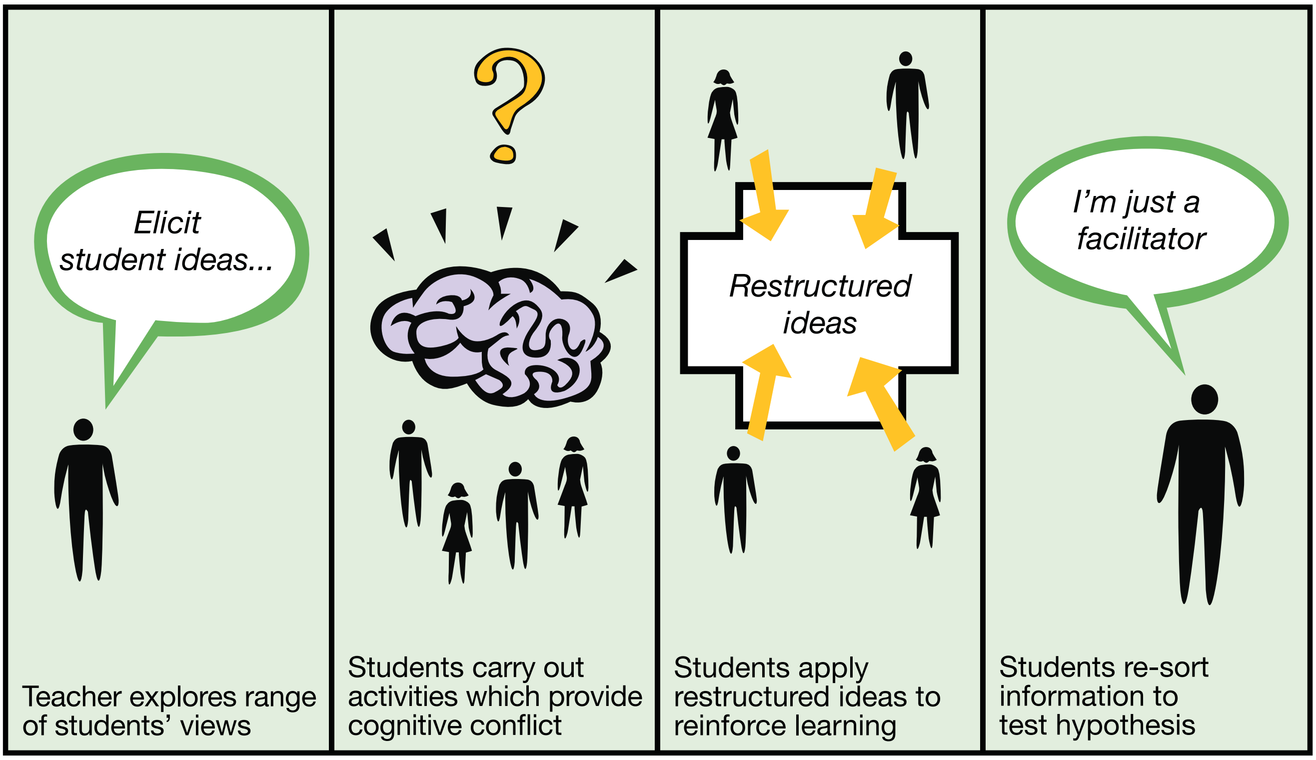
Teacher skills and techniques involve modelling, guiding, demonstrating, defining conventions, composing together, scaffolding first attempts, reviewing new learning, and mnemonics.

This model is practised effectively by many teachers and could be described as a default teaching model for some.

Example: A video of the Contact process is shown to the class. Students record information about the process as they watch the film and then answer questions relating equilibria and rates of reaction to the optimum conditions for the process. A plenary session summarises the key points of the process.

dit **In this publication, teaching and learning activities based on the direct interactive teaching model are marked with this symbol.**

Constructing meaning



Constructing meaning is a learning model that recognises that students already have ideas about the way they view the world. This is a constructivist approach that helps them reformulate and refine their understanding through metacognitive processes, providing opportunities to address and resolve misconceptions.

In this approach, students' ideas are made explicit so that the range of views can be explored. Providing examples that cannot be explained by students' ideas leads to cognitive conflict, which leads to clarification and evaluation of the students' views. These newly agreed, restructured views are then applied to test understanding in new situations. Finally, students review their understanding through discussion. The teacher often acts as a facilitator and manages the process, especially through providing scaffolding for students.

Teaching skills and techniques often employ the use of direct teaching, group discussion, concept-mapping, concept cartoons and experimentation.

Example: Students are challenged to define a strong and weak acid and whether these are the same thing as concentrated and dilute acids respectively. They observe how the pH changes for different acids that have the same molarity and reassess their understanding of the terms 'strong', 'weak', 'dilute' and 'concentrated'.

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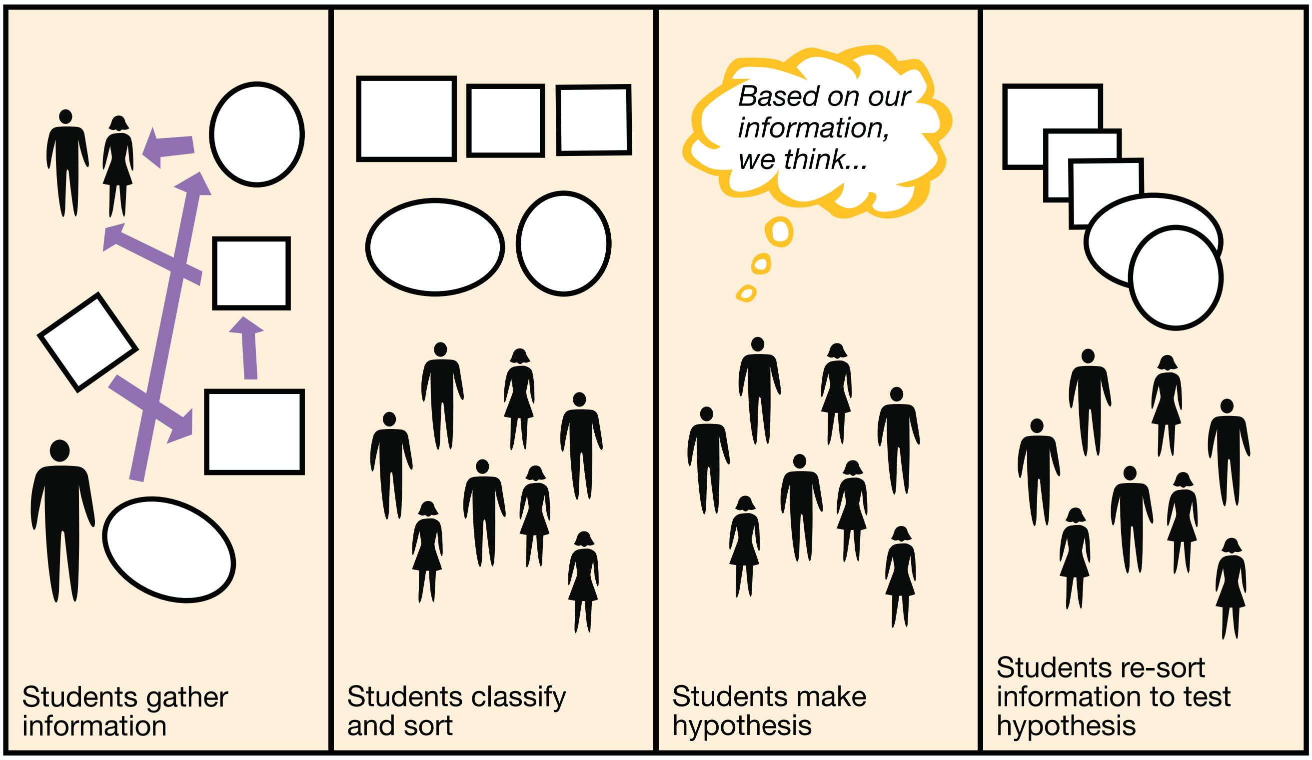
In this publication, teaching and learning activities based on the constructing meaning model are marked with this symbol.

Enquiry (inductive)



Inductive teaching is a model that encourages students to categorise the subject knowledge, skills and understanding that they are learning and to test and use those categories in challenging their level of understanding. It is a model that nurtures thinking skills and helps enable students of all abilities to process the information at their disposal effectively.

This teaching model is very powerful in helping students to learn how to build knowledge and as such is closely related to constructivism (constructing meaning) as a support for student learning.

The inductive model requires students to sort, classify and re-sort data to begin to make hypotheses that can be tested in future work. It is used when teachers want to explore the concepts that underpin subject knowledge, and want students to recognise the ways in which their knowledge is constructed.[2]

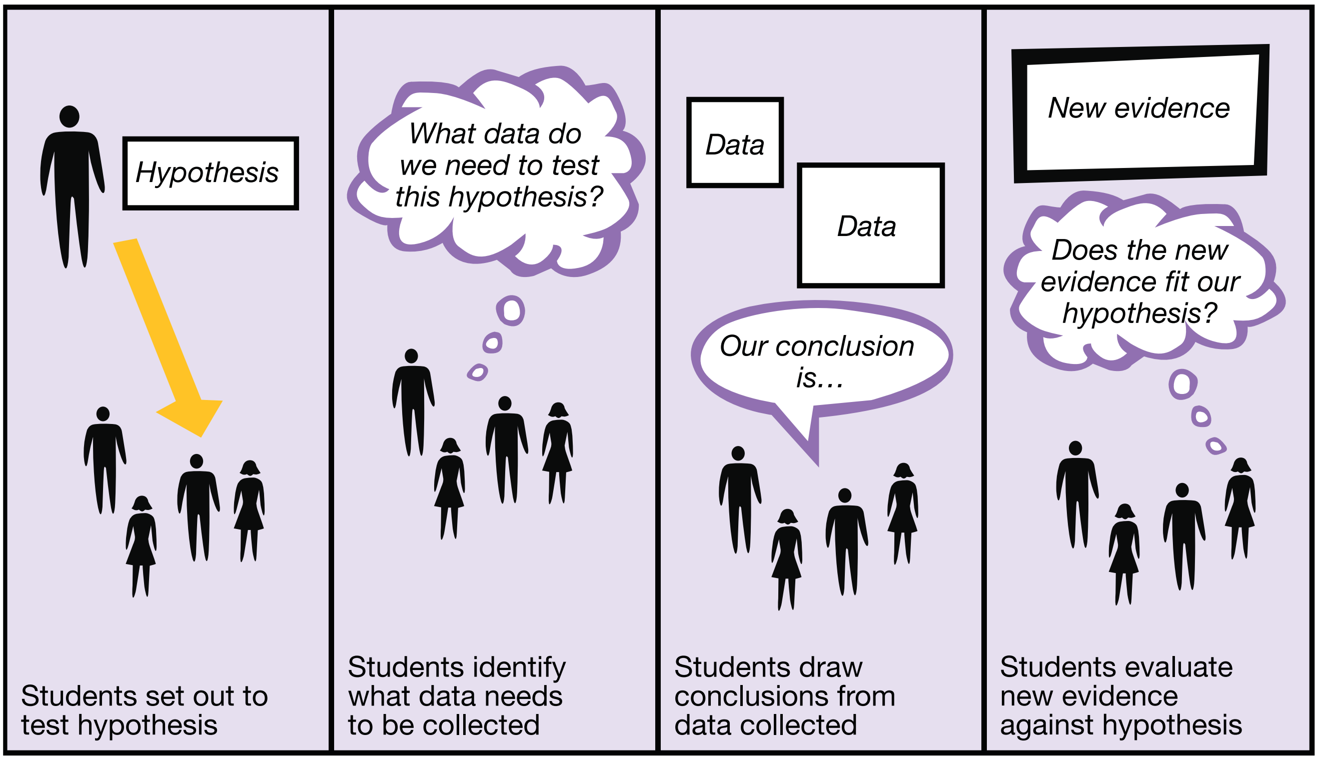
It is important to note that the enquiry (inductive) model can easily be developed into the enquiry (deductive) model if the hypotheses then go on to be tested with new data. Teachers must be conscious that the inductive model may be tested only by re-sorting original data.

Example: Students carry out test tube experiments or use secondary data to learn about the reactions that occur between ions in solution. They sort and classify ideas to develop hypotheses for standard tests for cations and anions.

In this publication, teaching and learning activities based on the enquiry (inductive) model are marked with this symbol.

2
This is drawn from DfES (2004). *Pedagogy and practice: teaching and learning in secondary schools – Unit 2: Teaching models*, Department for Education and Skills (Ref: DfES 0425-2004 G).

Enquiry (deductive)



An enquiry (deductive) approach encourages students to solve problems using deductive reasoning. Deductive reasoning produces conclusions that are reached from previously known facts called premises. The assumption is that if a number of related premises are true, a conclusion that supports them should also be true.

Given a hypothesis, data is then collected directly or from secondary sources in order to confirm or refute it. Conclusions are then drawn and any new evidence is compared with the original hypothesis to see whether it also leads to the same conclusion or not. If not, the validity of the conclusion drawn needs to be questioned further. It is important to note that if the original hypothesis is refuted and the data is used to develop a new hypothesis, this enquiry model has moved to the inductive model.

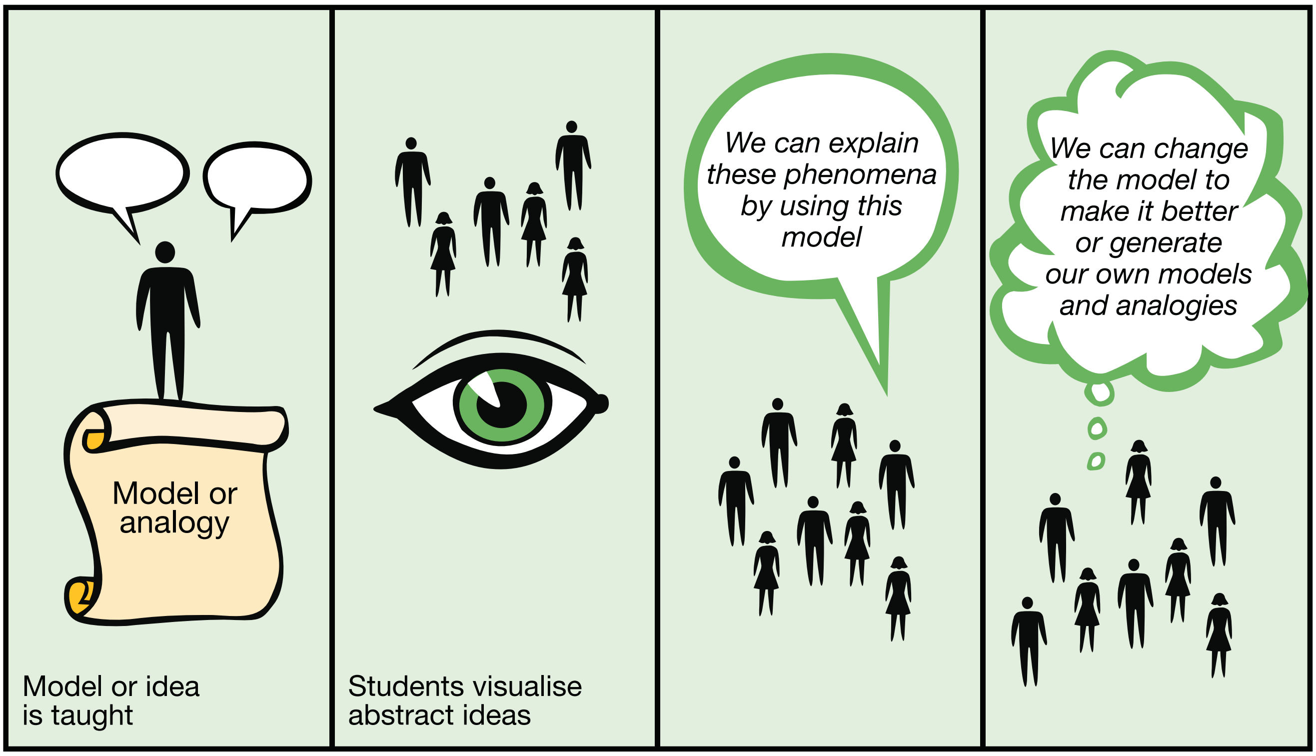
Teaching skills and techniques employ the use of experimentation, practical work, research and modelling each stage and reasoning.

Example: Students explore how primary and secondary data about alkanes and alcohols could support predicted relationships between molecular structure and physical and chemical properties.

e(d)

In this publication, teaching and learning activities based on the enquiry (deductive) model are marked with this symbol.

Using models



Models are an important mechanism for advancing understanding within the scientific community.

Teachers use modelling to help students make sense of observations, findings and abstract ideas through the visualisation of:

- objects that are too big (eg an ecosystem)
- objects that are too small or not seen easily (eg a cell)
- abstract ideas (eg energy transfer).

Allowing students to question, restructure and develop their own models to explain other phenomena helps reinforce understanding.

Scientific models are built by consensus within the scientific community. They are often pictorial and this can be two-dimensional (eg a diagram of the eye), three-dimensional (eg molecular models) or include a time dimension (eg animations to illustrate the particulate nature of matter).

Analogies are a subset of teaching models and are based on comparisons with familiar objects or processes. They are useful illustrations but often have only superficial parallels with the abstract idea being illustrated.

Example: Students use molecular models to determine the number of bonds broken and formed in a reaction and then calculate energy changes. Students put in energy to pull the models apart, representing the energy needed to break bonds.

um **In this publication, teaching and learning activities based on using models are marked with this symbol.**

How Science Works

The teaching is based, of course, on the Programme of Study, mediated by the selected awarding body, and although there may be a different emphasis placed on this in different courses, it will be ultimately fairly similar. For example, the study of calorimetry of combustion reactions gives opportunities to gather data to develop and support explanations for energy changes in reactions and then apply these principles to compare the energy provided by different fuels and foods. This enables students to gain an understanding of the applications and implications of science in society issues such as obesity and sustainability, irrespective of which awarding body has accredited the course. Further exemplification of how the How Science Works Programme of Study can be taught in the context of the GCSE Chemistry extension topics is found in Section 5. A list of relevant resources, many of which support the How Science Works agenda, can be found in Section 7.

Assessment, however, is materially different and the way in which students gain credit for understanding How Science Works varies significantly depending on the specification; this needs to be borne in mind whilst using this guide. There is a more detailed treatment of the assessment of How Science Works in each specification in Annex 3.

In the material provided for each of the topics in Section 5 there are extracts from the Programme of Study for How Science Works. These have been selected to highlight principal opportunities within that topic: this is not to say that others couldn't be addressed in that context.

Many departments will, of course, have made substantial progress in their understanding and their delivery of How Science Works since the GCSE courses were first prepared. The Secondary National Strategy has a considerable amount of helpful guidance and resources available at http://nationalstrategies.standards.dcsf.gov.uk/search/results/%22how+science+works%22

Using investigations and demonstrations

Investigations and demonstrations give students an opportunity to explore science in a way that leads to them becoming questioning adults. They are both opportunities to introduce scientific enquiry and can be taught throughout the whole of the science curriculum to promote students' thinking and questioning skills. They should move away from the student only doing practical work as part of a full investigation and towards enquiry being an integral part of lessons.

Practical work, like any other aspect of teaching, needs careful planning. There is much evidence to show that the various forms of practical work open to a teacher to use can be highly motivational for students; however, motivation and providing 'fun' activities are not sufficient justification for doing practical activity. The teacher, and therefore the students, should recognise the purpose of the activity, whether student-centred or led from the front in the form of a demonstration.

A short demonstration at the start of the lesson could:

- challenge the students to explain a phenomenon unfamiliar to them
- lead to further investigations which students themselves will conduct
- excite the students about a new topic they are about to encounter
- generate questions about the new topic.

Later in, or at the end of a lesson, a demonstration might help to summarise what the students have been learning during the lesson. In these cases, it is good practice to encourage the students to link their learning with the observations they are making by attempting explanations of what is happening.

Again, where students are being asked to undertake an investigation, the teacher should think about the learning outcomes he or she wants to achieve from it. Sometimes it is not necessary for students to conduct the whole investigation from the planning stage through to the conclusion. Depending on what the teacher wants to achieve, he or she may start or stop the investigation at different stages. For example:

- planning and evaluation of the plan
- carrying out the final plan
- collecting and analysing data (in terms of validity and interpreting its meaning)
- drawing conclusions (in terms of the validity of the investigation and the science that has been learnt from doing it).

Sometimes the teacher will use part of an investigation to enable the students to learn and practise new skills (both practical and enquiry skills); for example when students are learning to use titrations in the chemical detection topic. At other times, when the skills are familiar, the teacher may introduce an investigation to allow students to have an opportunity to explore and develop their understanding of a scientific concept, to see if they can offer their own explanation. An example of this would be to investigate the increase in combustion enthalpies for a series of alcohols. Occasionally, the teacher might suggest a number of alternative explanations, and through investigation the students derive a view of which explanation best fits the evidence they have collected.

Whether teachers are running an investigation or doing a demonstration, it is important that they are familiar with the practical activity and should therefore practise anything unfamiliar in advance. This will ensure that teachers feel competent and confident in their expectations of what will happen; it also ensures that they manage all the risks that might arise.

All employers have a legal duty to carry out risk assessments for hazardous activities which their employees (and in the case of schools, their pupils) are involved in. This duty is delegated to headteachers, who subsequently delegate it to heads of department and classroom teachers. Employers should provide model risk assessments that teachers should consult and adapt to their own circumstances. Examples of model risk assessments are the CLEAPSS Hazcards. It is expected that teachers should carry out a risk assessment whenever they are undertaking practical work, but that does not have to mean a lengthy form-filling exercise.

Risk assessment is not to reduce the amount of practical work being done in schools; it should lead to a greater range and variety of practical work encountered by students, all of which are managed safely. CLEAPSS will give guidance and advice to school science departments when they are introducing new practical work (see Section 6). It can also be useful for the students to build an awareness of safety by carrying out their own risk assessments.

There are often particular concerns about the safety of practical work in chemistry. The Royal Society of Chemistry's report *Surely that's banned?* exposes the myths and misunderstandings. It is available at: www.rsc.org/Education/Policy/SurelyThatsBanned.asp

Ideas for practical work come from:

- websites and publications provided by professional bodies, such as the Royal Society of Chemistry and the Association of Science Education. The Practical Chemistry website (www.practicalchemistry.org) has been referenced widely in this publication as it provides a wealth of guidance
- published resources
- continuing professional development courses, such as those provided by the national network of Science Learning Centres and its Resource Bank, which can be found on the portal www.sciencelearningcentres.org.uk and other sites on the web such as those listed in Sections 5 and 7.

Enhancing science using ICT

Will ICT make the lesson easier, better or different? ICT should be chosen as a resource only if it will support the lesson's learning objectives (Betts, 2003).[3] Used appropriately, ICT can enhance learning and teaching, for example, by providing animations and video clips of scientific concepts which can help students' understanding of scientific phenomena. ICT can be particularly useful for hard-to-teach topics by providing 'concrete' examples of phenomena that are difficult to observe in a school laboratory or difficult to test using traditional experiments.

The Secondary National Strategy identifies the main applications of ICT in science as:

- simulations and modelling
- data logging
- databases, spreadsheets and graphical calculators
- information resources
- publishing and presentation software.

Additionally, there is increasing scope for the sharing and communication of science through online facilities, and the use of multimedia techniques for the recording of information and data.

Simulations and modelling

ICT can give students and teachers an opportunity to use a computer model to change variables and investigate the effects in situations that are difficult to create in the classroom. For example, teachers can present an animation to students demonstrating the reaction of nitrogen and hydrogen to form ammonia. Students then use a model of the Haber process to vary the temperature and pressure of the reaction to investigate the change in the yield of ammonia.

Data logging

Data logging helps students to record, present and analyse results. For example, students use data loggers and a light sensor to record quantitative results in the 'disappearing cross' experiment – measuring the rate of reaction between sodium thiosulphate and hydrochloric acid. In this version of the experiment the data logger gives an accurate quantitative measure of the light passing through the reaction mixture.

Databases, spreadsheets and graphical calculators

These applications allow students to see data visually as well as organise, search, sort and display information in order to explore relationships, look for patterns and test hypotheses. For example, using a database of the elements of the periodic table, students can use the search and filter functions to look for patterns and properties of groups and periods of elements.

Information resources

By using the internet and CD-ROMs, students are able to develop their knowledge and understanding of science. For example, students undertake a 'virtual visit' to an oil refinery to discover information on the refining process, the different fractions of crude oil and how they are used.

The Fawley Refinery tour (ASE schoolscience)
http://resources.schoolscience.co.uk/exxonmobil/index.html

Oil strike (a game from the RSC)
www.rsc-oilstrike.org

Teachers may also use information resources to enrich their teaching. For example, introducing video clips to start a lesson can make the subject topical and relevant by showing science in the real world. News stories can introduce activities looking at How Science Works.

3
Betts S (2003). 'Does the use of ICT affect quality in learning science at Key stage 3?' *Studies in teaching and learning*, pp9–17.

Publishing and presentation software

Research shows that when students present their findings to their peers, their own understanding of the subject is improved. For example, students use presentation software to produce a TV quiz-type game with questions on a topic they have studied, such as the periodic table. Then acting as quiz master, they present the 'TV quiz' to their peers.

One of the growing areas of ICT usage in chemistry is the use of digital video to capture presentations and practical activities. This has a number of advantages, including:

- encouraging students to be clear, precise and concise in presenting ideas that they have developed
- providing an opportunity to analyse material in the lesson from experiments
- providing an opportunity to revisit ideas and questions later in the lesson or series of lessons
- using footage with other teaching groups as exemplar material.

Interactive whiteboards are also an important classroom tool for many science teachers. Advice and guidance on how to use them effectively in science can be found in the spring 2007 Secondary National Strategy science subject leader development materials. See http://nationalstrategies.standards.dcsf.gov.uk/node/97407

Links to other subjects

Maths

The links between maths and science are many and obvious. For example, calculations involving moles, balancing the symbol equations of chemical reactions and titration calculations are included in many of the extension topics for GCSE Chemistry. Students need to be confident working with ratios and percentages, and gain an appreciation of very big and very small numbers to understand the numbers of particles involved and the size of particles respectively. This underpins their ability to move between observations at the macroscopic level and models describing what is happening at the molecular and atomic levels.

Students may also confuse the seemingly different equations encountered in physics, maths and chemistry. It is also necessary to use graphs to illustrate and interpret relationships such as solubility and temperature and pH vs. volume of acid/base added for titrations. The reliability and validity of data and errors can be explored using the results of calorimetry and titration experiments.

It is therefore useful for there to be a dialogue between the maths team and the science team to identify a number of issues at the planning stage, such as when these particular topics are covered in maths and science and also what is meant by terms such as 'equations', which are seemingly different in maths, physics and chemistry. It is also useful to be able to raise issues such as the difficulty that students may have with certain mathematical concepts, so that strategies to address these can be shared.

English

The Triple Science Support Programme's 'raising attainment' publication covers a number of issues here in some detail. In essence there is a need to address four areas throughout the course.

The effective use of key words is essential, and the awarding of assessment marks often hinges upon the correct usage of such words. They need to be introduced, used and reinforced appropriately throughout. They can be raised in importance by their explicit use in starter activities and highlighted in the evaluation of conclusions, for example. Using writing frames to introduce key words can be followed by peer assessment.

Speaking and listening are key skills in the learning process. If they are a strong feature of lesson design, students will learn more effectively. If they are not present or not structured appropriately, students will not have as good an opportunity to explore and internalise new ideas. Teachers need to be able to manage such activities effectively by, for example, the use of effective questioning.

Writing needs to have a clear purpose; where there is none, students are rightly critical of the time and effort spent on it. Summaries for revision need to be brief and well structured, and all writing needs to actively engage the mind for it to be meaningful. Once written, text needs to be reviewed and assessed. A well written (and re-written) conclusion to an experiment may well add significantly more to a student's learning than a whole experimental write-up never looked at again. Ideas need to be shared and re-worked so that, for example, an explanation of particle activity is clear and accurate. Tables can be used effectively to summarise various facts and patterns.

Reading is also a key skill. Students need to be encouraged to read for a purpose and to be given ways of extracting information, such as highlighting key points and identifying the use of evidence to support an argument. English teachers are often very effective in using group work to present cases for and against issues and it may be useful to observe others using this technique.

PSHE

A key aspect of PSHE is the development of individuals into confident and responsible people. This is obviously a function of the whole curriculum, but science has its part to play in this; it provides a number of contexts that give students an opportunity to develop and demonstrate skills and dispositions. For example, with a topic such as fuels, students need to realise the significance and application of the ideas and to present ideas confidently about the opportunities and risks involved.

PSHE also involves students in being healthy and safe. Fundamental to this is students developing an understanding of how to manage their own lives so as to be healthy and safe. It is not only an understanding of what this might involve but also experience of assessing and managing risk. Students who have been kept safe but who don't know how to recognise and respond to hazards are less likely to remain safe. Students should therefore be involved in discussions about the nature of investigations they carry out and propose safety measures.

Citizenship

Responsible and effective citizens can conduct enquiries. Although this is obviously a wider area than scientific enquiry, science can offer a number of opportunities for students to formulate questions, design investigations, gather evidence and draw conclusions. The concept of learning from the evaluation of evidence is strong in science and is a key way in which it makes a contribution to the whole curriculum. It is therefore important that students are involved in the design of enquiry so that they see enquiry as a tool that they can use in life as in science.

Communication is also a fundamental aspect of citizenship and one that can be developed through science. Scientists need to be able to communicate their ideas effectively, and the subject provides contexts for the development of these skills. For example, students studying particle models need to be able to draw together ideas from a number of sources and synthesise an overall view. To do this effectively, students need to have a command of a range of communication skills including speaking, listening, reading and writing.

Engagement and attainment

Progression and formative assessment

The concept and significance of progression is increasingly well established at Key stage 3; most teachers accept that students should be faced with challenges that progress as their learning develops and that the curriculum should be structured accordingly. However, at Key stage 4, the place of progression is not so well founded. It is sometimes a challenge to reconcile progression within the structure of a modular course, although there are some clear strands that run through the chemistry specifications. How Science Works is also moving towards making progression explicit. Contexts can be selected that are more complex and less familiar. Explanations can be developed that draw upon more than one model and involve synthesising ideas.

Formative assessment has a fundamental role in this: students and teachers need to know what current levels of understanding are and then to understand how improvement is possible. There is much good practice to draw upon to support this: the use of learning objectives to base lesson design upon, effective questioning, the use of data to set targets and the development of peer and self-assessment. There is a risk that this falls by the wayside if teachers and students are faced with a large amount of content and become mainly concerned with coverage.

Making learning meaningful

As well as being well structured in accordance with students' learning needs, it is also important that lessons support students in making sense of the world. Students need to feel that science is a tool they can use to make sense of the world, to understand it and to change it. The outcome from the course has to be not only in terms of completing tasks, passing exams and gaining qualifications but also in being empowered to make a contribution to society.

Science, of course, offers much in this way. Extension Chemistry topics include the ozone layer and CFCs, alcohols and analytical procedures vital to the food industry, forensic science and many industrial processes. This needs to be apparent in the design and delivery of lessons, and teachers need to be explicit about why some of the fundamental topics are important and how they are used by chemists in the real world.

Working in the world of science

Scientists work in a particular way (or ways) and it is their distinct approach that represents the particular contribution of science to the curriculum. This includes enquiry and the role of gathering primary data, but it goes further than that. Students need to learn how secondary data can be used, how explanations are constructed, how ideas are presented, and then how the scientific community works to review and validate new ideas. Students need to appreciate the provisional nature of scientific knowledge.

They need to see how this happens in practice. They won't find out how the scientific community functions simply by doing lots of experiments. If effective, outside speakers and mentors can give students an insight into how scientists operate and make progress. There are several organisations that can help identify suitable, trained researchers from industry and academia. These are listed in Section 7. There is also a role here for off-site visits. Some students will have little idea about how a scientific workplace functions or how scientists go about their work.

Some departments have a sound track record of inviting outside speakers who are effective and engaging. It is important to remember that not all students will see themselves as professional scientists in the future, so as well as speakers who fall into that category consider people from other walks of life who are using science in their work.

Guidance on effective collaboration between schools and external organisations along with case studies can also be found at: www.standards.dfes.gov.uk/secondary/keystage3/subjects/science/focus/collaboration_science/

Section 5
Specific GCSE Chemistry topics

A brief overview of the range and content of chemistry in Extension Science (see Annex 1 for single-page summaries of the chemistry content in each specification overall).

	AQA Extension Science	Edexcel360 Extension Science	OCR Twenty First Century Extension Science	OCR Gateway Extension Science	WJEC Extension Science
	Chemistry 3	3: Chemical detection 4: Chemistry working for us	C7: Further chemistry	C5: How much? C6: Chemistry out there	Chemistry 3
Atomic structure, properties and bonding	• Development of periodic table • Group 1 and Group 7 • Transition metals	• Transition metals • Alkali metals			
Changing materials and chemical reactions	• Strong acids and bases • Solubility • Food, fuel and energy changes (quantitative)	• Electrolysis	• Energy changes in reactions • Activation energy • Reversible reactions and equilibria • Strong and weak acids	• Oxidation and reduction • Electrolysis • Strong and weak acids • Neutralisation • Reversible reactions and equilibria • Precipitation reactions	• Fuels • Strong and weak acids (vs concentration) • Neutralisation • Thermal decomposition of carbonates
Obtaining and using materials	• Water	• Water • Organic acids, alcohols and esters • Sulphuric acid • Soap and detergent • Alkali metals and their compounds • Transition metals	• Alcohols – production of ethanol • Carboxylic acids and esters • Fats and oils • (Un)saturated bonds • Green chemistry	• Sulphuric acid • Fuel cells • Rust protection • Alcohols – production of ethanol • Salt • Ozone layer and CFCs • Water chemistry • Natural fats and oils • Analgesics	• Alkanes, alkenes • Ethanol production and uses • Ethanoic acid • Sulphuric acid: Contact process, reactions • Limestone, quicklime, slaked lime and cement

	AQA Extension Science	Edexcel360 Extension Science	OCR Twenty First Century Extension Science	OCR Gateway Extension Science	WJEC Extension Science
Chemical detection	• Tests for ions, tests for organic compounds • Gas-liquid chroma-tography, spectroscopy: atomic absorption, infrared, UV, NMR. Mass spectrometry • Titrations	• Tests for ions • Titrations	• Analytical procedures • Chromatography (paper, thin layer, gas) • Titrations • Test for ions	• Quantitative analysis • Titrations	• Tests for alkenes, carboxylic acids • Tests for ions, tests for gases • Chroma-tography, distillation, filtration • Titrations
Chemical calculations	• Titration calculations • Energy changes in chemical reactions	• Moles, masses and volumes in reactions • Basic titration calculations	• Moles, masses and volumes in reactions and solutions • Basic titration calculations	• Moles, masses and volumes in reactions • Empirical formulae • Concentrations	• Moles, masses and volumes in reactions • Concentrations

Topics covered in this guide

The guide covers the topics that come up most often in the GCSE Chemistry extension units and those found to be most challenging or least familiar to teachers. These are:

1 food, fuels and energy changes in reactions

2 fuel cells

3 reversible changes and equilibria

4 strong and weak acids and bases

5 sulphuric acid

6 water purity

7 alkanes and alcohols

8 carboxylic acids, esters, fats and oils

9 green chemistry

10 chemical analysis: testing for ions and gases

11 chemical detection: instrumental methods

12 moles, masses and volumes.

You will find a list of resources specific to each topic in this section, and details of how to obtain them in Section 7.

Changing materials and chemical reactions

1. Food, fuels and energy changes in reactions

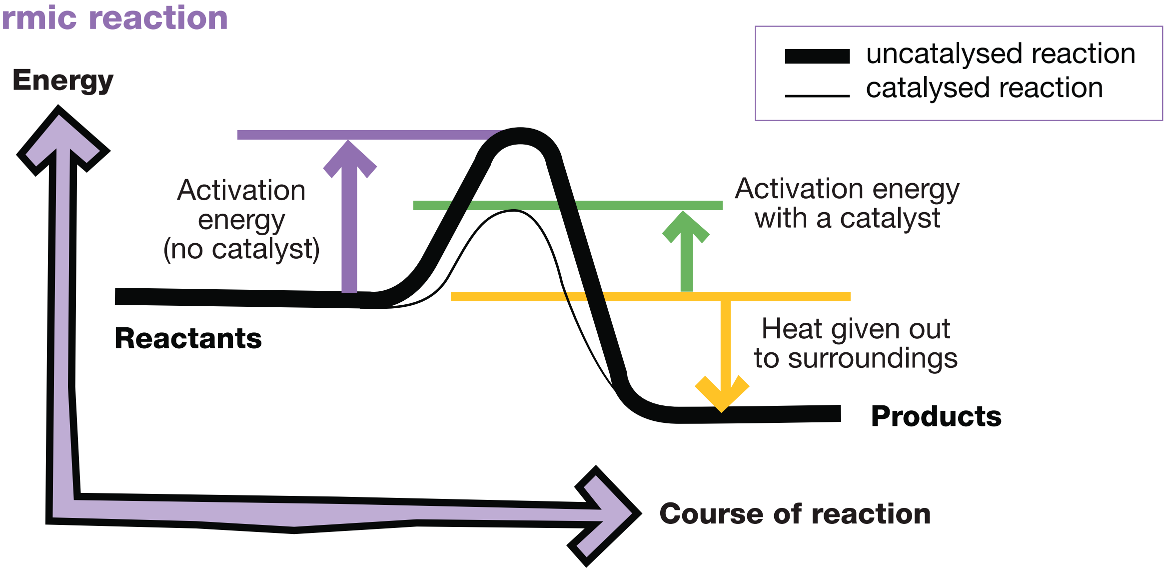
Subject knowledge and challenging concepts

Energy is conserved in a chemical reaction. Some reactions give out energy, often as heat, which exits the system. These reactions are called exothermic. Other reactions take in energy and are called endothermic.

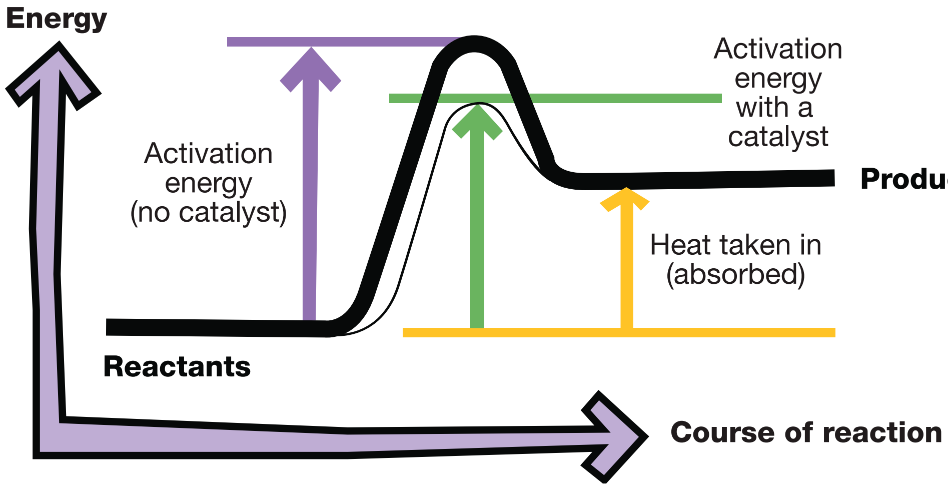
Energy is required to break bonds; it is released when bonds are formed. Energy changes can be represented in the form of an energy change diagram (see Figure 1).

Figure 1. Energy changes in (a) an exothermic reaction and (b) an endothermic reaction

Exothermic reaction



Endothermic reaction



In exothermic reactions, more energy is released when new bonds are formed than is taken in to break bonds initially. The energy change for the whole reaction is negative as the products contain less stored energy than the reactants. As heat is transferred to the surroundings, the temperature of the surroundings increases. Energy changes for chemical reactions are usually called 'enthalpy changes' and are given the symbol ΔH (the H stands for heat). They are usually measured in kilojoules per mole ($kJmol^{-1}$). Examples include combustion of hydrocarbons, neutralisation of acids and alkalis, and using hydrogen in fuel cells.

In endothermic reactions, the energy needed to break bonds is greater than the energy released when forming new bonds. The energy change, ΔH measured in $kJmol^{-1}$, is always positive for an endothermic reaction and heat is absorbed from the surroundings. Examples include the thermal decomposition of limestone and cracking of oil fractions.

If a reaction is reversible, the backward reaction's energy change is also reversed.

Energy changes in reactions can be calculated using energy level diagrams and/or supplied bond energies.
Energy change = Energy of bonds broken – energy of bonds formed.

Many reactions have an activation energy (E_a), shown on the energy diagrams in Figure 1. This is the amount of energy needed for the bonds in the reactants to break so that the chemical reaction can begin. When gases and liquids are heated, the particles gain kinetic energy. Before molecules can react, they need a minimum kinetic energy: this is the activation energy required for a reaction to occur. At higher temperatures, there is more chance of a collision resulting in a reaction. Activation energy is lowered by a catalyst. The catalyst may take part in the reaction, but it is not used up.

Misconceptions

According to Kind's work on misconceptions, students struggle to understand the links between energy and the making or breaking of chemical bonds.[4] Often it is only the breaking of bonds which is focused on, and hence, in a reaction such as combustion, students end up thinking that bond breaking releases heat. Bond formation needs to be taught explicitly. Students need to appreciate the energy flows between the chemical system and the surroundings, and its relation to the bond breaking or formation process occurring. A useful teaching aid to help pupils appreciate the energy changes in bond forming and breaking is a rechargeable handwarmer. This consist of a flexible sealed plastic packet containing a saturated solution and a small metal clicker. When the clicker is activated, the saturated solution rapidly crystallises, releasing a considerable amount of heat – this is the heat released when the bonds of the crystal lattice are formed. To return the handwarmer to its liquid state, it has to be placed in boiling water for a few minutes – this provides the energy to break the bonds of the crystal lattice. Unlike a chemical reaction, the handwarmer allows the two processes of bond formation and bond breaking to be observed independently of one another. In chemical reaction it is impossible to separate the two processes.

Fuels and foods release energy through burning and respiration respectively. It is important to stress that these are reactions between the fuel or the food and oxygen, and that products form – the energy changes are not just about the fuel molecules, which is a common misconception. Different fuels and foods release different amounts of energy through burning or respiration.

4
Kind V (2004). *Beyond appearances: students' misconceptions about basic chemical ideas*, 2nd edn.

Teaching model examples

cm

1 The teacher asks students in small groups to share and present ideas about burning fuels, such as:

- what are the products and reactants?
- is energy being taken in or given out when a fuel burns?

2 Students discuss their ideas and record them on a concept map.

3 The teacher then demonstrates the temperature change that takes place with burning using a calorimeter and uses models to explore bond breaking and formation.

4 Students are then challenged to consider what is happening at the molecular level. They use their new understanding to explain other exothermic and endothermic changes.

um

1 Students build molecular models of the hydrocarbon and oxygen molecules. They then break the bonds, noting how many of each sort of bond have been broken. Do they need to put in energy or take out energy to break something? Video clips of breaking boards or demolishing a building could be used to get the point across. Students then build the models of the products. If bond formation is the opposite of bond breaking, is energy put in or taken out? Sound being given out as magnets snap together can be used to illustrate energy being given out when bonds are formed.

2 Using a spreadsheet of bond energies, the amount of energy in the reactants can be calculated and plotted on an energy diagram, as can that of the products. The actual heat given out can also be calculated based on a change in temperature (it takes 4.2J to raise the temperature of 1g of water by 1°C or 1K).

Examples of investigations and demonstrations

Examples of exothermic reactions:

- Dilute sodium hydroxide solution and dilute hydrochloric acid
- Copper II sulphate solution and magnesium powder
- Dilute sulphuric acid and magnesium powder.

Examples of endothermic reactions:

- Sodium hydrogencarbonate solution and citric acid
- Solid barium hydroxide and solid ammonium chloride (see *Classic chemistry demonstrations* (44)).

Experimental details are outlined in *Classic chemistry experiments* (22).

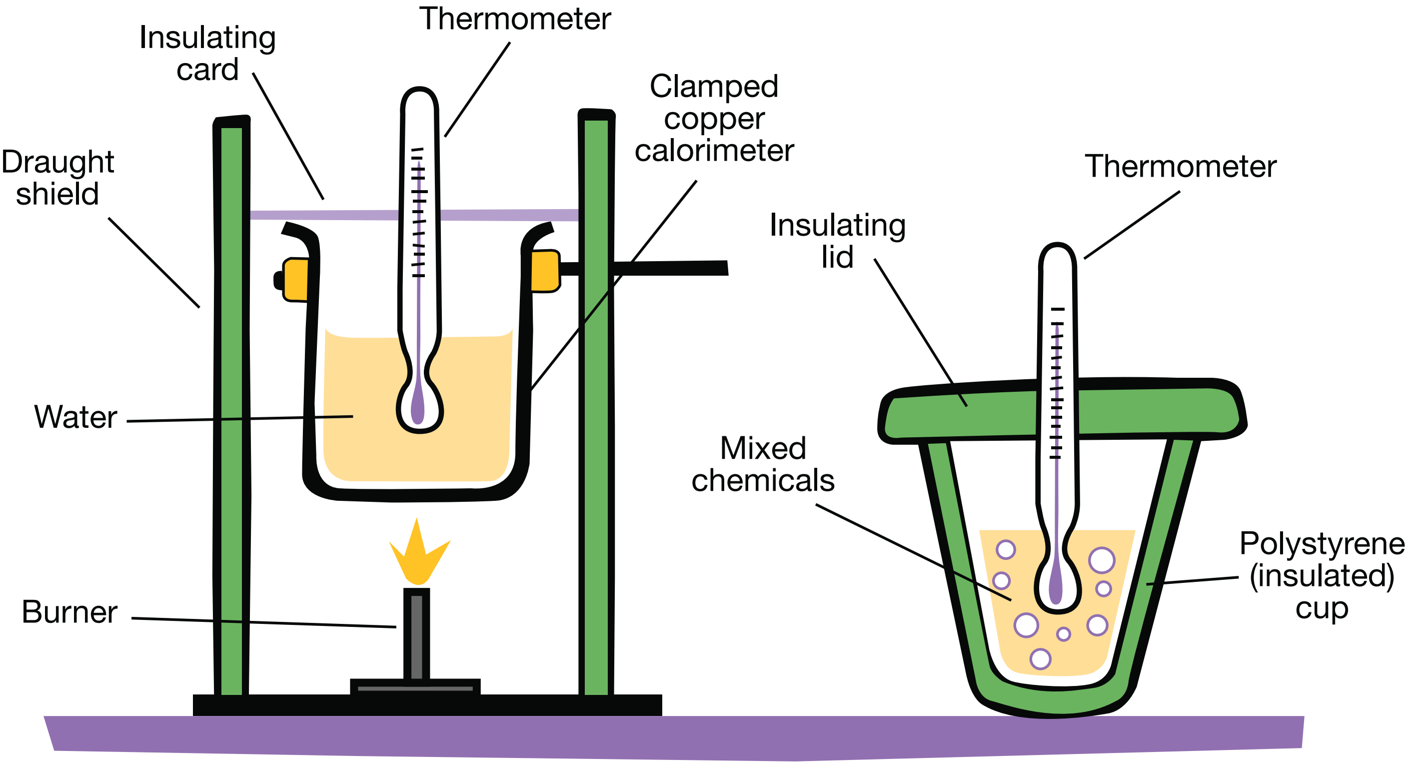
The relative amounts of energy released when different substances (eg fuels and foods) burn can be measured and compared using calorimetry, using either of the simple apparatus shown below (see Figure 2). Data loggers can be used instead of thermometers to capture and manipulate data more readily. Energy is measured in Joules (J). Some dietary information is given in calories rather than Joules although the 'calories' referred to when we are talking about food are in fact kilocalories.

Heats of reaction (exothermic or endothermic reactions) are detailed in *Classic chemistry experiments* (84). Experiments to compare the energy values of food are in *Classic chemistry experiments* (13).

To calculate the amount of energy released using the equipment illustrated overleaf, use the equation: $E = m \times c \times \Delta T$, where E is the energy (in joules), m is the mass of water being heated (in grams), c is the specific heat capacity of water (4.2 J/g/K) and ΔT is the change in temperature of the water (in °C or K).

Note that in order to get the most accurate value of ΔT it is customary to take temperature measurements at fixed intervals (eg 20 seconds) and plot a graph of temperature against time.

Figure 2. Simple calorimeters for (a) combustion reactions and (b) non-combustion reactions



Additional classroom activities

Research and compare the energy values of different foods using calories or kJ listed on the packaging. Which types of food tend to have the highest calories? Carry out calculations to compare how many calories are eaten in a typical day against how many calories are required for the amount of physical exercise done.

Opportunities for How Science Works

Data, evidence, theories and explanations

1a Students should be taught how scientific data can be collected and analysed.

1c Students should be taught how explanations of many phenomena can be developed using scientific theories, models and ideas.

Practical and enquiry skills

2a Students should be taught to plan to test a scientific idea, answer a scientific question or solve a scientific problem.

2b Students should be taught to collect data from primary or secondary sources, including ICT sources and tools.

2c Students should be taught to work accurately and safely, individually and with others, when collecting first-hand data.

2d Students should be taught to evaluate methods of collections of data and consider their validity and reliability as evidence.

Centre-marked assessment opportunities

Calorimetry experiments to compare different foods or fuels provide opportunities for students to: plan investigations; formulate hypotheses; carry out experimental work; perform calculations; interpret, analyse and evaluate the resulting data; draw conclusions and generate ideas for further work. The differences between theoretical and actual results can be explored as well as the reliability and validity of data.

This topic also acts as a starting point for discussion, debate and written work about science in the news, such as obesity and fuel choices. Calorimetry data can be combined with the analysis of other environmental factors such as relative amounts of carbon dioxide released, the efficiency of engines and the renewability of fuel sources.

Students can demonstrate their ability to carry out experiments to show that combustion of a hydrocarbon in a plentiful supply of air produces carbon dioxide and water and do an experiment to find the energy output per gram of a liquid fuel.

Resources

Garforth Community College has produced a bond energy spreadsheet that students can use with molecular models to calculate the energy changes of reactions: www.school-portal.co.uk/GroupHomepage.asp?GroupID=9107. This site also has a wider range of energies and could be useful for energy change calculations for other reactions beyond burning.

Simulations of bond making and bond breaking that can be altered to show stronger and weaker bonds are available at http://chemsite.lsrhs.net/FlashMedia/html/flashFormingAndBreaking.htm

www.chemistry-videos.org.uk shows clips of endothermic reactions.

Contemporary chemistry for schools and colleges from the RSC includes a module called 'Chemistry and diet'. It contains some excellent resources to compare the fat content and energy provided by particular foods, interactive ICT activities, relevant experiments and discussion activities on obesity and lifestyle. It also has a section on fuel cells that includes a comparison of different fuels.

CLEAPSS sheet PS67-10 details how to make biodiesel.

Obtaining and using materials
2. Fuel cells

Subject knowledge and challenging concepts

Hydrogen provides an alternative to fossil fuels. Hydrogen and oxygen react to give water.

$$2H_{2\,(g)} + O_{2\,(g)} \longrightarrow 2H_2O_{\,(g)}$$

Hydrogen is a flammable gas which will explode if enough oxygen is available. In a test tube it typically produces a squeaky pop when ignited. The reaction between hydrogen and oxygen is very exothermic. The challenge is how to use this reaction to release energy in a controlled and safe manner. This is what is achieved in a fuel cell.

A fuel cell is a 'gas battery' that extracts electrical energy from the reaction above. In batteries, chemical energy is stored inside the battery (in the electrodes and the electrolyte). In a fuel cell, gases are fed in to react at the electrodes where chemical energy is converted to electrical energy.

One kind of fuel cell introduces hydrogen and oxygen at each electrode (see Figure 3). The electrodes are made from platinum or a related catalyst. The electrodes are separated by a polymer membrane. Hydrogen ions pass through the membrane but electrons do not. The membrane is known as a proton-exchange membrane.

At the anode, protons (H^+ ions) and electrons are produced from hydrogen. Hydrogen is oxidised.

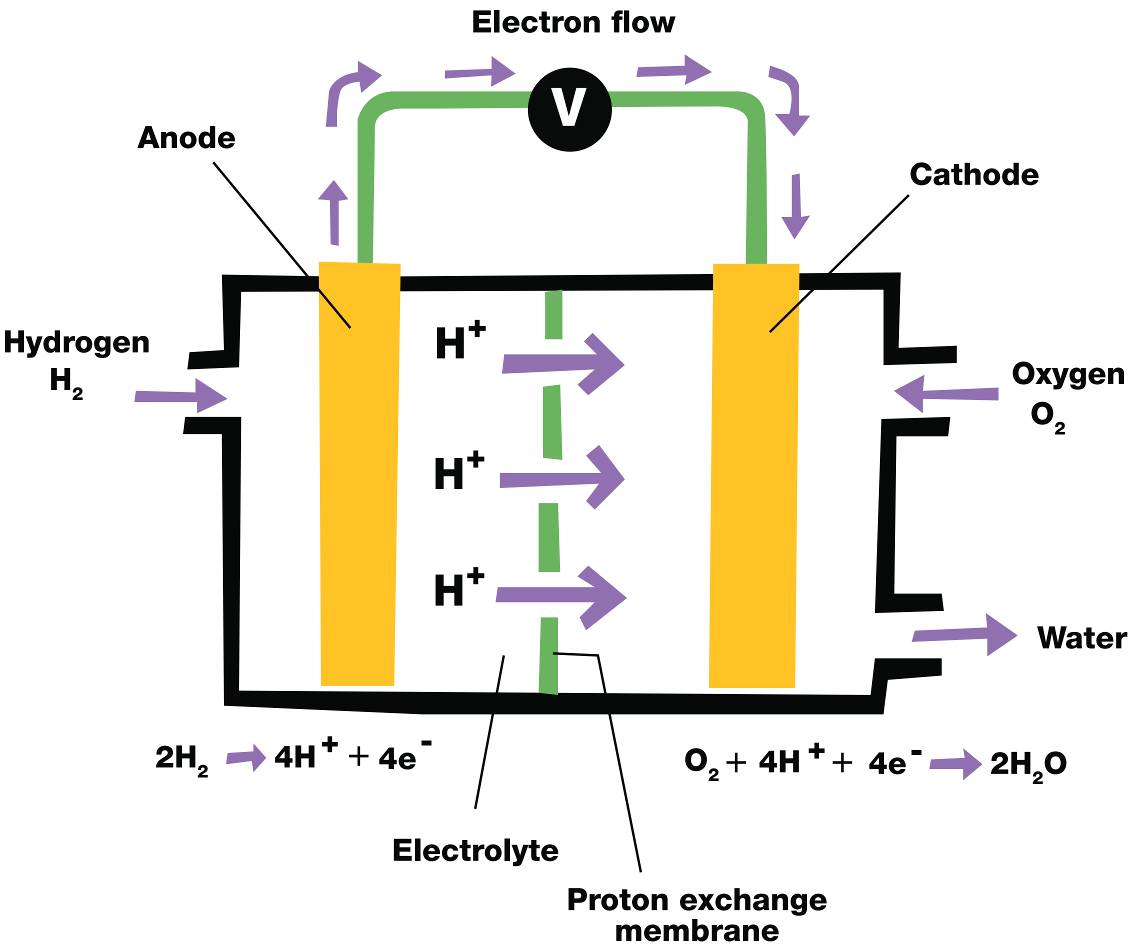
$$2H_2 \longrightarrow 4H^+ + 4e^-$$

At the cathode, oxygen reacts with protons and electrons to produce water. Oxygen is reduced.

$$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$$

The fuel cell basically splits the reaction into two half-reactions (given by the half equations above), which occur separately in each half of the fuel cell. The equations show that hydrogen releases four electrons at the anode. These four electrons are used by the oxygen at the cathode. (Ultimately the hydrogen ions and the oxygen combine into water molecules.)

Figure 3. How a hydrogen fuel cell works



The electrons flow from anode to cathode as a current by means of an external circuit, during which their energy can be made to do useful work (eg making a vehicle move). In other words, the energy from the reaction of hydrogen and oxygen is being transferred to electrical energy instead of heat (and sound and light) which would happen if the two elements were ignited in an explosion. The way the fuel cell works is just like the reverse of electrolysing water. The fuel cell is not 100% efficient: gases escape and electrical resistance means heat is lost. Still, it is 45–60% efficient compared with an engine, which is 15–35% efficient.

Hydrogen is considered a 'clean' fuel compared with carbon-based fuels such as petrol or diesel because only water is produced: there is no CO_2 nor other polluting products. Spills do not need to be cleaned up because the gas diffuses. Hydrogen fuel cells are especially appealing for urban areas: there are several electric buses and a small number of cars that run on fuel cell power.

Fuel cells were actually invented back in the 1830s, long before cars came onto the road. NASA scientists developed them in the 1950s to use on the Apollo missions and in the space shuttle. The water produced is used for astronauts on the shuttle.

An important question is 'where do the gases come from for fuel cells?' Oxygen and hydrogen may come from electrolysis of water, which may need energy from fossil fuels to start with. Solar power can be used to electrolyse the water. Alternatively, liquefied oxygen from the air can be used. A major area of research explores how to extract hydrogen from alkanes or methanol without using much energy. Fuel cells using these fuels are also being developed. Some algae also produce hydrogen and these are being researched.

Storage and transportation of liquid hydrogen and oxygen need to be considered. They can be stored as compressed or liquefied gases. Research into hydrogen storage using nanotechnology such as carbon nanotubes is under way, as is research into chemical storage using metal hydrides.

Teaching model examples

e(i)

1. The teacher carries out various demonstrations to show how hydrogen reacts with oxygen, how water is electrolysed and how cell (batteries) work.
2. Students are then challenged to come up with ideas about how a gas battery (or fuel cell) might work and what reactions would need to take place.
3. The students then draw together these ideas to produce an overall picture of how fuel cells work.
4. They then apply this to explain applications such as powering cars and the space shuttle.

um

1. Students can use models and bond energy calculations to explore the energy changes of reacting hydrogen and oxygen together to form water. They can also carry out these calculations to compare the amount of energy released with other fuels.

dit

1. The teacher introduces the topic of fuel cells.
2. Students carry out research into how a fuel cell works and what its benefits and limitations are.
3. Key learning points are summarised in a whole class plenary session.

Examples of investigations and demonstrations

There are a number of practical activities that help develop understanding of the reactions involved in fuel cells. It may be useful to start with the standard test for hydrogen, or 'Exploding balloons' (*Classic chemistry demonstrations* (37) – see Section 7) where hydrogen and oxygen are reacted together. The hydrogen-oxygen rocket also involves making water by exploding hydrogen and oxygen gases and is quite spectacular.

It is also useful to show the electrolysis of water. 'Bubble trouble' splits water by electrolysis and then an exploding mixture of hydrogen and oxygen is bubbled through soap solution. Details for this experiment can be found in the Future fuels section of *Contemporary chemistry for schools and colleges* and also CLEAPSS guide L195, section 7.2. *Green chemistry,* the RSC book by Dorothy Warren, has a section on 'Fuels for the future' which explains how fuel cells work and how to make a hydrogen cell.

Making or using a hydrogen fuel cell in a model car demonstrates its use. Fuel cell kits are available for purchase – see below.

Additional classroom activities

Students can research different car companies' developments in fuel cells, eg General Motors, Toyota, Ford, BMW, etc. They can compare petrol, hybrid and fuel cell cars. They can stage a role play debate, taking on the viewpoints of different interest groups. A full outline is given in the unit on fuel cells in *Contemporary chemistry for schools and colleges*.

www.vcacarfueldata.org.uk has data on emissions and fuels for a range of makes and models of car.

Opportunities for How Science Works

Data, evidence, theories and explanations

1d Students should be taught that there are some questions that science cannot currently answer, and some that science cannot address.

Practical and enquiry skills

2b Students should be taught to collect data from primary or secondary sources, including ICT sources and tools.

Applications and implications of science

4a Students should be taught about the use of contemporary scientific and technological developments and their benefits, drawbacks and risks.

4b Students should be taught to consider how and why decisions about science and technology are made, including those that raise ethical issues, and about the social, economic and environmental effects of such decisions.

Centre-marked assessment opportunities

This topic enables students to identify samples of hydrogen and oxygen, collect samples of gas and make a simple fuel cell. Further opportunities for discussion, debate and written work on the future of fuels are also relevant.

Resources

Contemporary chemistry for schools and colleges includes a unit on future fuels, including ideas and materials for a range of activities including demonstrations, investigations, numerical problems, modelling, literacy tasks and role playing a debate.

There is an upd8 activity called Pump Wars in which students compare fuel choices: www.upd8.org.uk/activity/71/Pump-Wars.html

A factsheet on hydrogen fuel cells is available at: www.hydrogen.energy.gov/pdfs/doe_fuelcell_factsheet.pdf

Fuel cells for educational use are available from the following website: www.economatics-education.co.uk

The Greener Industry website includes a section on greener cars: www.greener-industry.org

Changing materials and chemical reactions
3. Reversible changes and equilibria

Subject knowledge and challenging concepts

In a reversible reaction, there is a forward and a backward reaction. Students will have encountered reversible and irreversible reactions, eg hydration and dehydration of copper (II) sulphate and combustion. This is an example of a static reversible reaction. But students won't have experienced many examples of dynamic equilibrium: this is where a forward reaction and a backward reaction happen at the same time, ie the products react to turn themselves back into the reactants. To understand dynamic equilibrium it is necessary to consider what is happening at the molecular level.

Misconceptions

A common misconception is that at equilibrium, both the forward and reverse reactions have stopped, and this is why the concentrations stay the same. An analogy that helps understand that things can be 'moving' but appear to stay still is the rower paddling upstream: the water is moving in one direction and the rower in the other, but the rower appears to be stationary when the two are moving at equal and opposite speeds.

Dynamic equilibria are very unstable, so changing the conditions of the reaction changes the situation. With the rower, if the current is twice as fast, she has to paddle twice as fast to maintain the same position. In the case of reactions, changes in temperature, pressure or the concentration of the reactants or products can each alter the position of the equilibrium.

The changes in the position of the equilibrium can be predicted using a useful convention called Le Chatelier's Principle. This states that if a constraint is placed on a system in equilibrium, the position of the equilibrium will shift in order to counteract the constraint.

If a forward reaction is exothermic, this means that the corresponding backwards reaction will be endothermic. As the forward reaction occurs, the temperature of the reaction and its surroundings increases (because it is exothermic). If we heat the reaction up, the equilibrium will move in such a way to counteract this (ie to lower the temperature), which it can do by making more of the backwards reaction occur (which is endothermic and thus makes the reaction and the surroundings cooler). The equilibrium thus moves 'to the left' – ie more of the reactants are formed in the equilibrium mixture.

In reactions involving gaseous reactants and products, pressure can be a constraining factor. The equilibrium can move according to which reaction (forwards or backwards) leads to an increase or decrease in pressure. (Note – by implication the reaction would have to be taking place in a closed vessel.) If the forward reaction leads to fewer moles of gas in the product(s) than were in the reactants, then there will be a drop in pressure as this reaction proceeds. Raising the pressure on the reaction will make the equilibrium move to reduce the pressure – in other words it will move to the right, and more product will be formed. Lowering the pressure will have the opposite effect, and the equilibrium shifts to the left.

Concentration effects work in the same way as pressure. If products are removed from the reaction mixtrure, then this is the same as decreasing their concentration, and thus the equilibrium shifts to the right, and more product is formed.

A catalyst does not affect the position of the equilibrium: it speeds up both the forward and back reactions so equilibrium is reached more quickly. A catalyst reduces the amount of energy required as the activation energy is lowered. Less energy makes it more economical.

Examples of reversible reactions that can be discussed include the following.

1 Carbon dioxide + Water $\rightleftharpoons$ Carbonic acid

$CO_2 + H_2O \rightleftharpoons H_2CO_3$

This happens in fizzy drinks and the equilibrium is disturbed by opening the can or bottle.

2 $Cl_2 + NaOH \rightleftharpoons NaClO + Cl^- + H^+$

NaClO is household bleach. If other products containing chlorides are added, the reverse reaction will lead to Cl_2 being produced.

3 Industrial processes such as the Contact process and the Haber process.

4 Ethanoic acid is a weak acid because it is in equilibrium with ethanoate and hydrogen ions in water.

5 $H_2 + I_2 \rightleftharpoons 2HI$

Teaching model examples

cm

1 Students are asked to identify reactions and changes of state that are reversible and irreversible. What happens at the molecular level during these changes?

2 To build up a picture of what is happening at the molecular level, students can look at a series of images showing a magnified view of the particles involved at the start of a reaction (t = 0) (see Figure 4).

The next picture shows the situation after a short time has elapsed (t = 1): some of the reactants have become products (note conservation of atoms must be held).

The third picture shows the situation at t = 2: more of the reactants have become products.

The fourth picture shows the situation at t = 3. Again the same number of molecules remains, but they are in new positions. The final picture shows the situation at t = 4. It has the same number of each type of molecule, but they are again in new positions.

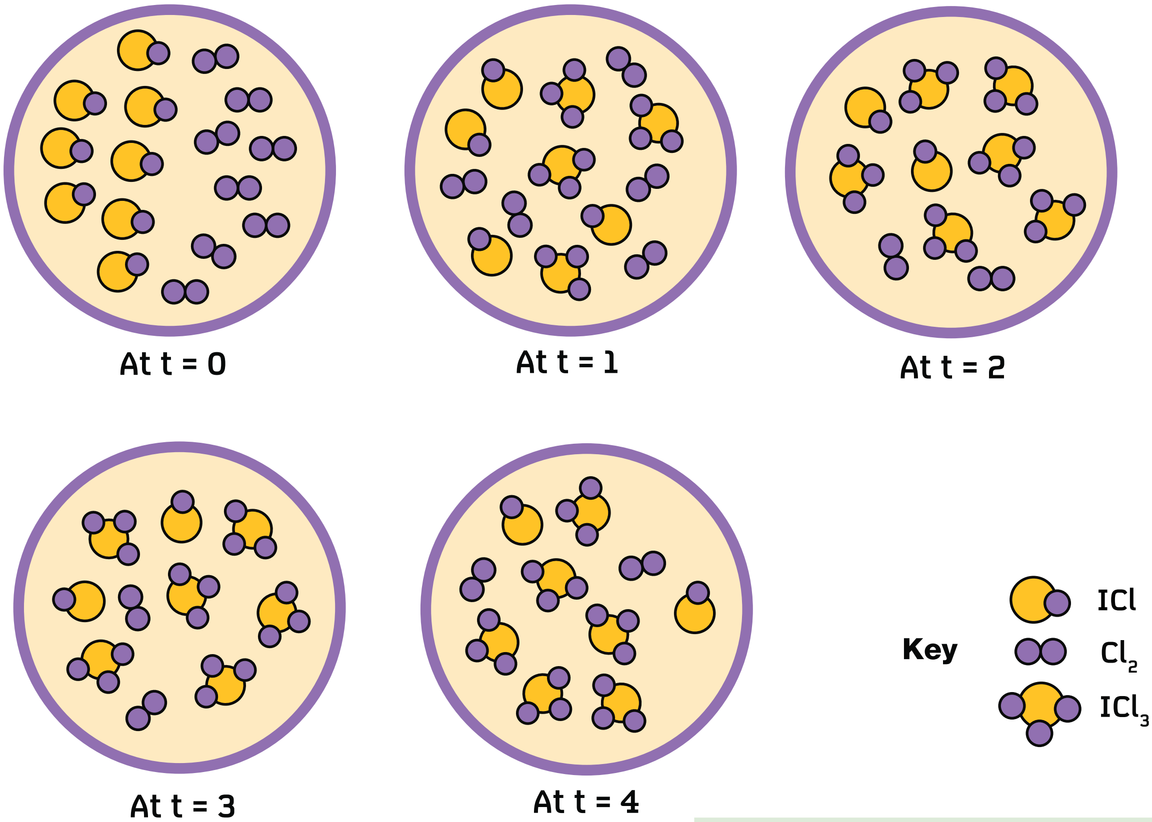
3 Students explain what is happening to the concentrations of products and reactants over time and can draw a graph of this.

4 Students discuss whether the particles are just moving around or whether they are reacting.

5 A plenary summarises the key points about dynamic equilibrium.

6 Students can then draw their own diagrams relating to other reversible changes.

Figure 4. A dynamic equilibrium varying with time: $ICl + Cl_2 \rightleftharpoons ICl_3$



1 The teacher provides students with a general outline of a chosen reversible reaction and with the students, considers how the product can be maximised by changing the temperature, pressure and concentration of reactants.

2 Students are then challenged to apply these principles to a series of other reactions, such as those listed above.

3 Students then summarise the generic characteristics of dynamic equilibria and how these can be used to maximise the products of the forward reaction.

Models can be used in several different ways in this topic:

1 Molecular models like that above describe what is happening at the molecular level.

2 Computer simulations of the Haber process can be used to explore how the equilibrium shifts with temperature and pressure.

3 The analogy of the rower helps illustrate why dynamic equilibrium may appear to be static.

Examples of investigations and demonstrations

The equilibrium between ICl and ICl_3 can be set up in a U-tube in a fume cupboard and the concentration of chlorine can be varied to demonstrate its effect on the position of the equilibrium. The effect of temperature can also be shown. ICl is brown, Cl_2 is green and ICl_3 is yellow. The forward reaction is exothermic. Full details are given in *Classic chemistry demonstrations* (4).

The equilibrium between $Co(H_2O)_6^{2+}$ and $CoCl_4^{2-}$ is described in *Classic chemistry demonstrations* (8). The former is pink while the latter is blue.

ICT animations and simulations are very useful for this topic, as it is hard to visualise what is happening at the molecular level. Searching by curriculum and then by your specification on www.chemistryteachers.org will reveal several simulations and animations, including the Haber process. www.chemistry-videos.org.uk has videos of equilibria demonstrations.

Opportunities for How Science Works

Data, evidence, theories and explanations

1c Students should be taught how explanations of many phenomena can be developed using scientific theories, models and ideas.

Practical and enquiry skills

2b Students should be taught to collect data from primary or secondary sources, including ICT sources and tools.

Communication skills

3c Students should be taught to present information, develop an argument and draw a conclusion, using scientific, technical and mathematical language, conventions and symbols and ICT tools.

Centre-marked assessment opportunities

This topic can be difficult to use to gather primary data, as many of the reactions need to occur in a closed system. However, there are opportunities to use secondary data on reversible reactions as evidence to explain the yields obtained and conditions used in industrial reactions.

Changing materials and chemical reactions

4. Strong and weak acids and bases

Subject knowledge and challenging concepts

There is a risk that this topic becomes part of a 'circular' curriculum where students feel they are covering the same ground repeatedly, as students will have encountered acids and bases earlier in school. They may have already encountered the use of indicators to test for acids and bases, neutralisation (eg indigestion remedies), and acid rain – and many will be familiar with the reactions of acids to make salts:

- acid + alkali ⟶ salt + water
- acid + metal oxide ⟶ salt + water
- acid + metal hydroxide ⟶ salt + water
- acid + metal carbonate ⟶ salt + water + carbon dioxide
- acid + metal ⟶ hydrogen gas + salt

In understanding strong and weak acids and alkalis, students need to consider what is happening at the particle level more deeply. They also learn that over time, different theories have been used to define what acids and alkalis are and what is happening at the particle level. It is not surprising that students find these concepts challenging: it took scientists hundreds of years to work out what acids and bases are and how they work!

In the 17th century, Robert Boyle suggested that acids had particles that squeeze in between spaces and break materials apart. In the 18th century, Lavoisier gave oxygen its name meaning 'acid maker' because he thought all acids contained oxygen. In the mid 1800s, Laurent showed that acids contain hydrogen, which is correct, but didn't explain how it worked.

In 1887, Arrhenius suggested that in water, substances could be split into positive and negative ions. He called this 'electrolytic dissociation' and this gave rise to the Arrhenius definition for acids and bases:

- an acid is any substance that produces positive hydrogen ions (H^+) in water
- an alkali is anything that produces negative hydroxide ions (OH^-) in water.

When any acids and alkalis react together, the neutralisation can be summarised as

$$H^+_{(aq)} + OH^-_{(aq)} \longrightarrow H_2O_{(l)}$$

Arrhenius's definition was not accepted widely as people did not believe that molecules could be split. Later, as people understood more about atomic structure, they doubted the theory even more because it seemed unlikely that such a small ion could exist in water.

In 1923 Brønsted and Lowry independently defined an acid as a proton donor and a base as a proton acceptor.

In neutralisation, the hydroxide ion is the base and accepts a proton from the acid:

$H^+_{(aq)} + OH^-_{(aq)} \longrightarrow H_2O_{(l)}$ which is the same as what Arrhenius proposed.

Brønsted and Lowry realised that in water, the H^+ ions bond to water molecules (or are hydrated) forming $H_3O^+_{(aq)}$ ions. (At GCSE level, $H_3O^+_{(aq)}$ is represented as $H^+_{(aq)}$.) By this point, protons and electrons were well understood and accepted, so scientists had little difficulty accepting Brønsted and Lowry's definition. H^+ is just a proton after all! As a result, Arrhenius's ideas became accepted.

(At higher levels, students will encounter the Lewis definition of acids and bases: acids are electron acceptors and bases are electron donors, but this is not needed at GCSE.)

How do these definitions help to understand the difference between strength and concentration?

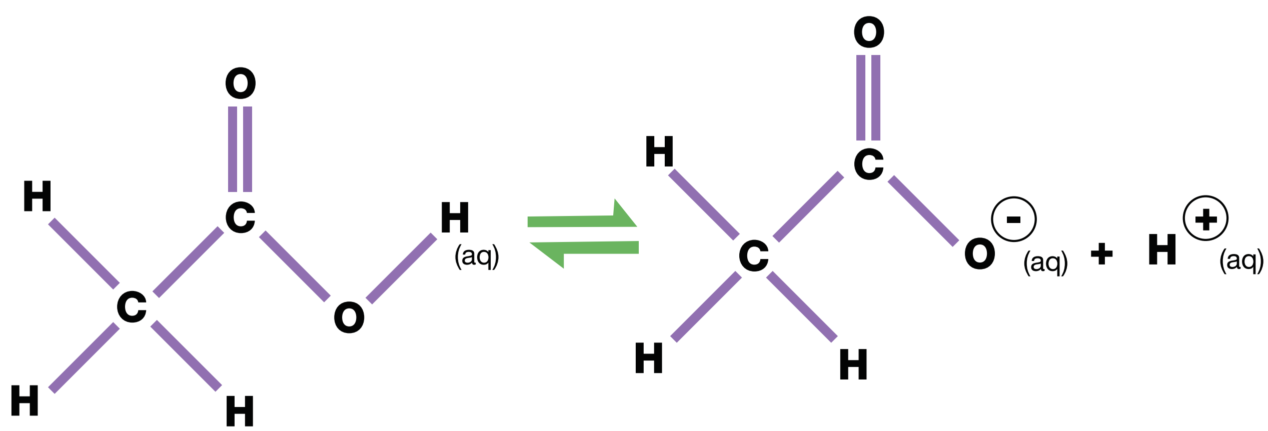
The concentration of an acid or alkali is a measure of how much acid or alkali is dissolved in a known volume of liquid, eg water. The molarity of a solution is a measure of concentration: the number of moles dissolved in 1000cm^3 of water. Concentration of solutions is usually expressed in moles per litre of solution. (A litre is the same as 1dm^3 or 1000cm^3.) This way of stating concentration is sometimes called 'molarity'. A solution with a concentration of 2 moles per litre can have its concentration stated as 2 mol/dm^3, 2 mol/l or 2M. The last of these is called '2 molar'.

In a concentrated acid or alkali there is a relatively large amount of solute dissolved, compared with a dilute acid or alkali. However, this does not tell us what the concentration of H^+ ions is in the acid or OH^- ions is in the alkali. This depends on the strength of the acid or alkali.

Strength refers to the degree of ionisation in water. A strong acid or alkali is one that is nearly or completely ionised in water. Examples are: hydrochloric acid, nitric acid and sulphuric acid. Sodium and potassium hydroxide are examples of strong bases.

A weak acid or alkali, on the other hand, is only partially ionised in water. Ethanoic, citric and carbonic acids are all weak acids. The ethanoic acid molecule and the ions reach a dynamic equilibrium with the equilibrium normally well to the left, so there is little H^+ present (see Figure 5).

Figure 5. Ethanoic acid is a weak acid in water as the equilibrium lies to the left



The pH scale shows a measure of the concentration of hydrogen ions. To find the pH of a solution, an indicator or pH meter is used. An indicator is a substance (or mixture of substances) that when added to a solution gives a different colour depending on the pH of the solution. Universal indicator gives a variety of colours to match the pH. Most solutions are between pH 0 and pH 14. Acid solutions have a pH of less than 7, neutral solutions have a pH of 7 and alkaline solutions have a pH of greater than 7.

Other indicators are appropriate for different pH ranges, such as litmus, phenolphthalein and (screened) methyl orange. Volumes of acid and alkali solutions that react with each other can be measured by titration using a suitable indicator. For example:

- strong acid + strong alkali: any acid base indicator
- strong acid + weak alkali: methyl orange indicator
- weak acid + strong alkali: phenolphthalein.

If the concentration of one of the reactants is known, the results of a titration can be used to find the concentration of the other.

Teaching model examples

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1. This topic should stimulate students to think about what is happening at the molecular level.
2. Students draw concept maps of their existing knowledge and understanding of acids and alkalis.
3. In groups, students discuss how they would define a strong acid, and how the strength of an acid is measured. They are challenged to consider whether strength and concentration are the same property.
4. Students carry out experiments or observe demonstrations of how pH changes when different acids at the same initial concentration are diluted.
5. Ideas about the differences between strength and concentration are summarised in a plenary.

e(i)

1. The teacher demonstrates the differences in pH for concentrated HCl, dilute HCl, dilute ethanoic acid and concentrated ethanoic acid (the molarity being the same for each of the concentrated solutions and each of the dilute solutions). The teacher tells the students that pH is a measure of concentration of hydrogen ions.
2. Students start with labelled pictures of what is happening at the particle level for concentrated HCl, dilute HCl, dilute ethanoic acid and concentrated ethanoic acid.
3. Students are challenged to write equations for the pictures using appropriate equilibrium arrows and develop a hypothesis about how the degree of ionisation varies with acid strength and concentration.

1 The teacher presents the general concept that the strength of an acid is related to the degree of ionisation in water with the general equation:

$$HA \rightleftharpoons H^+_{(aq)} + A^-_{(aq)}$$

2 Students look at four different diagrams at the particle level illustrating a concentrated strong acid, a dilute strong acid, a concentrated weak acid and a dilute weak acid.

3 Students describe how they are different and identify which diagram shows which acid and why. (This exercise can also be done for alkalis.)

4 Students can then look at data relating to the pH of different acids and bases at different concentrations and determine which are strong, weak, concentrated and dilute.

5 Students can also use these models to explain a number of other phenomena: why is hydrochloric acid a better conductor than ethanoic acid? Which of these acids will react more quickly with magnesium or marble chips?

Examples of investigations and demonstrations

Several demonstrations and investigations relevant to this topic can be found in *Classic chemistry experiments* and *Classic chemistry demonstrations*, including the ammonia fountain, making an indicator and dry ice demonstrations. A more unusual comparison of strong and weak acids is given in *Classic chemistry demonstrations* (10): the rates and extent of reaction of hydrochloric acid and ethanoic acid are compared approximately by looking at the heights of froth produced with calcium carbonate.

This next activity explores what happens to the pH of strong and weak acids and alkalis as they are diluted. It is based on an activity outlined in *Beyond appearances: students' misconceptions about basic chemical ideas,* by Vanessa Kind (available at www.rsc.org/education/teachers/learnnet/pdf/LearnNet/rsc/miscon.pdf)

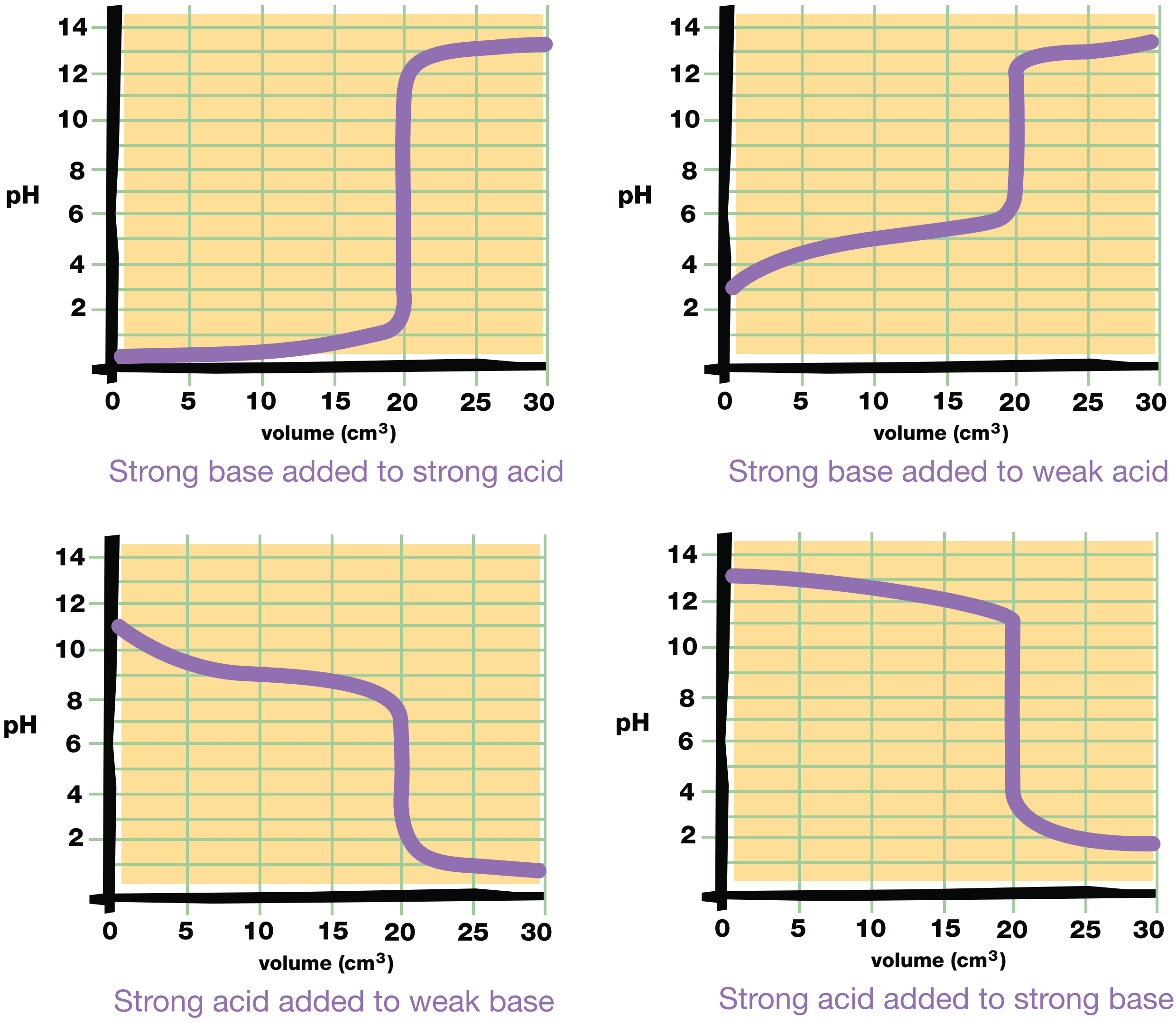
Solutions of a weak acid, a weak base, a strong acid and a strong base are made up and the pH is noted. These are each then diluted by a factor of 10 and the pH is taken again. This is repeated until the strong acid and strong base reach the same pH as the weak acid and the weak base respectively, and students build up a table of data stating pH and concentration of the acid or base added to the water in mol dm^{-3}, often written as M. Each solution approximates to a pH number. Each solution with a given pH number differs in concentration from the one with the next pH number by a factor of 10.

It will take more dilutions for the strong acids and bases to reach the same pH as the weak ones. Students are told that pH is a measure of the concentration of hydrogen ions in solution. They make a hypothesis about what happens to levels of hydrogen ions as the strong and weak acids are diluted. The data should suggest that there are more particles responsible for acidity/alkalinity present in strong acids and bases than in weak ones.

Investigations to find out how pH changes during neutralisation of an alkali with an acid can be carried out. Titration curves can be plotted if the titration equipment is set up, the alkali is dripped into the acid at a steady rate and a pH data logger is used to record the change in pH with time.

This could be extended to show how the titration curve varies between weak and strong acids and bases (see Figure 6).

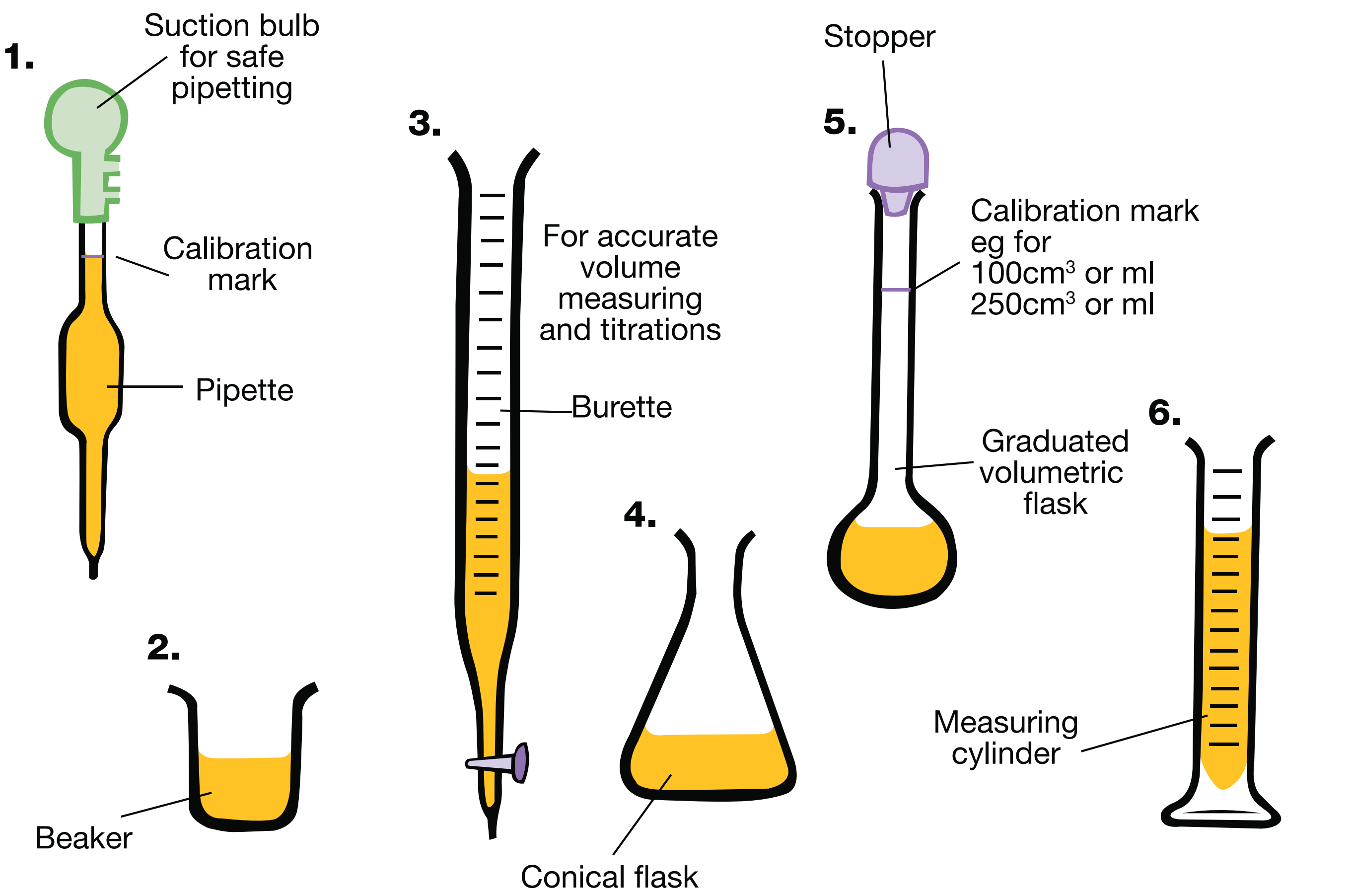
Figure 6. Titration curves



Indicators can be investigated to identify their colour changes. Use this to explain why indicators to determine end points should be single indicators rather than mixed indicators, such as universal indicator.

Titrations are an important form of chemical analysis which can be used to determine the concentrations of either an acid or an alkali. The equipment used for titrations is shown in Figure 7.

Figure 7. Titration apparatus



A description of titrating an acid with an alkali is as follows:

1 An accurate volume of alkali (of unknown concentration) is pipetted into the conical flask using a suction bulb. Indicator is added.

2 The acid, of known accurate concentration, is put into the burette. It is filled above the zero mark and the tap is released to gently bring the reading down to zero. This waste acid is collected in a separate beaker and removed to avoid confusion. The meniscus needs to be read carefully at the bottom of its curve. The acid is then added to the conical flask slowly by running it out of the burette tap in a controlled way with only small quantities being added at a time. The conical flask should be swirled gently after each addition of the acid to ensure all the acid reacts.

3 Near the end of the titration, the indicator begins to change colour but returns to the alkali colour on swirling. At this point, the acid should be added dropwise just until the indicator remains its acid colour, showing that all the alkali has been neutralised. This is called the end point. The volume of acid needed to titrate-neutralise the alkali is read from the burette.

4 The titration is first done in rough to get an approximate value for the volume of the acids required. Repeated accurate titrations are then performed until two are obtained with values within $0.5cm^3$ of each other. These results are said to be concordant, and will be used in the calculations to determine concentrations.

5 As the concentration of the acid is known, and the volume required to react with an accurate volume of alkali has been found out by titration, it is then possible to calculate the concentration of the alkali. The balanced equation for the reaction must be known also, so that the mole ratio between the acid and alkali in the reaction (the stoichiometry) can be taken into account in the calculation.

Additional classroom activities

Students conduct internet research about how the theories about acids and bases have developed over time or learn more about how titrations are used in industry.

Opportunities for How Science Works

Data, evidence, theories and explanations

1c Students should be taught how explanations of many phenomena can be developed using scientific theories, models and ideas.

Practical and enquiry skills

2c Students should be taught to work accurately and safely, individually and with others, when collecting first-hand data.

2d Students should be taught to evaluate methods of collections of data and consider their validity and reliability as evidence.

Communication skills

3c Students should be taught to present information, develop an argument and draw a conclusion, using scientific, technical and mathematical language, conventions and symbols and ICT tools.

Applications and implications of science

4c Students should be taught how uncertainties in scientific knowledge and scientific ideas change over time and about the role of the scientific community in validating these changes.

Centre-marked assessment opportunities

Acid-base titrations using a burette and pipette to determine the exact concentration of an unknown acid or base are ideal. Students have to work accurately and safely to generate data, carry out calculations and answer a scientific question. There are opportunities to explore data and their limitations and error.

Neutralising a range of different indigestion tablets with hydrochloric acid would enable students to plan and carry out an investigation to compare which is the best value for money. Details are given in *Classic chemistry experiments* (60). Titration to determine whether vinegars are watered down is another context that could be used. A thermometric titration (*Classic chemistry experiments* (45)) uses temperature change instead of an indicator to determine the end point: this is a nice link to energy changes in reactions.

Resources

Chemical misconceptions – prevention, diagnosis and cure, vol. 2: ‘classroom resources’ provides a very good probe to help students understand the differences between strong and concentrated, and between weak and dilute. The activity includes a series of pictures of acids shown at the particle level and students identify which models represent different descriptions of acids, eg strong concentrated, strong dilute, weak concentrated and weak dilute. This version shows H_3O^+ and is better suited to post-16, but the Chemsheets website has adapted them to include H^+, which is more appropriate for GCSE: www.chemsheets.co.uk

CLEAPSS sheet PS67-04 explores how to generate acid rain.

There are several good ICT simulations of titrations that could be used alongside an investigation, to generate data for calculations or for revision.

A simulation of acid base reactions, including testing various substances using litmus paper and universal indicator paper, and neutralisation reactions using different concentrations of acid and alkali: www.bgfl.org/bgfl/custom/resources_ftp/client_ftp/ks3/science/acids/universal.htm

Obtaining and using materials
5. Sulphuric acid

Subject knowledge and challenging concepts

Sulphuric acid is a very important chemical due to its many uses. It is used in car batteries, for making fertilisers, as a dehydrating agent, as a catalyst for making esters, plastics and fibres, to make paints, pigments and dyes, for treating metals, and as a cleaning material. Sulphuric acid has so many uses that annual consumption was once used as a measure of a country's wealth. These days service industries and electronics have become more important indicators, and in terms of chemicals, it is the production of ethene (ethylene) which is a more reliable way of showing a country's economic prowess.

Concentrated sulphuric acid contains about 98% H_2SO_4 and only 2% water. It must be handled with extreme care. It is highly corrosive. It is an oily liquid that reacts with water to give off a lot of heat. So the acid should **always** be added to a large volume of water: never add water to the acid as the water will boil and spit acid. Sulphuric acid can be used as a drying agent because it readily absorbs water. It is used to dry gases. It will also remove the elements of water, hydrogen and oxygen from other compounds.

Sulphuric acid is a strong acid. Pure water and pure sulphuric acid are both poor electric conductors as they are molecular, not ionic. When they are mixed, hydrogen and sulphate ions are produced and the solution becomes a good conductor. Dilute solutions react like typical strong acids (see above).

Sulphuric acid is made using a series of reactions which include the Contact process (see Figure 8). Sulphuric acid is manufactured via sulphur dioxide. The raw materials are sulphur, air (for oxygen) and water. Most of the sulphur comes from North America. There are three stages in the process.

1 Sulphur dioxide is made by burning sulphur in air or oxygen in a combustion chamber.

$$S_{(s)} + O_{2\,(g)} \longrightarrow SO_{2\,(g)}$$

Sometimes iron disulphide is burned in air instead. The sulphur dioxide is purified to remove impurities that would damage the catalyst at later stages.

2 The sulphur dioxide is then converted to sulphur trioxide. This step is called the Contact process. Sulphur dioxide is mixed with oxygen and passed over a catalyst (Vanadium(V) oxide: V_2O_5) at 450°C at 1–2 atm. These are the optimum conditions for the reaction and about 99% of the sulphur dioxide is converted into sulphur trioxide under these conditions.

$$\text{Sulphur dioxide} + \text{Oxygen} \rightleftharpoons \text{Sulphur trioxide}$$

$$2SO_{2\,(g)} + O_{2\,(g)} \rightleftharpoons 2SO_{3\,(g)}$$

This a reversible reaction. The forward reaction is exothermic. Increasing the temperature decreases the yield. However, at very low temperatures, the rate of reaction is very slow and the time required would make the process costly. A catalyst and temperature of 450°C are used to speed up the reaction while still achieving a reasonable yield. An increase in pressure would also increase the yield and the rate, but the costs of this would be high.

The catalyst speeds up the rate of both the forward reaction and the backward reaction. The catalyst causes the reaction mixture to reach its equilibrium composition more quickly. This stage takes place in the converter (c.f. catalytic converters in cars).

3 Finally the sulphur trioxide is converted to sulphuric acid. Overall, this process can be summarised as:

$$SO_{3\,(g)} + H_2O_{\,(l)} \longrightarrow H_2SO_{4\,(l)}$$

Please note that this can't be done simply by adding water, as the sulphur trioxide does not dissolve very easily in water: the reaction is highly exothermic and uncontrollable and creates a fog of sulphuric acid. So sulphur trioxide is dissolved in 98% sulphuric acid. The product is called oleum.

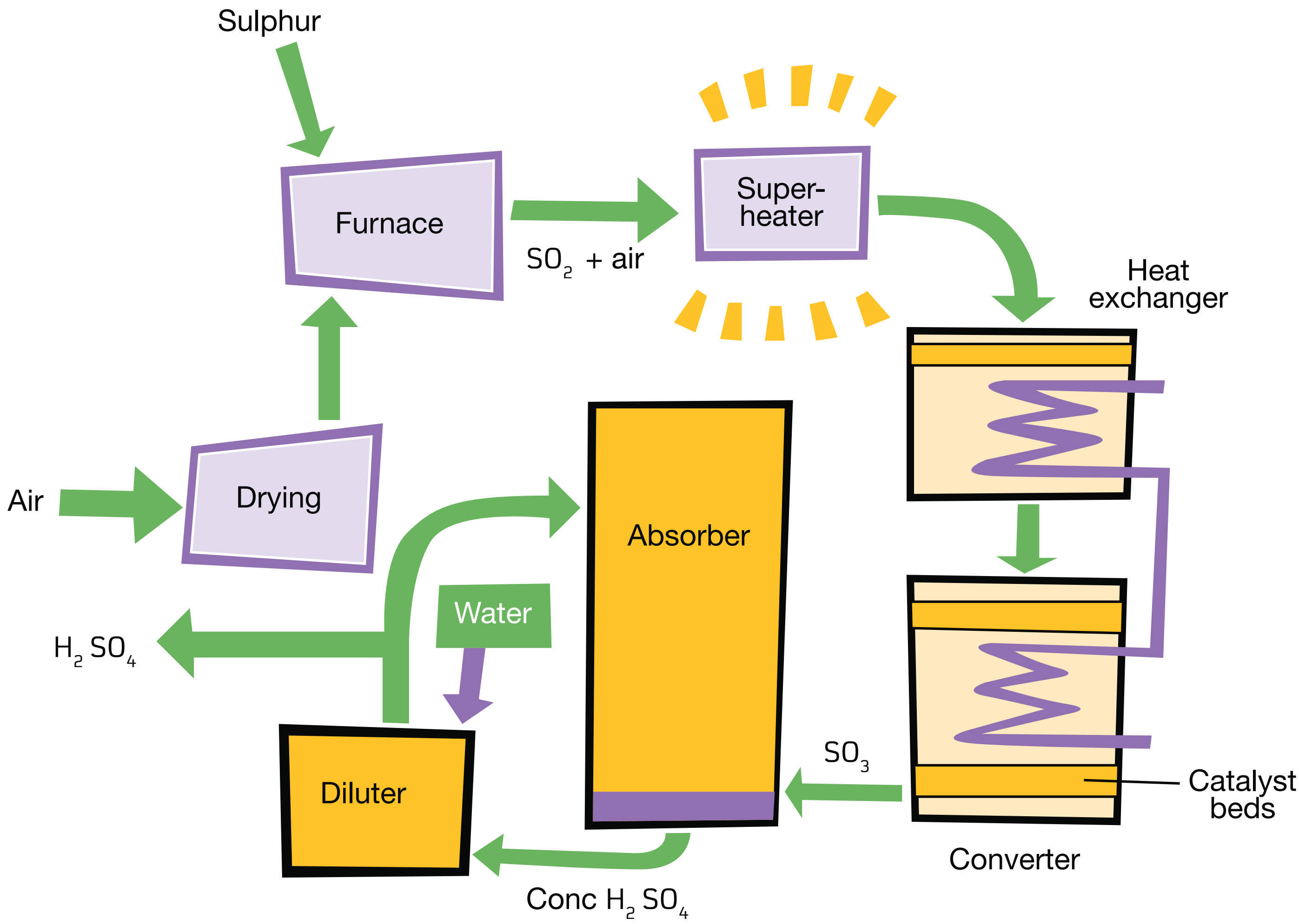
$$H_2SO_{4\,(l)} + SO_{3\,(g)} \longrightarrow H_2S_2O_{7\,(l)}$$

This compound can be safely reacted with water to make concentrated sulphuric acid.

$H_2S_2O_{7\,(l)} + H_2O_{(l)} \longrightarrow 2H_2SO_{4\,(l)}$

The process was patented in 1831 by a British vinegar merchant named Peregrine Phillips. It was a more economical process than the previous one used.

Figure 8. The main stages in the manufacture of sulphuric acid



Teaching model examples

1 Teaching the Contact process can be used as a context to bring together a range of the key concepts introduced throughout GCSE, namely rates of reaction, catalysis and reversible reactions, equilibria and acids.

2 Students watch a video about the Contact process. They then discuss answers to a range of key questions, putting their existing knowledge into practice. Questions might include:

- In stage 2, what is the effect of increasing temperature on the rate of reaction?
- What impact does this have on the yield of sulphur trioxide?
- What is the effect of increasing pressure on the rate of reaction and the yield?
- Why is a catalyst used?
- How are the conditions chosen to minimise cost and use of energy?
- What properties of sulphuric acid need to be accounted for in its manufacture?
- Why is it important not to allow the products of stage 3 to escape into the atmosphere?

3 The key learning points are summarised by the students and the teacher so that learning is consolidated.

Examples of investigations and demonstrations

Sulphuric acid as a dehydrating agent can be demonstrated by adding concentrated sulphuric acid to sugar in a beaker, or by adding the acid to hydrated copper sulphate. Both provide spectacular changes. The sugar turns black and rises up the beaker, evolving steam. This is irreversible. The blue copper sulphate turns white and the reaction can be reversed by adding water. Details are listed in *Classic chemistry demonstrations* or on the Practical Chemistry website (go to intermediate>acids, alkalis and salts> sulphuric acid as a dehydrating agent). Videos and simulations of these reactions can be easily found through a search engine.

Additional classroom activities

Students gather data from secondary sources about how sulphuric acid is used in a range of products. They could gather first-hand data from demonstrations showing sulphuric acid as a dehydrating agent. They could take or gather photos from the internet and present a PowerPoint® presentation showing what products and processes rely on sulphuric acid. They could take pictures of everyday scenes and remove the images that rely on sulphuric acid to point out what may be missing from modern life if we didn't have sulphuric acid. Students draw conclusions about how sulphuric acid is used and its importance.

Opportunities for How Science Works

Practical and enquiry skills

2b Students should be taught to collect data from primary or secondary sources, including ICT sources and tools.

Communication skills

3a Students should be taught to recall, analyse, interpret, apply and question scientific information or ideas.

3c Students should be taught to present information, develop an argument and draw a conclusion, using scientific, technical and mathematical language, conventions and symbols and ICT tools.

Resources

The 'Alchemy?' website provides video clips and other resources about industrial processes. It is available at www.rsc.org/education/teachers/learnnet/alchemy and includes a video tour of a sulphuric acid plant showing where each of the key processes takes place and how the plant and catalyst are adapted to optimise production. The resource also includes a fact file, images and schematics that can be used in worksheets, weblinks and focus questions to use while watching the video.

www.greener-industry.org covers the Contact process and also wider issues about its production and use such as recycling sulphuric acid, controlling emissions, energy efficiency, sulphur mining and catalyst replacement.

Chemsheets provide some useful worksheets on the Contact process and the properties of sulphuric acid.

www.chemguide.co.uk/physical/equilibria/contact.html provides detailed information to explain the optimum conditions of the Contact process.

Johnson Matthey's education site on catalysis provides a wealth of information on the different sorts of catalysts used in industry. It has a page dedicated to the Contact process: http://resources.schoolscience.co.uk/JohnsonMatthey/page9.htm

Obtaining and using materials
6. Water purity

Subject knowledge and challenging concepts

The water cycle shows evaporation of water from lakes, oceans and rivers. Vapour rises and as it cools, it condenses to form clouds. Water droplets join together to form rain. Water dissolves a range of substances, some of which are beneficial to health and others that are not.

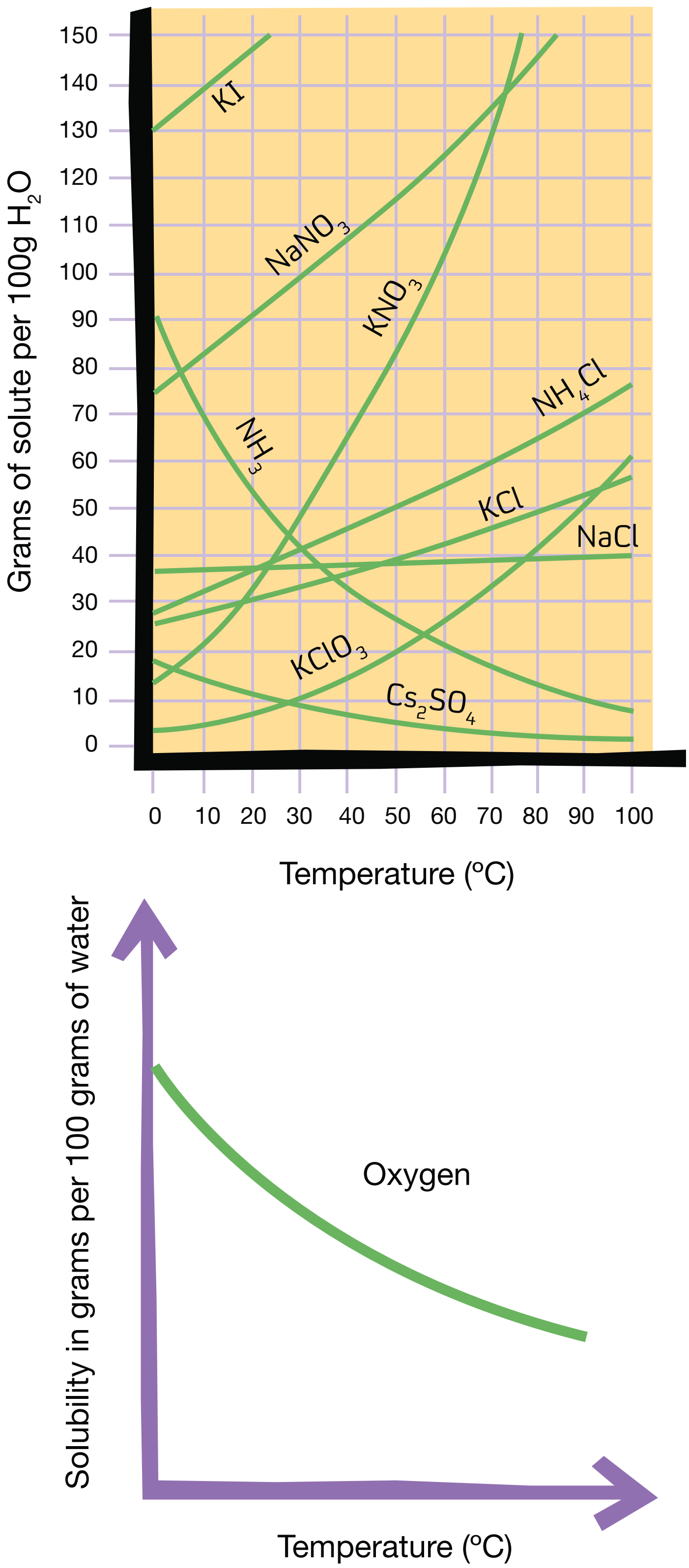
The solubility of a solute in water (or another solvent) is usually given in grams of solute per 100 grams of water (or other solvent) at a particular temperature. Solubility curves plot solubility in grams of solute per 100g of water against temperature (see Figure 9). These curves show when crystallisation occurs. A saturated solution is one in which no more solute will dissolve at that temperature. When a hot saturated solution cools, some of the solute comes out of solution.

Most ionic compounds dissolve in water but many covalent compounds are insoluble. Most solid solutes' solubility increases as temperature increases, although there are a few exceptions such as caesium sulphate.

Many gases are also soluble in water. Their solubility increases as temperature decreases and as the pressure increases. Carbonated water is made by dissolving carbon dioxide in water at high pressure. When the pressure is decreased, the gas comes out of solution in bubbles. Some carbon dioxide is dissolved naturally in rainwater.

Dissolved oxygen is essential for aquatic life. Some power stations use water as a coolant and pump warm water into rivers, and this reduces the oxygen available to aquatic plants and animals.

Figure 9. (a) The solubility curves of a range of salts in water and (b) The solubility curve for oxygen in water



Hard water contains dissolved minerals, usually containing calcium and magnesium. These minerals come from chalk or limestone, which the water has flowed over or through. Rainwater dissolves carbon dioxide from the atmosphere to create carbonic acid. This reacts with calcium carbonate to create calcium hydrogen carbonate. This causes temporary hardness. It can be removed by heating the water, giving calcium carbonate (a precipitate), carbon dioxide and water. The calcium carbonate is limescale.

Permanent hardness cannot be removed by heating and is caused by dissolved salts such as calcium and magnesium sulphates.

Soft water has very little of these. The difference can be seen with soap lather: soft water readily forms lather but hard water reacts with the soap to form scum. One option is to use detergent rather than soap in hard water areas. The calcium in hard water gives health benefits, however.

The limescale from hard water can build up in heating systems and kettles, reducing their efficiency and increasing energy costs. Dissolving the calcium and magnesium ions makes the water softer. This can be done with sodium carbonate, which produces as precipitate of calcium carbonate and magnesium carbonate, or with an ion exchange column containing hydrogen ions or sodium ions. These ions replace the calcium and magnesium ions as water passes through the column.

Water of the correct quality is essential for life. Water should have sufficiently low levels of dissolved salts and micro-organisms. Water is filtered to remove solids and sterilised with chlorine. Filters with carbon and ion exchange resins remove some of the dissolved substances in tap water to improve the taste and quality. Pure water can be produced by distillation.

Teaching model examples

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1 The teacher asks students to state their hypothesis about what will happen to the solubility of salts and gases as temperature is increased.

2 Students carry out experiments to plot solubility curves for a range of salts and/or look at secondary data for other salts and gases.

3 They draw conclusions about what will generally happen to solubility of salts and gases as temperature is increased. They then apply their understanding to a range of situations, eg what will happen to the wildlife in rivers near to power stations?

cm

1 The teacher shows the class a kettle with scale and asks where it has come from.

2 Students give their ideas. Why doesn't it dissolve in the hot water and get poured away when tea is made?

3 Students carry out investigations on hard water and research the topic to refine their models for understanding hard water.

Examples of investigations and demonstrations

A dramatic way to start a discussion about solubility is to demonstrate a supersaturated solution of sodium ethanoate crystallising rapidly to form a stalagmite. This is outlined on the Practical Chemistry website.

Plotting a solubility curve

Students warm a mixture of potassium nitrate and water until all the solid has dissolved. Solutions are stirred whilst they are left to cool down, and the temperature at which recrystallisation occurs is noted. Class results are combined and used to plot a solubility curve for potassium nitrate.

The effect of temperature on solubility is also detailed in *Classic chemistry experiments* (98).

Investigations that could be used for this topic include:

- comparing hardness of different water samples using soap solutions
- comparing limescale removers
- removing hardness from water
- evaporating water from a known mass of solution to determine mass dissolved.

Classic chemistry experiments (42) and (47) give full details for the first and fourth of these experiments.

Links can be made to topics on limestone by creating hard water. A marble chip is added to hydrochloric acid and the resulting carbon dioxide gas is passed through limewater (calcium hydroxide) to form the insoluble calcium carbonate. Continuing to bubble carbon dioxide through results in the cloudiness disappearing as soluble calcium hydrogencarbonate is formed. If this solution is heated, the cloudiness returns as the soluble hydrogencarbonate turns back into insoluble carbonate. This cloudiness is the scale you see in kettles in hard water areas.

Additional classroom activities

Students research different types of water softening systems for the home and research how they work.

Students review recent stories about water pollution in the news.

A visit could be made to the local water treatment works or a visit from someone in the water industry could be arranged.

Opportunities for How Science Works

Data, evidence, theories and explanations

1c Students should be taught how explanations of many phenomena can be developed using scientific theories, models and ideas.

Practical and enquiry skills

2a Students should be taught to plan to test a scientific idea, answer a scientific question or solve a scientific problem.

Communication skills

3b Students should be taught to use both qualitative and quantitative approaches.

Applications and implications of science

4b Students should be taught to consider how and why decisions about science and technology are made, including those that raise ethical issues, and about the social, economic and environmental effects of such decisions.

Centre-marked assessment opportunities

Students can plan investigations, manipulate apparatus and gather and analyse data from tests comparing the hardness of water.

The ethics of adding or removing chemicals (eg adding fluoride, removing hardness) at water treatment plants could be a topic for discussion, debate and written work.

Obtaining and using materials

7. Alkanes and alcohols – organic chemistry

Subject knowledge and challenging concepts

Organic chemistry was originally associated with the chemistry of living things. Chemists began to work out how to synthesise the same molecules outside living systems: in 1848, Wohler synthesised urea from entirely inorganic precursors and now chemists can make a wide range of products that are part of our everyday life. Carbon atoms can usually have up to four covalent bonds so they can form all sorts of large and small molecular compounds. As well as carbon, organic compounds often include hydrogen, oxygen, nitrogen and halogens.

Chemists group organic compounds together into different families with similar properties, in the same way that they use the periodic table to group elements with similar properties together.

Alkanes

Many students will have met the alkanes in earlier topics in most specifications. They have the general formula C_nH_{2n+2}. They come from crude oil. They are oily and don't mix with water. The more carbon atoms in an alkane, the less volatile it is. CH_4 to C_3H_8 are gases, C_4H_{10} to $C_{17}H_{36}$ are liquids and $C_{18}H_{38}$ onwards are solids. Alkanes burn in air to give carbon dioxide and water, but are otherwise pretty unreactive: they don't react with most acids and alkalis.

Alcohols

The alcohols are a second family of organic compounds, with ethanol being the best known member of the group. Structurally, they are like alkanes but one of the H's is replaced with an –OH group.

They have some similar properties to alkanes, eg they burn, giving carbon dioxide and water. The –OH group has some of the properties of water: sodium only reacts with the –OH group in ethanol to give ionic sodium ethoxide and hydrogen. Even though ethanol has a higher molecular mass than water, it is more volatile because the attractions between molecules are weaker than in water. The –OH group also enables small alcohol molecules to mix with water.

Methanol is an important chemical feedstock and is made from methane and steam. Ethanol is a useful solvent and is used as a fuel as it burns easily. As a fuel, ethanol produces about 70% as much energy per litre as petrol. It is actually the fuel that Henry Ford's Model T used back in 1908. The countries most able to introduce biofuels such as ethanol need a lot of sunlight and arable land to grow the crops. Ethanol is also present in alcoholic drinks and used as a feedstock for many industrial processes.

Ethanol can be made by at least three methods, which give useful environmental comparisons between industrial processes.

1 By fermentation of sugars with yeast at optimum temperature (25–50°C).

$$\text{Glucose} \xrightarrow{\text{yeast}} \text{ethanol} + \text{carbon dioxide}$$

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2$$

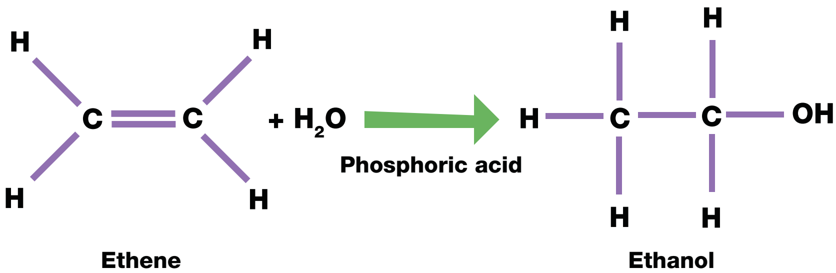
The yeast respires anaerobically and its enzymes act as a catalyst to convert sugar into carbon dioxide and ethanol. This must be carried out in the absence of air, as ethanoic acid is produced if oxygen is present. Ethanol is separated from the mixture of ethanol and water by distillation.

This method of production is a batch process and is used to make alcoholic drinks. As yeast can only survive to a concentration of 10–15% alcohol, production stops at this point and the reaction vessel must be emptied, cleaned and then refilled with fresh starting materials, ie a batch. Batch processes take longer and cost more than a continuous process, but may be unavoidable.

Most of the world's ethanol is produced by fermenting crop biomass such as sugar cane, sugar beet, rice and maize. The sugars in the biomass need to be broken down into simple sugar molecules before fermentation can take place with yeast.

2 Genetically modified *E.coli* bacterium can be used to convert water biomass into ethanol. To get round yeast's limitations of only converting simple sugars such as glucose to ethanol, a genetically modified bacterium called KO11 has been developed. It converts the large complex polymers made from sugars, such as hemicellulose, in biomass to ethanol. This makes it cost effective to use biomass such as wood waste corn stalks and rice husks that would not be economic for yeast fermentation.

3 Ethene (from oil refining) can be converted into ethanol. Ethanol can be made by hydrating ethene using steam in the presence of phosphoric acid, which acts as a catalyst. The ethene comes from cracking the distillation products of crude oil.



The reaction has a theoretical atom economy of 100%, but some side reactions do occur. The reaction is exothermic. The equilibrium is shifted towards the product by using a low temperature and a high pressure of steam. A temperature of 300°C, a pressure of 60–70 atmospheres and a steam:ethene ratio of 0.6:1 is used. A continuous process is used to recycle unreacted ethene and steam around the plant. This raises the yield from about 5% for a single 'pass' to 95% overall.

This process always produces a mixture of ethanol and water and even distillation results in a mixture of 96% ethanol and 4% water. The water is removed by refluxing with a dehydrating agent, although more recently zeolites have been used to remove the water without further heating. The molecular structure of zeolites provides holes just the right shape and size for water molecules which they strongly attract.

Ethanol can be dehydrated by passing the vapour over aluminium oxide catalyst to produce ethene.

Teaching model examples

1. Students are given cards with the names and chemical formula of several members of the family.
2. They sort the cards according to different properties, eg lowest to highest boiling point, and make a hypothesis about the relationship between relative formula mass and volatility. Generalisations about naming and the formula can also be made.
3. A plenary summarises the key learning points.

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1. Students use molecular models of several alkanes, several alcohols and water to examine the similarities and differences in structure between the three types of compound.
2. They research the physical and chemical properties of each of the three, including volatility/boiling points, combustion, reactions with alkali metals and solubility.
3. Students make hypotheses about how the structures of the molecules relate to the different properties and summarise their findings in a class discussion. They can apply their findings to predict what reaction would take place with dilute sodium hydroxide.

Investigations and demonstrations

The properties of alkanes and alcohols are straightforward to demonstrate or for students to investigate.

The heat energy produced through the combustion of alcohols and alkanes can be compared using calorimetry as described previously. The alcohol gun (*Classic chemistry demonstrations* (28)) is a spectacular demonstration of ethanol as a fuel, and illustrates the principle of the internal combustion engine: a plastic bottle is fitted with spark electrodes, filled with ethanol vapour and corked. The vapour is ignited with a spark and the cork is fired across the room with a small explosion.

Additional classroom activities

Labels of foods, drinks and cosmetics can be examined to identify organic molecules, especially acids, ethanol, esters, fats and oils. This could lead to a discussion about natural and synthetic products to address the misconception that these are different chemicals.

The social issues associated with alcohol are well-covered by the 'Alcohol and you' website: www.at-bristol.org.uk/alcoholandyou/ which includes interactive quizzes and discussion stimuli, as well as teachers' resources for classroom activities.

Opportunities for How Science Works

Data, evidence, theories and explanations

1c Students should be taught how explanations of many phenomena can be developed using scientific theories, models and ideas.

Practical and enquiry skills

2b Students should be taught to collect data from primary or secondary sources, including ICT sources and tools.

Communication skills

3a Students should be taught to recall, analyse, interpret, apply and question scientific information or ideas.

Applications and implications of science

4a Students should be taught about the use of contemporary scientific and technological developments and their benefits, drawbacks and risks.

4b Students should be taught to consider how and why decisions about science and technology are made, including those that raise ethical issues, and about the social, economic and environmental effects of such decisions.

Resources

The Greener Industry site www.greener-industry.org provides detailed but accessible information about the production of ethanol via three key routes.

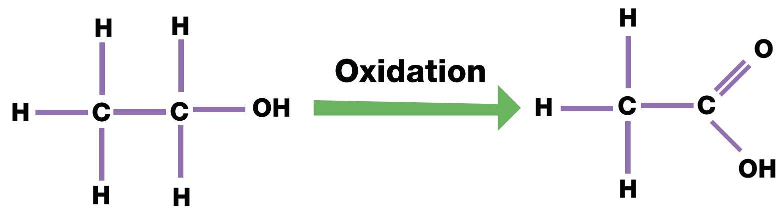
Obtaining and using materials

8. Carboxylic acids, esters, fats and oils – organic chemistry

Subject knowledge and challenging concepts

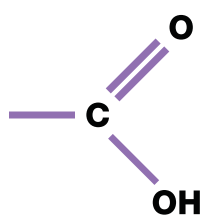
Ethanoic and other carboxylic acids

When ethanol is exposed to air, it is oxidised to ethanoic acid. This is how vinegar is made. For example, oxidation of beer results in malt vinegar. Bacteria in the solution help this process.



Ethanoic acid is one of the family of carboxylic acids – other members include methanoic acid, propanoic acid and butanoic acid, and their systematic naming follows the same rules as the alkanes and alcohols. Many of the acids also have familiar names: ethanoic acid is called acetic acid and methanoic acid is called formic acid.

The key functional group is:



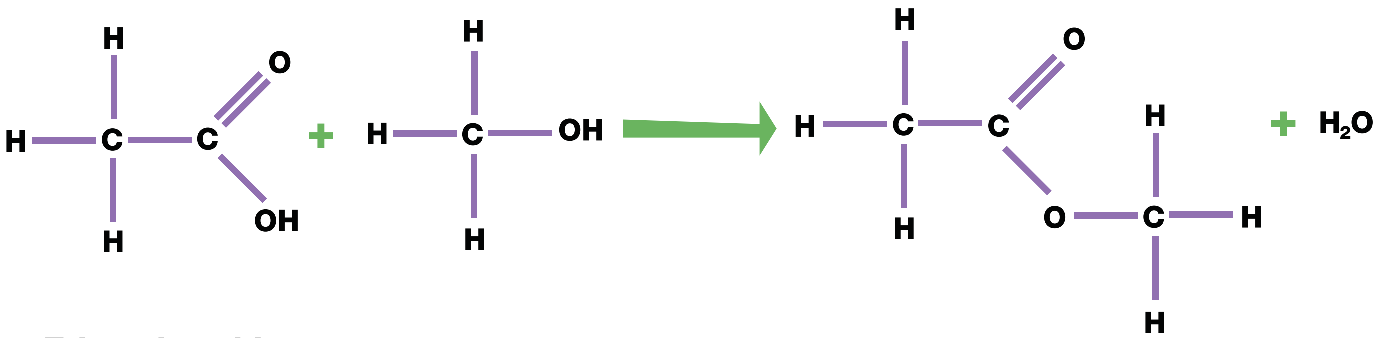
There are many organic acids found in nature. The ones with more carbon atoms often have unpleasant smells, including body odour.

Carboxylic acids are weak acids – see section on strong and weak acids for further details.

Esters

Unlike the carboxylic acids, esters give sweet and fruity smells. They are widely used in perfumes and food flavourings, and some medicines are esters such as aspirin and paracetamol. Many esters are good solvents. Polyester is a polymer with lots of ester links.

Under acid catalysed conditions, ethanol reacts with carboxylic acids to form esters and water: ethanoic acid + methanol ⟶ methyl ethanoate + water



Ethanoic acid **Methanol** **Methyl ethanoate + water**

Sulphuric acid is used as a catalyst for making esters.

Esters' systematic names derive from the alcohol and the acid from which they were formed.

Fats and oils

Many molecules have more than one ester link in their structure. Fats and oils are examples of these. The alcohol in fats and oils is glycerol and it has three –OH groups. The carboxylic acids in fats and oils have long hydrocarbon chains. They are called fatty acids. An ester link forms from each of the –OH groups to three fatty acid molecules.

Fats are generally solids at room temperature and are animal products. Vegetable oils are usually liquids. Saturated fats have no double bonds in their hydrocarbon chain: all the carbon is 'saturated' with hydrogen. Unsaturated fats have carbon-carbon double bonds in their hydrocarbon chains. Saturated chains have a more regular shape and pack together, giving solid structures.

Unsaturated chains give more irregularly shaped molecules that do not pack together as easily, so these have lower melting points and can therefore be liquid at room temperature. Polyunsaturated fats have more than one carbon-carbon double bond.

Unsaturated fats and oils will decolourise bromine water.

Saturated fats and oils lead to high cholesterol levels in the body, which cause hardening of the arteries and heart problems. Polyunsaturated fats and oils are healthier.

Oils and waters don't mix but can be shaken together to form an emulsion. Emulsifiers help keep oils and water mixed together.

Soaps can be made from fats and oils. They are the sodium or potassium salts of fatty acids and are created by hydrolysing esters. This is very slow unless there is a catalyst present.

$$\text{Ester + Water} \xrightarrow[\text{(catalyst)}]{\text{Sodium hydroxide}} \text{Acid + Alcohol}$$

Teaching model examples

1 The teacher introduces the ester family of compounds, explaining how they are made from alcohols and acids.

2 Students are given the structure of a number of esters to make along with a selection of acids and a selection of alcohols. They carry out test tube experiments to make and smell different esters, using different alcohols and acids, noting their smells. Details at www.chemheritage.org/educationalservices/pharm/asp/ester.htm

3 Students and the teacher together summarise the general formula for ester synthesis from alcohols and acids. They have modelled the process of chemical synthesis used by chemists who are designing specific molecules such as drugs.

4 Students apply their understanding to the synthesis of fats and oils, and look at the structures of esters that are used as drugs.

Examples of investigations and demonstrations

Unsaturation in fats and oils is a common test using bromine water. Details to compare different oils and fats using titration are given in *Classic chemistry experiments* (9).

Students can observe ethanoic acid's properties as a weak acid by carrying out *Classic chemistry experiment* (78).

Calorimetry can be used to compare ethanol with other fuels.

Additional classroom activities

Labels of foods, drinks and cosmetics can be examined to identify different organic molecules, especially acids, ethanol, esters, fats and oils. This could lead to a discussion about natural and synthetic products to address the misconception that these are different chemicals.

Students explore fats, oils and health through internet research. Areas to research could include saturated and unsaturated fats, trans and cis fats and omega oils.

Opportunities for How Science Works

Applications and implications of science

4a Students should be taught about the use of contemporary scientific and technological developments and their benefits, drawbacks and risks.

Centre-marked assessment opportunities

Preparing a sample of aspirin from salicylic acid or preparing an ester and calculating percentage yield provides opportunities to demonstrate practical skills and analysis of results.

Comparing the methods of manufacturing ethanol provides opportunities for 'Applications and implications' of science written work, in which students can present logical, well-reasoned arguments for and against each method.

Resources

The Greener Industry site includes an accessible section on the production of ethanoic acid: www.greener-industry.org

Contemporary chemistry for schools and colleges includes a topic on soaps and detergents (Cleaning Chemistry) and a topic on chemistry and diet.

CLEAPSS publication L215 covers microscale organic chemistry, while PS67-01 outlines an experiment to find the degree of unsaturation in oils, and PS67-02 outlines how to make soap. Sheet PS67-07 details how to make esters.

Obtaining and using materials
9. Green chemistry

Subject knowledge and challenging concepts

We depend on the chemical industry to make useful products for our everyday lives. Bulk chemicals are made on a large scale, often millions of tonnes per year. Examples are sulphuric acid, sodium hydroxide and ethene. Fine chemicals are produced on a much smaller scale and examples are drugs, food additives and liquid crystals.

The chemical industry takes raw materials (crude oil, air, water, vegetable material and minerals such as metal ores, salt, limestone and gypsum) and converts them into feedstocks that can be purified and reacted together to make another chemical. The reactions take place in a chemical reactor and usually require energy. Catalysts are used to reduce the energy required.

The reaction will create the main product and some by-products. It will be mixed with the reactants. The reactants are often recycled into the reaction mixture again. Products need to separated from by-products and reactants, and purified. Waste and by-products need to be disposed of. Sensors are used to monitor the process.

Government agencies regulate industry to protect the environment and ensure the health and safety of all those associated with the production and use of chemicals.

Percentage yield and atom economy of processes are important measures of its efficiency.

$$\text{Yield} = \frac{\text{Actual yield in grams}}{\text{Theoretical yield in grams}} \times 100\%$$

The theoretical yield is calculated by considering the balanced equation and the mass of the limiting reactant.

$$\text{Atom economy} = \frac{\text{Mass of atoms in the ‘green’ product}}{\text{Mass of atoms in the reactant}} \times 100\%$$

It is calculated using the total relative atomic masses for the reactants and ‘green’ product. The products are divided into ‘green’ and ‘brown’ products, with the former being the desired products and the latter being the waste products.

Industrial processes can be made greener by considering the principles of green chemistry (condensed from Anstas and Warner (1998). *Green Chemistry: Theory and Practice*, Oxford University Press.).

1 Prevention is better than cure – it is better to design processes that produce no waste than to produce waste and clean it up.

2 Processes should be designed to incorporate the maximum amount of the raw materials into the final product, thus reducing waste products.

3 Raw materials should come from renewable sources.

4 Energy requirements should be minimised.

5 Catalysts are better than reagents that are used up in a process.

6 Chemical products should be designed so that they break down at the end of their useful life to form harmless products.

7 Methods of making chemicals should be designed to make products that cause no harm to human health or to the environment and that do not cause accidents such as explosions and fires.

8 Methods of making chemicals should be monitored to prevent the formation of hazardous substances.

Examples of chemical processes that have been made greener can be found on the Greener Industry website (www.greener-industry.org). These include processes associated with aluminium, ammonia, ethanoic acid, ethanol, nitric acid, nylon, poly(ethene), PVC and sulphuric acid.

Teaching model examples

e(d)

1 The teacher presents to students a number of routes to synthesise a particular compound.
2 Students develop a hypothesis about which will be greener according to the green chemistry principles.
3 Students establish a number of criteria for assessing how green the process is, eg atom economy, yield, energy use, waste to be disposed of, use of renewable resources, etc.
4 They compile the data and draw a conclusion about which process is most environmentally friendly.

dit

1 The teacher introduces the principles of green chemistry.
2 Students research industrial processes that have been made greener and present their findings to the group.
3 A plenary session draws together the key learning points.

Investigations and demonstrations

Fermentation can be carried out to produce ethanol (see section on alcohols), using traditional lab apparatus or a home brewing kit. Details are given in *Classic chemistry experiments* – see Section 7.

Additional classroom activities

Students conduct internet research to find out how various industrial processes have become greener and present their findings.

Consider a visit to a local company or inviting a speaker into school. The Science and Engineering Ambassadors Scheme run by STEMNET can help (details in Section 7).

Encourage interested students to take up work experience linked to the chemical industry.

Opportunities for How Science Works

Applications and implications of science

4a Students should be taught about the use of contemporary scientific and technological developments and their benefits, drawbacks and risks.

4b Students should be taught to consider how and why decisions about science and technology are made, including those that raise ethical issues, and about the social, economic and environmental effects of such decisions.

Centre-marked assessment opportunities

Green chemistry provides many opportunities for work on case studies relating to the environmental impacts of industry and weighing up costs and benefits.

Resources

Examples of industrial processes that have been made greener can be found at:

www.greener-industry.org

www.chemsoc.org/networks/learnnet/green/index2.htm

The RSC book *Green chemistry* has a wide range of classroom activities and ideas, and the RSC book and CD-ROM *Inspirational chemistry – resources for modern curricula* includes a chapter on 'Sustainable development and green chemistry'. It covers degradable plastics, packaging and waste, nappy choice and the environment, dry cleaning, fertilizers and the atom economy. As well as student and teacher resources to accompany experiments, literacy and data analysis activities, the book also lists many useful relevant websites highlighting contemporary contexts.

Chemical detection

10. Chemical analysis – testing for ions and gases

Subject knowledge and challenging concepts

Chemical analysis is used to find out whether, and if so how much, particular chemicals are present in a wide range of contexts: forensic science, consumer advice, environmental protection, health care, quality control, customs and excise and in scientific research. There are laws regulated by Government agencies determining safe and acceptable levels of chemicals in the environment and in all sorts of products.

Qualitative analysis identifies the chemical present in a sample, while quantitative analysis measures how much of a chemical is in a sample. Regardless of the technique, it is important to analyse samples that are representative. Decisions need to be made about how many samples need to be taken, when they are taken, how they are collected and how to store and transport them to ensure they are not contaminated.

Tests for cations

Water is commonly tested for different ions. Flame tests can help determine the presence of metal cations (positive ions). But several ions give the same colour.

Cation	Flame colour
Calcium (Ca^{2+})	Brick red
Sodium (Na^{+})	Yellow
Potassium (K^{+})	Lilac
Copper II (Cu^{2+})	Green with blue streaks
Strontium (Sr^{+})	Bright red
Lithium (Li^{+})	Crimson
Barium (Ba^{2+})	Apple green
Lead (Pb^{2+})	White

Another method is to see what happens if sodium hydroxide solution is added to a sample solution.

Cation	Precipitate when NaOH is added
Alkali metal ions (Li^{+}, Na^{+}, K^{+})	None
Ammonium (NH_4^{+})	None
Aluminium (Al^{3+})	White
Calcium (Ca^{2+})	White
Copper (II) (Cu^{2+})	Blue
Iron (II) (Fe^{2+})	Dark green
Iron (III) (Fe^{3+})	Brown (rust)

Further tests are needed when a white precipitate is the product. When excess sodium hydroxide is added, the aluminium precipitate will dissolve but the calcium one will not.

Ammonium ions can be distinguished from alkali metal ions by heating the unknown sample: if ammonium ions are present, ammonia will be given off with its distinctive smell. It will turn universal indicator paper blue.

Tests for anions

Hydroxide ions, sulphite ions and carbonates

If the unknown solution turns universal indicator blue/purple, it is likely to contain hydroxide ions. If they are not present, add hydrochloric acid. If carbonate and sulphite ions are present, the solutions will give off a gas. Sulphite ions give off the acidic gas sulphur dioxide, which has a choking smell. Carbonates give off carbon dioxide, which turns limewater milky. Two carbonates give distinct colour changes when heated: copper(II) carbonate is green and when it is heated, it gives black copper(II) oxide and carbon dioxide that turns limewater milky.

Zinc carbonate is white and when heated, it decomposes to zinc oxide, which is lemon yellow when hot, white when cold.

Sulphates

Adding barium chloride solution can be used to test for sulphate ions, which form a white precipitate of barium sulphate. Barium carbonate and barium sulphite are also white precipitates, but these dissolve with the addition of hydrochloric acid.

Halides

Halide ions (chloride, bromide and iodide) can be identified with silver nitrate solution acidified with dilute nitric acid, giving the following results. Note that silver halides decompose in sunlight (and have been used in photography for this reason). The nitric acid removes any carbonates, sulphite and hydroxide ions present.

Halide ion	Precipitate with acidified silver nitrate solution
Chloride (Cl^-)	White
Bromide (Br^-)	Cream
Iodide (I^-)	Yellow

Nitrates

Sodium hydroxide solution is added to the unknown solution and warmed with aluminium powder. This reduces nitrate ions to ammonium ions, which react with the hydroxide to form ammonia gas. Red litmus will turn blue.

Tests for gases

Hydrogen

Apply a lit splint to the test tube of gas. A squeaky pop will be observed and some condensation may be seen. Energy is given out as hydrogen reacts with oxygen to give water.

Carbon dioxide

Bubble the gas into limewater (aqueous calcium hydroxide solution). The limewater turns cloudy as a fine white precipitate of calcium carbonate is formed.

Oxygen

Apply a glowing splint to the test tube of gas. It will reignite, giving a flame. The carbon in the wood is oxidised to carbon dioxide.

Chlorine

Chlorine bleaches moist blue litmus paper.

Teaching model examples

e(i)

1. Students are given the reactants for the tests for cations. They use their existing knowledge of chemistry to hypothesise what the products of the reactions will be, eg will there be a precipitate, and if so, what colour will it be? The class draw together their suggestions.
2. Students carry out tests or research the answers to confirm whether they are correct and to find the answers to reactions unfamiliar to them.
3. They apply these findings to determine the composition of unknown samples.

e(d)

1. Groups of students are given known ionic reactions to carry out or use textbooks and the internet to research. They observe and record what happens, or complete a table outlining what is observed. A nice addition would be to capture the results with digital pictures.
2. The class brings together this information to construct a flowchart of reactions for a forensic chemist to try to determine the composition of unknown samples.
3. The students are given unknown samples with which to use their flowcharts or given 'results from the laboratory'.

dit

1. The teacher presents the results of different tests used for detection of ions and gases.
2. Students then answer questions about what they would observe if unknown solutions contained particular ions, or what they would expect to observe from particular reactions producing a gas.
3. A plenary session would draw together the key learning points.

Investigations and demonstrations

The tests for ions and gases provide many opportunities for investigations and demonstrations.

Tests for ions can be done as either test tube or microscale experiments to save on the amounts of chemicals being used and the washing up.

Full details of microscale reactions of positive ions with sodium hydroxide and tests for negative ions are given at www.chemsoc.org/networks/learnnet/inspirational/

Classic chemistry experiments (80) outlines the experimental details for tests for anions and cations and for traditional flame tests using nichrome wire. *Classic chemistry demonstrations* (34) describes flame tests that are more dramatic: a saturated solution of the salt in ethanol is sprayed into the flame.

Opportunities for How Science Works

Data, evidence, theories and explanations

1a Students should be taught how scientific data can be collected and analysed.

1b Students should be taught how interpretation of data, using creative thought, provides evidence to test ideas and develop theories.

Practical and enquiry skills

2a Students should be taught to plan to test a scientific idea, answer a scientific question or solve a scientific problem.

2b Students should be taught to collect data from primary or secondary sources, including ICT sources and tools.

2c Students should be taught to work accurately and safely, individually and with others, when collecting first-hand data.

Resources

Contemporary chemistry for schools and colleges has a unit on fireworks, which puts flame tests in a real context.

Inspirational chemistry – resources for modern curricula has a chapter on analysis that is particularly relevant to this topic. It provides experimental details for tests for positive and negative ions, and problem solving activities.

Chemical detection
11. Instrumental methods

Subject knowledge and challenging concepts

Elements and compounds can also be detected and identified using a variety of instrumental methods. Some instrumental methods are suited to identify elements, while others identify compounds. At this level, students are expected to know the applications of the techniques in broad terms, and with appropriate guidance, interpret spectra. They do not need to know how the instruments work.

Industry needs rapid and accurate methods for the analysis of its products. There have also been increasing demands from society for safe and reliable monitoring of our health and environment and for crime detection, eg forgery. Research into new compounds and materials also needs more sophisticated analysis. The development of modern instrumental methods has been aided by the rapid progress in technologies such as electronics and computing.

Various factors have influenced the development of instrumental methods. With modern methods it is possible to achieve greater sensitivity, so smaller amounts of material can be used, or much smaller amounts of a trace element or compound can be detected in a mixture, eg testing water for pollutants and drug testing of athletes. These methods enable:

- more accurate data
- automation of analysis, multiple samples efficiently analysed
- a greater range of analytical techniques; today's laboratory is far more versatile than ever before.

They are, however, often expensive, require special training and some give results that can only be interpreted by comparison with known specimens.

Key techniques are:

- **Mass spectrometry** is useful for identifying elements and the relative ratio of isotopes. For molecules, it can help to determine a molecular structure. The atoms or molecules are vaporised and converted to positive ions (based on a single atom or molecular fragment) by bombardment with high energy electrons (see Figure 9). The gaseous ions' masses are analysed according to how far they are deflected in a powerful magnetic field.

- **Atomic emission spectroscopy** can be used to identify elements and mixtures of elements. In atomic emission spectroscopy, the electrons in atoms are 'excited' with heat or electrical energy. The electrons fall back to their original energy levels, emitting the energy they absorbed as visible light. This is also observed in simple flame colour tests, which are also used to identify elements. However, these colours are formed from many specific frequencies of visible light added together, so it is hard to distinguish between two different reds, for example. The sample may also be contaminated with other elements, particularly sodium. Detailed analysis of the different emitted frequencies of visible light (eg using a triangular prism) gives a characteristic 'fingerprint pattern' by which to identify elements. Atomic emission spectroscopy can also give a measure of how much of an element is present. The greater the relative intensity of light frequency, the more there is of that element.

  Atomic emission spectroscopy has many applications. For example, it is used to trace levels of pollutants in water and other products and to monitor the composition of alloys as the molten mixtures are being made. Astrophysicists can identify the composition in distant stars from the light emitted to determine their age.

- **Infrared spectroscopy** helps to identify organic compounds and determine molecular structures. Each molecule absorbs infrared radiation at characteristic energy levels corresponding to particular molecular vibrations. This gives rise to a 'fingerprint' pattern of absorption of different infrared frequencies (see Figure 10).

Figure 9. A mass spectrometer

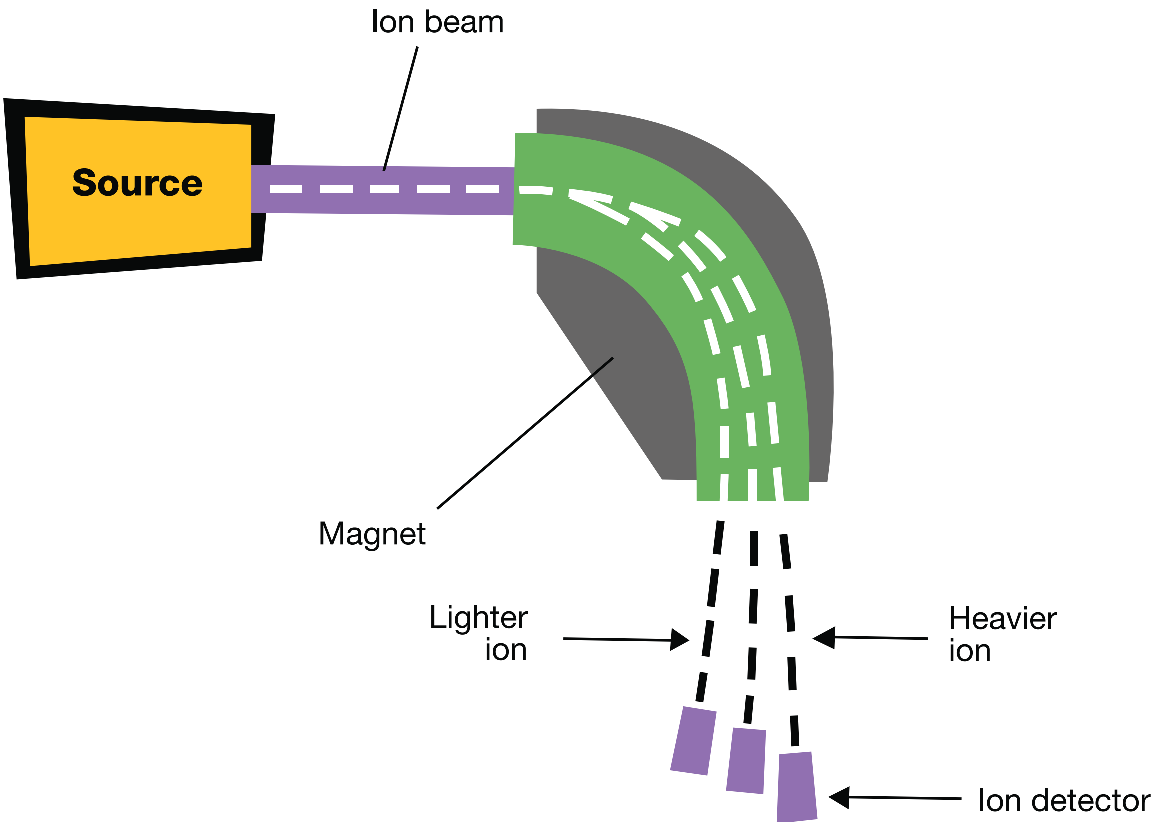
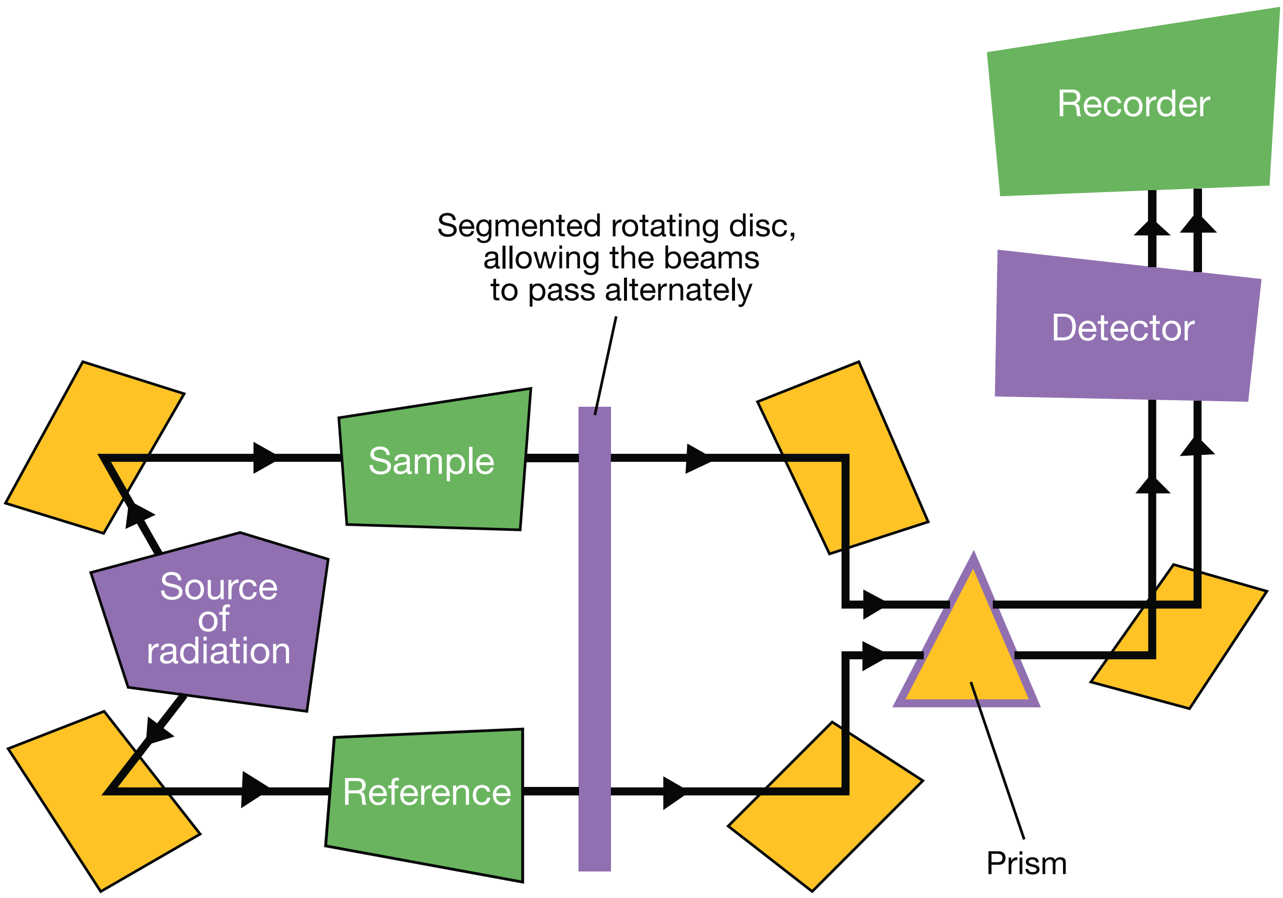


Figure 10. Infrared spectrometer



- **Ultra-violet spectroscopy** is used to determine the purity or concentration of solution of a substance that absorbs UV light.
- **Nuclear magnetic resonance** spectroscopy (NMR) is one of the most powerful analytical tools for determining the molecular structure of organic compounds. It is very expensive for routine analysis but is invaluable in designing and analysing new molecules or finding the structure of natural molecules that the drug industry might find useful in developing new pharmaceutical products. The MRI scanners used in hospitals are specialised NMR machines.

Chromatography

Paper and thin layer chromatography are used to separate and identify the chemicals in a mixture. It is low tech compared to gas-liquid chromatography, which is used to analyse liquid mixtures that can be vaporised (eg petrol, blood for alcohol or drug content).

In chromatography, a mobile phase moves through a medium called the stationary phase (see Figure 11). The sample of a mixture to be analysed is added to the stationary phase. As the mobile phase moves, the chemicals in the sample move through the stationary phase. Different chemicals move at different speeds so they separate out.

The principles of gas chromatography are the same, but in this case the mobile phase is a gas such as helium (see Figure 12). It is a more sensitive technique and can be used to separate and measure the composition of complex mixtures.

Gel electrophoresis can be considered as another form of chromatography. It is used for DNA fingerprinting.

Teaching model examples

1. Students are presented with labelled spectra of known compounds.
2. They are then presented with a range of molecules and asked to suggest what the key features of these new molecules' spectra might be.
3. The actual spectra are then revealed and students study and compare them with their own ideas.

1. The teacher introduces the different instrumental methods, what each method can be used for and why.
2. Students are given a range of different analytical problems and determine which method or methods might be used in each situation.
3. The class together reviews their suggestions and summarises key learning points.

Examples of investigations and demonstrations

Most schools are not in a position to have the equipment required to carry out instrumental techniques. A few schools may have access to UV and IR spectroscopy: check if your local authority knows of any such schools.

Chromatography experiments include Smarties chromatography and ink chromatography – both can be found in *Classic chemistry experiments*.

Students can carry out paper or thin layer chromatography experiments using the apparatus shown in Figure 11. They can interpret the chromatograms to identify the chemicals present using the retardation factor (see Figure 13).

$$Rf = \frac{\text{Distance moved by chemical}}{\text{Distance moved by solvent}} \times 100\%$$

Figure 11. Paper chromatography

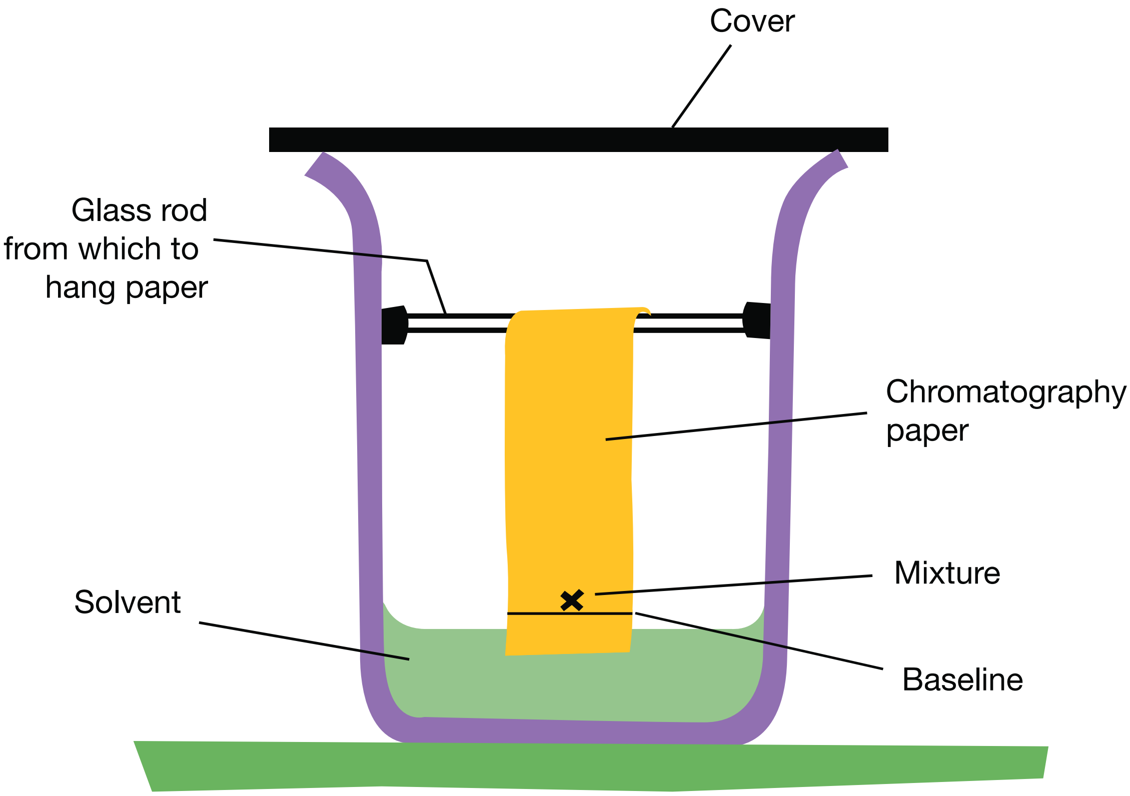


Figure 12. Gas chromatography

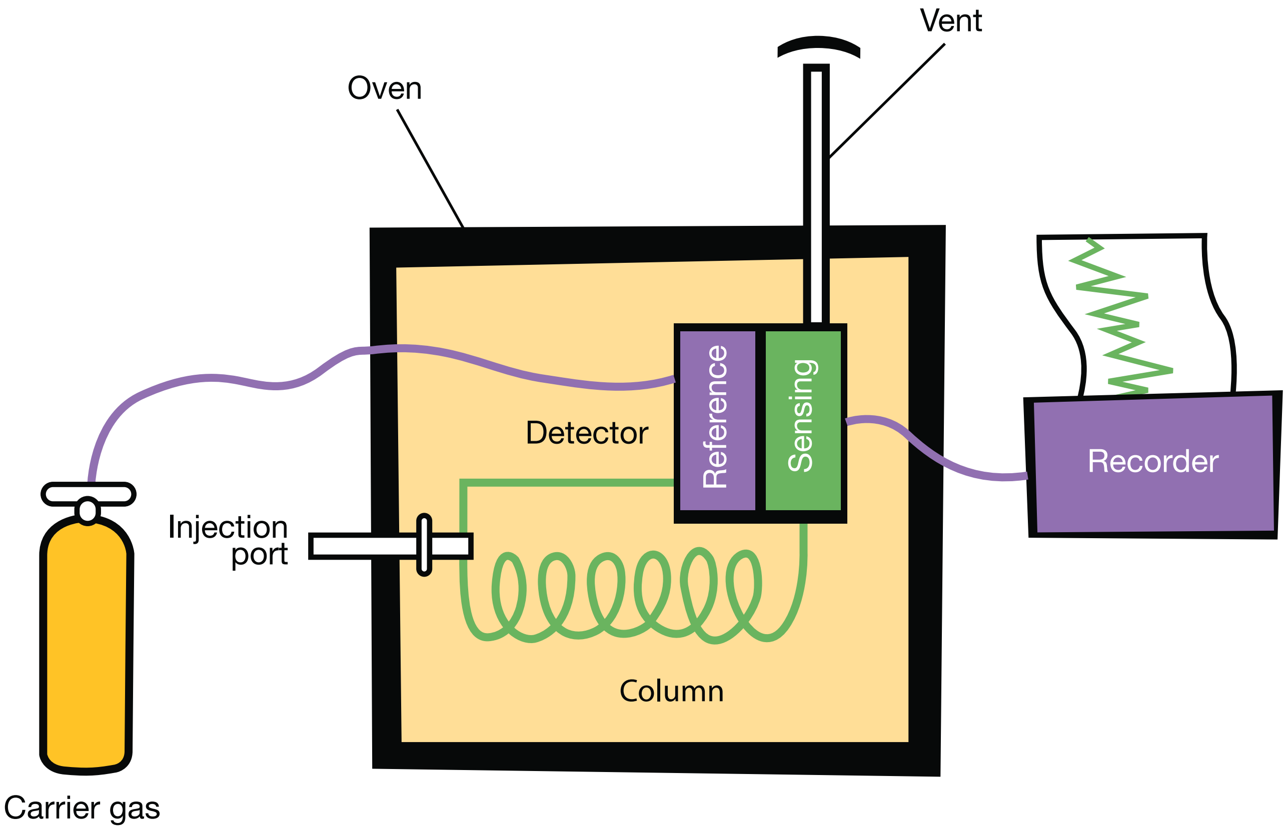
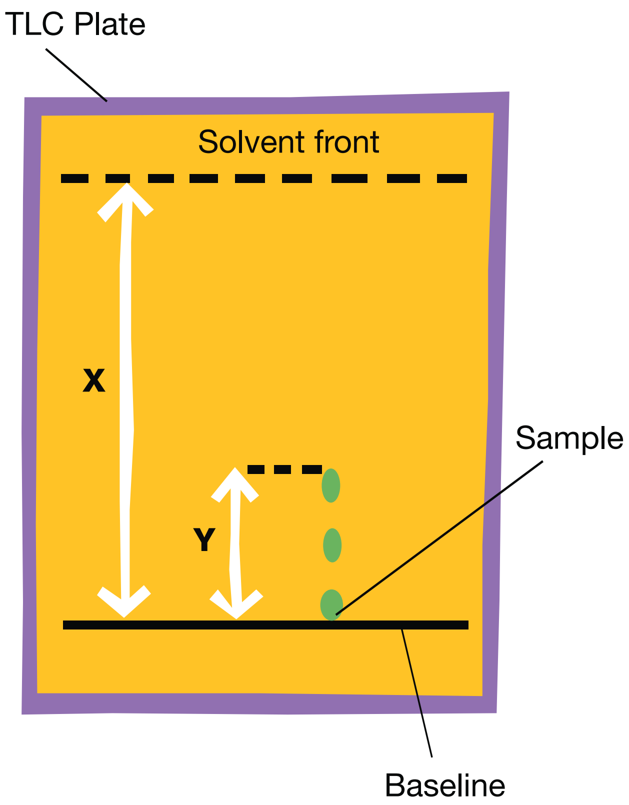


Figure 13. Retardation factor



Additional classroom activities

Many university chemistry departments offer the opportunity to visit the department to see spectroscopy in action. Some will run spectra for schools. Others have mobile units that can be brought into schools. The same is true of some of the larger pharmaceutical companies. The Royal Society of Chemistry can provide advice.

Analytical techniques can be used to discuss the role of science in crime detection and how industry is regulated. This can raise ethical questions about individuals' and companies' rights and responsibilities that can be discussed and debated through role play, for example.

Opportunities for How Science Works

Data, evidence, theories and explanations

1a Students should be taught how scientific data can be collected and analysed.

Practical and enquiry skills

2b Students should be taught to collect data from primary or secondary sources, including ICT sources and tools.

2d Students should be taught to evaluate methods of collection of data and consider their validity and reliability as evidence.

Communication skills

3b Students should be taught to use both qualitative and quantitative approaches.

Applications and implications of science

4a Students should be taught about the use of contemporary scientific and technological developments and their benefits, drawbacks and risks.

Resources

Inspirational chemistry includes a chapter with some good introductory activities for UV (cold light) and infrared spectroscopy (chemical aerobics). There are example IR spectra that can be used for analysis.

CLEAPSS guide L202 includes NMR, IR and mass spectra for use with students.

www.atworkwithscience.com from GlaxoSmithKline gives virtual tours of analytical and research facilities and shows these techniques in context.

The RSC books *Modern chemical techniques, More modern chemical techniques* and *Cutting edge chemistry* all provide good background information for teachers new to these topics, although they are aimed more towards A-level teachers. They cover how the techniques work and how they are actually used in chemical research and analysis.

The Royal Society of Chemistry's Spectroscopy for Schools resource www.chemsoc.org/networks/learnnet/spectra/index.htm has video clips showing how IR, NMR and Mass spectrometers are operated as well as a database of spectra, and a tutorial. Again aimed at A-level but useful background.

http://riodb01.ibase.aist.go.jp/sdbs/cgi-bin/cre_index.cgi?lang=eng provides a comprehensive database of spectra: challenging to use but rich.

Chemical calculations

12. Moles, masses and volumes

Subject knowledge and challenging concepts

Calculations underpin many of the topics in GCSE Chemistry. Ideally, these should be used and practised repeatedly throughout the course rather than just taught within a discrete unit.

Teaching about moles and mole calculations is challenging and requires students to make links between the particle level and the macroscopic level. Students have no previous knowledge of the terminology and are often not used to working with large numbers. They need to be able to work confidently with ratios, and remember to convert to the correct units.

The unit for the amount of a substance is the mole. The mole contains 6×10^{23} particles (atoms, molecules or ions as appropriate). 6×10^{23} is the Avogadro constant, sometimes called Avogadro's number. It has the units mol^{-1}.

$$\text{The number of particles} = \text{Number of moles} \times \text{Avogadro's constant.}$$

One mole of an element that exists as atoms weighs the same as its relative atomic mass (RAM) in grams. The relative atomic mass of an element is the average mass of an atom of the element compared to the mass of 1/12th of an atom of Carbon-12.

One mole of a compound (or an element that exists as molecules) weighs the same as its relative formula mass (RFM) or relative molecular mass (RMM) in grams. The molar mass of an element or compound is defined as the mass, in grams, of one mole of an element or compound with units g/mol.

$$\text{Moles} = \frac{\text{Mass}}{\text{RFM}} \text{ (expressed in grams)}$$

or

$$\text{Moles} = \frac{\text{Mass g}}{\text{Molar mass gmol}^{-1}}$$

The term 'molar' in molar mass refers to the mass of a mole. This may be confused with the term 'molar' used for concentration, as in 2 molar (2 M) hydrochloric acid.

The empirical formula gives the simplest whole number ratio of each type of atom in a compound, eg the empirical formula of ethene (C_2H_4) is CH_2.

Mass is conserved during a chemical reaction. The number of one type of atom present in the reactants has to be the same in the products. This is known as the conservation of atoms law.

Molar gas volume: one mole of any gas, at room temperature and atmospheric pressure (r.t.p.) occupies $24dm^3$ or $24\,000cm^3$ or 24 litres. Room temperature is taken as 20°C and atmospheric pressure is 1.01×10^5 Pa.

$$\text{So number of moles of gas} = \frac{\text{volume (in dm}^3\text{)}}{24dm^3}$$

Concentration is the number of moles of solute in $1dm^3$ of solution. The units are mol/dm^3.

Teaching model examples

e(i)

1 The teacher tells students that a unit called a mole is used to measure the number of atoms or molecules in a substance.

2 Students are given a table of substances with the headings and some information.

Number of moles of …	Relative atomic/ formula masses	Has a mass of	Contains this number of particles	(If a gas) has this volume at room temperature and pressure
1 mole of carbon	12	12g		N/A
2 moles of carbon			12×10^{23}	N/A
0.5 moles of carbon				N/A
n moles of carbon		36g		N/A
1 mole of iron	56			N/A
10 moles of iron				N/A
1 mole of water			6×10^{23}	N/A
1 mole of carbon dioxide gas		44g		$24dm^3$
5 moles of hydrogen gas	2			$120dm^3$
And so on …				

3 Students fill in the table and come up with hypotheses for how many particles there are in one mole, and the relationships between RAM/RFM, mass and number of moles.

4 Students then use these relationships to carry out more complex calculations.

dit

1 The teacher gives students an explanation of the Avogadro constant and provides the rules linking relative atomic mass and number of grams per mole, and the relationship between moles and volumes of gas.

2 Students then use these rules to practise mole calculations.

3 They then proceed to using mole calculations with balanced equations to calculate percentage yields.

cm

1 Students discuss ideas about how they would know how many atoms are in a gram of carbon or how many molecules are in a gram of water.

2 They then consider how we deal with measuring large numbers in everyday life and consider terms such as a pair of doves, a dozen eggs, a ream of paper, £1 of pennies and a bushel of apples. Students consider how banks deal with customers who bring in £1 of pennies. Students are given a bag of pennies (and possibly a balance) and asked how they would go about telling how many pennies are in the pile quickly and without counting them. What is their value? What about if two pence pieces are considered?

3 The teacher tells them that chemists use a unit called the mole to measure how many particles are present. It is important to know the relationship between the number of particles present and mass so that we can use balanced equations to work out how much of a reactant we will need to make a certain amount of product.

4 The teacher tells the students that carbon is used as a reference and introduces Avogadro's number and the mole. Students are shown a mole of various substances, eg 18g of water, 56g of iron and so on.

5 Students return to answering the initial question.

Examples of investigations and demonstrations

Chemical calculations can be used alongside any number of experiments. Common ones include:

- finding the formula of a metal oxide by experiment
- heating copper oxide in a stream of hydrogen
- finding the number of moles of water of crystallisation in hydrated Cu (II) sulphate
- neutralisation reactions.

Classic chemistry experiments (68) provides details of measuring the volume of one mole of hydrogen gas.

Measuring the mass of purified precipitates obtained from the reactions described in the chemical detection give a quantitative measure of concentration. Comparing the actual and predicted amounts of chemicals obtained gives an opportunity to explore and explain measurement uncertainty through random and systematic errors, validity and reliability of data and the accuracy and precision of measurements.

Opportunities for How Science Works

Data, evidence, theories and explanations

1b Students should be taught how interpretation of data, using creative thought, provides evidence to test ideas and develop theories.

Communication skills

3b Students should be taught to use both qualitative and quantitative approaches.

3c Students should be taught to present information, develop an argument and draw a conclusion, using scientific, technical and mathematical language, conventions and symbols and ICT tools.

Centre-marked assessment opportunities

These chemical calculations are important for data analysis in many of the investigations used for centre-marked assessments, particularly for higher tier candidates.

Resources

Moles: a survival guide for science by Keith Brown provides a useful supplement for this topic. There are many practice worksheets available for chemical calculations, especially in the revision resources listed in Section 7.

Section 6
Managing a department to deliver Triple Science

For some departments, the provision and delivery of Triple Science will not be seen as a major area of development, especially if the school has a sixth form and if it has a successful track record of curriculum design and innovation. The curriculum coverage and resources may already be available and the confidence to approach this area may be strong.

However, for other departments it may be more of a challenge. They may be just as successful in terms of student attainment, but it may be that there are some aspects that cause particular issues, such as time management, funding or staff expertise. It is also the case that the requirement for all students with level 6 or higher in Key stage 3 Science to be offered Triple Science has arrived at a time when there are other significant changes in secondary science.

The desirable outcome, of course, is being able to offer an alternative curriculum pathway at Key stage 4, and one that may meet the learning needs and aspirations of a particular group of students. The pitfall, of course, is that if not delivered well it may only serve to dissuade students from studying science at A-level.

Here are some issues to consider.

Planning

As a department, consider your short-, medium- and long-term objectives for introducing Triple Science. How will these be achieved? Who will be involved, and how will you tell if you have been successful? It is important to brief all staff about the rationale behind the change and engage everyone in identifying and overcoming challenges and concerns.

Consideration should be given both to topics and the teaching and learning strategies that will be used. Regular meetings should be scheduled throughout the year to evaluate the impact of the changes and identify issues. Information can be shared and made accessible for future reference.

Issues relating to curriculum modelling and timetabling are considered in detail in the 'Curriculum modelling' publication.

Skills and expertise of staff

Staff delivering Triple Science need time for planning and preparation. Often the immediate concern is in terms of subject knowledge and there is seen to be a need for subject specialists. Remember that it is equally important to have the skills and tools to teach the subject effectively, which include:

- understanding key ideas from within the subject and how these are related to one another
- pedagogical content knowledge or knowing how to explain ideas and design effective learning activities
- enquiry activities, or knowing how to run demonstrations, manage experiments, and ask and answer associated questions.

There needs to be a clear view as to which of these is (or are) the significant development needs. Teachers being taught the subject knowledge in great detail by someone more knowledgeable in that subject may be no better off at the end if teaching and learning are not considered as well. It is often more likely to be teaching strategies and practical activities that are major stumbling blocks.

The wider team

Teaching assistants (TAs) will also need support. It may be that many of the students traditionally receiving more intensive support from a TA don't choose to do Triple Science, but some may, and students with a physical disability or at some points on the Autistic Spectrum may do so too. There are several points to make here:

- There is a good case for one or more TAs being higher level teaching assistants (HLTAs) and for support on Triple Science being part of their role. There is a greater range of concepts to address and a wider range of experiments to cover. The Training and Development Agency (TDA) for schools is currently running support programmes for HLTAs. For further details, contact your local authority HLTA officer or go to the TDA site at www.tda.gov.uk/support/hlta.aspx
- As some schools have Triple Science as a well-established and successful course there may be scope for TAs from one school to visit another school to see how support is best managed. This needs setting up carefully to ensure that there is good practice to be seen in the host school.
- Some schools have made tremendous progress in publishing schemes of work, often on the school's intranet. This is a huge help, especially when joint planning time may be limited.
- Lab technicians may well find themselves faced with preparing experiments and demonstrations with which they are not familiar. The second and third points above apply equally well to lab technicians. It is also important to ensure that technicians have immediate and direct access to the current version of the CLEAPSS health and safety CD-ROM and to the internet. There are some highly effective email networks that some technicians use and these can be very useful in the exchange of ideas. Contact your local authority to find out what is happening in your area. The Association for Science Education has a technicians' membership and active technicians' groups. Visit www.ase.org.uk

Continuing professional development (CPD)

Support from within the department

CPD needs arising from the introduction of Triple Science need to be identified and addressed, and this should be considered in the context of the TDA's Professional Standards and performance management framework (www.tda.gov.uk/teachers/professionalstandards.aspx).

There may well be a need for identifying off-site CPD opportunities, for planning CPD activities with a team of staff and for building in planning and evaluation time. This needs to be done realistically and invoking senior leadership team (SLT) support. School managers may well not be able to give everything they've been asked for, but it shouldn't be assumed that they can't give anything.

There are likely to be CPD opportunities within the department and school. This may mean working with another teacher to develop subject knowledge or observing lessons in your own subject or another. Explore new practical activities using a circus of experiments for both teachers and technicians to gain confidence, understand the key ideas and discuss concepts that will be difficult to teach. It may also be possible to arrange visits to other schools where Triple Science has been established.

It is worthwhile approaching CPD managers at school, local network, local authority and Science Learning Centre level to see what is available. The Specialist Schools and Academies Trust and Secondary National Strategy also offer a range of support, guidance and advice.

One of the most valuable outcomes of CPD is informal networking and this can pay dividends when developing new courses. The Triple Science Support Programme will provide training and consultancy for targeted schools, as well as networks, resource packs and an online community. Look out for meetings, events and conferences offered by the Association for Science Education, the Royal Society of Chemistry and the awarding bodies.

Specific CPD programmes to develop subject knowledge and pedagogy in chemistry are being piloted by the TDA. See www.tda.gov.uk/teachers/continuingprofessionaldevelopment/science_cpd.aspx

The Royal Society of Chemistry is currently offering a four-day course called 'Chemistry for non-specialists for Key stage 4 chemistry'. It has been extremely well received. See www.rsc.org/Education/Teachers/INSET/ChemNonSpec/

Resources

The additional content may not always require additional equipment, and there is an opportunity to revisit and update some of the experiments already in the department's schemes of work.

There will, however, need to be some clear advance planning with respect to equipment and consumables.

- Again, it is important that the SLT is kept informed so that its members have the opportunity to offer support where possible.
- It may be that there are opportunities to share or borrow some pieces of equipment from other schools, or from a university department. This might include class sets of glassware for practicals, eg making esters.
- Consider also microscale chemistry experiments that demonstrate the same principles but only require small amounts of chemicals.
- With resources it is important that the course doesn't become a succession of 'teachers' show and tell' with a heavy emphasis upon demonstration and fewer opportunities for students to consolidate learning. Resources provision needs to include materials that teachers can use with students to encourage speaking and listening, as well as the effective exploration of ideas.
- Consider new ways to incorporate internet resources. For example, the use of video clips is becoming widespread with the growth of web 2.0 and the provision of video projectors. Sites such as YouTube, blinkx.com and Planet Sci-Cast have meant that the ICT-confident teacher can now use a wide range of clips as stimulus material for discussions. However, this needs some planning and research as some sites are blocked by school firewalls.

Detailed advice and equipment lists can be found on the CLEAPSS website and the Practical Chemistry website, and support may be found through schools already offering Triple Science.

Health and safety

If Triple Science is a new development for a department it is likely that there will be practical activities being undertaken that are less familiar to teachers and lab technicians. It is therefore particularly important that the safety considerations are taken into account. In many cases, teachers and technicians will be drawing upon guidance included in published schemes of work. Often this is clear and well founded. CLEAPSS is regularly consulted by publishers. However, consultation doesn't always happen and it shouldn't be assumed; there have been a crop of issues as new practical and demonstration activities are proposed. CLEAPSS guidance on these is combined in one publication but is being repeatedly updated. It can be downloaded from the website (www.cleapss.org.uk) as PS67 – *Practical activities in the new science GCSEs.*

Section 7
Resources

For full details of these publications and more, please go to the LSN publication: *Resources for your Triple Science courses: GCSEs in biology, chemistry and physics*.

Textbooks (general)

Longman GCSE Chemistry
Pearson Longman
www.pearsonschoolsandfecolleges.co.uk/GlobalPages/NewLongman/NewLongman.aspx

Moles: a survival guide for science
Cambridge University Press
www.cambridge.org

New chemistry for you
Nelson Thornes
www.nelsonthornes.com/wps/portal

Books from the Royal Society of Chemistry

To browse all Royal Society of Chemistry books relevant to GCSE Chemistry, visit www.chemsoc.org/networks/learnnet/resources.htm and select ‘books’. Purchasing details are available for each book and many titles can be downloaded in full or in part. Ordering is also possible by telephoning 01223 432360.

Chemists in a social and historical context
By Dorothy Warren
www.rsc.org/shop/books/2001/9780854043804.asp

Classic chemistry demonstrations
By Ted Lister
www.rsc.org/shop/books/1996/9781870343381.asp

Classic chemistry experiments
By Kevin Hutchings
www.rsc.org/shop/books/2000/9780854049196.asp

Contemporary chemistry for schools and colleges (book and CD-ROM)
By Vanessa Kind
www.rsc.org/shop/books/2004/9780854043828.asp

Inspirational chemistry (book and CD-ROM)
By Vicky Wong
www.rsc.org/shop/books/2006/9780854043996.asp

Microscale chemistry
By J Skinner
www.rsc.org/shop/books/1998/9781870343497.asp

Textbooks (specification based)

AQA

AQA Chemistry for GCSE student book
Heinemann Educational
www.pearsonschoolsandfecolleges.co.uk

AQA Science: GCSE Chemistry: students’ book
Nelson Thornes
www.nelsonthornes.com/wps/portal
A teachers’ book is also available

Edexcel

GCSE Science for Edexcel: science student book
Collins Educational
www.collinseducation.com/Pages/default.aspx

OCR Gateway

Gateway Science: OCR Science for GCSE Chemistry student book
www.pearsonschoolsandfecolleges.co.uk/Secondary/Science/AssessmentforLearning/OCRGatewayScience/ISBN/StudentBook(s)/GatewayScienceOCRScienceforGCSEChemistryStudentBook.aspx

OCR Twenty First Century Science

Twenty First Century Science: GCSE Chemistry textbook
Oxford University Press
http://ukcatalogue.oup.com/product/9780199150502.do

Twenty First Century Science: GCSE Chemistry workbook
Oxford University Press
http://ukcatalogue.oup.com/product/9780199150540.do

Revision guides

AQA Chemistry revision guide
Lonsdale
www.lettsandlonsdale.com
A workbook and workbook answers are also available

AQA Science: GCSE Chemistry: revision guide
Nelson Thornes
www.nelsonthornes.com/wps/portal

GCSE Chemistry revision guide
Heinemann Educational
www.pearsonschoolsandfecolleges.co.uk
Titles are available that cover the AQA and OCR specifications

GCSE Chemistry: the revision guide
Coordination Group Publications
www.cgpbooks.co.uk/pages/home.asp
A workbook, including answers, is also available

Twenty First Century Science: GCSE Chemistry revision guide
Oxford University Press
ukcatalogue.oup.com/product/9780199152377.do

Doc Brown's Chemistry Clinic for online revision
www.docbrown.info

This excellent, non-commercial site is constantly evolving and expanding and will be of enormous use to all chemistry teachers and students. It contains a wide range of revision notes and quizzes to support any UK-based GCSE specification incorporating chemistry.

GCSE flashrevise cards, Science and Additional Science: Chemistry

50 colour cards, with four short questions on the front, with a brief explanation of the concept or topic and the answers to the questions, together with an examiner's note on the back. These could be used by teachers to revise or recap with the whole class. Alternatively, individual students could work through selected cards as an alternative to textbooks.

Philip Allan Updates
www.philipallan.co.uk

AQA GCSE Core and Additional Science topic cue cards: Chemistry

Each pocket-sized card in the set focuses on a key chemical concept or term, combining discussion of the concept with diagrams and a summary of key points.

Philip Allan Updates
www.philipallan.co.uk

BBC Bitesize

BBC Bitesize is an online revision site covering a range of subjects at various levels, with revision notes and test questions.

www.bbc.co.uk/schools/gcsebitesize

S-Cool

S-Cool is an online revision site with materials for a range of subjects including GCSE Chemistry. Each topic includes a checklist of the key ideas, a study guide, questions and a revision summary.

www.s-cool.co.uk

Books: background reading for teachers

Chemistry in the marketplace
By Ben Selinger
Allen & Unwin
www.allenandunwin.com

Molecules at an exhibition
By John Emsley
Oxford University Press
ukcatalogue.oup.com

Nature's building blocks – an A–Z guide to the elements
By John Emsley
Oxford University Press
ukcatalogue.oup.com

School chemistry experiments
By Ralph Farley
Association for Science Education
www.ase.org.uk/htm/book_store

Teaching chemistry to KS4
By Elaine Wilson
Hodder & Stoughton
www.bookpoint.co.uk

Teaching secondary chemistry
By Bob McDuell (editor)
ASE/John Murray Publications
www.ase.org.uk/htm/book_store

The cartoon guide to chemistry
By Larry Gonick and Craig Criddle
Harper Collins
www.harpercollins.com

The essential chemical industry
By E Hubbard, M Stephenson and D Waddington
Chemical Industry Education Centre, University of York
www.ciec.org.uk/resources/ordering.htm

The following books are available from the Royal Society of Chemistry and provide background reading for teachers. Visit www.chemsoc.org/networks/learnnet/resources.htm and select 'books'. Purchasing details are available for each book and some titles can be downloaded in full or in part. Ordering is also possible by telephoning 01223 432360.

- Access to chemistry
- The age of the molecule
- Chemical misconceptions – prevention, diagnosis and cure: volume 1: theoretical background
- Chemical misconceptions – prevention, diagnosis and cure: volume 2: classroom resources
- Cutting edge chemistry

ICT resources

Alchemy? Chemistry and industrial processes for schools and colleges

www.rsc.org/education/teachers/learnnet/alchemy/

There are 15 case studies of industrial processes in the chemical and pharmaceutical industry on this two-disc CD-ROM: aluminium, ammonia, chemicals from salt, copper refining, gases from the air, iron and steel, nitric acid, nylon, oil refining, polythene, sodium, sulphuric acid, combinatorial chemistry, computational chemistry and making medicines. The same content is provided on the internet.

Chemistry – workroom activities with EasySense 14+

www.data-harvest.co.uk

Chemistry experiments that can be done with Data Harvest's EasySense data-logging hardware.

Tel 01525 373666

Boardworks

www.boardworks.co.uk

Designed for whole-class teaching using the interactive whiteboard are these thousands of multimedia slides matched to the GCSE 2006 specifications. Although focused on GCSE Science and Additional Science, many of the topics are included in different awarding bodies' extension topics for GCSE Chemistry.

Crocodile Chemistry

www.crocodile-clips.com/en/Chemistry

Crocodile Chemistry is a simulated chemistry laboratory where you can model experiments and reactions safely and easily. The powerful software allows you to drag chemicals, equipment and glassware from the toolbars at the side of the screen and combine them as you wish. Reactions are modelled accurately as soon as you mix the chemicals, and analysis can be performed on the results.

Multimedia Science School 11–16 edition

www.science-school.co.uk/home.php

The software provides tools that can be purchased individually or in sets. There are 20 chemistry tools and these are most suitable for whole-class teaching with an interactive whiteboard.

Plato Learning UK
Tel 0870 908 6868

Science investigations 1 and 2

www.focuseducational.com

These interactive experiment simulations on CD-ROM allow students to practise enquiry skills.

Focus Educational Software Ltd
Tel 01872 241672

Science issues and the National Curriculum

www2.glos.ac.uk/science-issues

This multimedia learning package helps students understand the scientific ideas behind a range of topical issues, including matter and waste, atmosphere, energy, agriculture and health.

University of Gloucestershire
Tel 01242 714450

Sunflower Learning

www.sunflowerlearning.com

Sunflower for Science is a suite of curriculum-focused programs designed to help tackle tricky topics in biology, chemistry and physics. They can be tried before purchasing. Content can be accessed over the internet from Sunflower's website or via the school's virtual learning environment, so there is potential for independent student e-learning at school or at home. Chemistry topics covered include atoms and ions, bonding, diffusion, dissolving, elements, compounds and mixtures, periodic table, rates of reaction, solids, liquids and gases.

Using ICT to enhance teaching and learning in chemistry

Materials can be downloaded from www.chemsoc.org/networks/learnnet/ChemIT.htm

A hard copy can be purchased at www.rsc.org/education/teachers/learnnet/ChemIT.htm

This spiral-bound book and accompanying CD-ROM, by Steve Lewis, look at how to integrate ICT into chemistry teaching. Although more suitable for A-level Chemistry, teachers will find many of the resources and tips useful for GCSE as well.

Websites

Amazing Grades

www.amazing-grades.com

Select ‘sciences’ and then ‘chemistry’ to gain access to a list of websites, many of which are a useful source of teaching material.

American Chemical Society

www.acs.org/education

The American Chemical Society has an enhanced education site offering curriculum materials, professional development opportunities for mid-career chemists, student programmes and support for academic and industrial institutions.

At Work with Science – GlaxoSmithKline

www.atworkwithscience.com

This site is mainly aimed at teachers and students at Key stage 4 and in post-16 education. It supports applied science courses and parts of the statutory work-related learning framework introduced in September 2005. It gives a context to show how key skills and science are used in the pharmaceutical industry. There is an excellent virtual plant tour looking at analytical and synthetic chemistry labs, which may be useful for green chemistry and chemical detection topics.

Espresso Secondary

www.channel4learning.com/sites/clipbank/subjects/subject_science.html

Video clips can enhance lessons in a way that no other teaching resource can. If you want to use television in the classroom but don’t have the time for sourcing, cueing and viewing videos, then use ClipBank – all the hard work is done for you.

ChemFont

www.scs-intl.com/frameload.htm?/chemfont.htm

Download this free font package that simplifies the entry of chemical equations and notation.

Chemical Heritage Foundation

www.chemheritage.org

An American site with interactive activities on the history of chemistry.

Chemical Industry Education Centre

www.ciec.org.uk/secondary/teachers.htm

Links to the CIEC’s website on a variety of topics including catalysis, green chemistry, risk and sustainability.

Chemistry demonstrations with visual interest

www.chem.leeds.ac.uk/delights/texts/

This website includes 40 chemistry experiments that are illustrated and explained. The theme is very much the visual and/or aural effect and there are plenty of colour changes and explosions. There is also a photo library and animations. Safety aspects are described.

Chemistry videos and photographs

www.chemistry-videos.org.uk

Downloadable clips and images of chemistry experiments and demonstrations.

www.chemistryteachers.org

www.chemistryteachers.org

The Royal Society of Chemistry’s (RSC’s) website for busy chemistry teachers. It organises a wide range of RSC and other online resources by curriculum and specification topic, so teachers can quickly find what will be relevant to their teaching. It includes simulations, animations, videos, images, worksheets, extracts from RSC books, PowerPoint® presentations, Excel® spreadsheets and other websites. The resources for each search are listed from the most to least relevant.

ChemIT

www.chemit.co.uk

A website supported by the Royal Society of Chemistry that makes a range of ICT materials available to chemistry teachers. It includes simulations (Java Applets) for atomic and ionic radii, reaction rates and choice of indicator.

Chemsoc

www.rsc.org/chemsoc

A website from the Royal Society of Chemistry that is suitable for anyone interested in chemistry and the chemical sciences.

Chime

www.symyx.com/downloads/downloadable

Chime is a browser plug-in that renders 2D and 3D molecules directly within a web page. The molecules are 'live', meaning they are not just static pictures, but chemical structures that scientists can rotate, reformat and save in various file formats for use in modelling or database applications.

Creative Chemistry

www.creative-chemistry.org.uk

The site contains worksheets, information sheets and practical activities to support the GCSE specifications. There are also teaching notes for fun activities suitable for a chemistry club, chemistry puzzles, interactive revision quizzes, molecular models and advice for students to help improve their GCSE science investigations.

Games for chemistry

www.rsc.org/Education/SchoolStudents/Games.asp

This site provides a listing of games available to download for teaching chemistry. Further games can be downloaded from http://education.jlab.org/indexpages/elementgames.php

GCSE Chemistry

www.gcsescience.com/science-chemistry-enter.htm

This site contains over 400 pages and is aimed at 14–16 year olds. The pages summarise all that is required for GCSE courses in the UK.

The history of the periodic table

www.rsc.org/education/teachers/learnnet/periodictable/

The interactive periodic table allows searches for discovery before, after and between dates, by country and by discoverer, in tabular, histogram or list formats. There are also individual biographical details of the chemists mentioned in the main pages.

LearnNet

www.rsc.org/education/teachers/learnnet/index.htm

From the Royal Society of Chemistry, this is a huge, well-organised bank of resources and links for teachers and students. There are many free resources.

Jim Hebden's chemistry resources

www.bcscta.ca/resources/hebden/genhebden.htm

Another bank of excellent resources, this time from a chemistry teacher in Canada.

Molar mass calculator and concentration calculator

www.chemclub.com/teachers/download.html

The freeware available via this site consists of three parts. There is a 'solutions assistant', allowing the calculation of concentrations or mass required, a molar mass calculator and a data bank on properties of elements – accessed by clicking on that element in a periodic table.

Practical Chemistry

www.practicalchemistry.org

This newly established site from the Royal Society of Chemistry groups chemistry demonstrations and investigations into the major topics.

Teachers TV

www.teachers.tv

Select ‘subjects’ then ‘science’ to find a listing of chemistry videos including: Demonstrating chemistry: exciting elements, Periodic table: ferocious elements, Banging chemistry: fireworks and Banging chemistry: fast and furious.

Video clips of experiments

www.rsc.org/education/teachers/learnnet/videoclips.htm

A clear listing of downloadable clips from Teachers TV programmes and Royal Society of Chemistry DVDs.

WebElements

www.webelements.com

This is an outstanding site that will be of use to all chemistry teachers. Its aim is to provide a high-quality source of information on the World Wide Web relating to the periodic table. The site is a very large database of the elements and some of their compounds. There is key data for each element that includes its history, uses, simple compounds, electronic properties, physical properties, crystallography and nuclear properties. There are excellent associated graphics to display the data and trends.

Other resources

Chemical jigsaw

Interlocking pieces representing atoms, ions and bonds fit together to build models of ionic and covalent compounds. A CD-ROM of Flash animations and PowerPoint® presentations accompanies the resource.

Middlesex University Teaching Resources
Tel 01992 716052
www.mutr.co.uk

Molymod molecular models

A popular set of molecular models appropriate for GCSE Chemistry.

Spring Enterprises Ltd
01403 782387
www.molymod.com

Orbit molecular building system

Another modelling system. ‘Basic structures’ (ref 0046) is probably the most appropriate for GCSE. Ideal for building macro-molecular structures.

Cochranes of Oxford Ltd
Tel 01993 832868
www.cochranes.co.uk

Posters

The Royal Society of Chemistry has a range of posters to display in the chemistry classroom, including ‘Chemists in their element’, ‘Not all chemists wear white coats’, ‘That’s chemistry’ and ‘Spectroscopic techniques’.

www.rsc.org/education/teachers/learnnet/cflearnnet/resource_dets.cfm?subj=s

Education in Chemistry

The only magazine in the UK aimed at all chemistry teachers. It is written by its readers for its readers, and covers the whole spectrum of chemistry teaching: from balanced science in secondary courses to the final stages of undergraduate courses. Print and electronic subscriptions are available at a discounted rate to Royal Society of Chemistry members and Association for Science Education members. Some articles are available online.

www.rsc.org/Education/EiC/index.asp

Visits

Science centres and museums

Many museums devoted to science and natural history organise interesting visits for students of science GCSEs. For the official guide to UK museums, galleries, exhibitions and heritage, visit www.culture24.org.uk/home

The Association for Science and Discovery Centres (formerly Ecsite-uk): This network represents over 80 science centres, museums and discovery centres in the UK. Their purpose is to raise the profile of science centres and to establish their role as a forum for dialogue between science specialists and the public and as an informal learning resource for learners of all ages. Visit sciencecentres.org.uk

A regional selection of science museums includes:

Science Museum (London)

www.sciencemuseum.org.uk

Natural History Museum (London)

www.nhm.ac.uk

Explore At-Bristol (South West)

www.at-bristol.org.uk

Birmingham Science Museum (West Midlands)

www.thinktank.ac

Catalyst Science Museum (Widnes)

www.catalyst.org.uk

Museum of Science and Industry (North West)

www.mosi.org.uk

Whitby Wizard (Yorkshire and Humberside)

www.whitbywizard.com

Magna (Sheffield)

www.visitmagna.co.uk

Other resources

Royal Society of Chemistry

www.rsc.org

The Royal Society of Chemistry is Europe's largest organisation for advancing the chemical sciences. It has a substantial education department that caters for all ages, produces some excellent books, websites and journals, and offers CPD opportunities. The organisation for authoritative information on chemistry.

Royal Society of Chemistry,
Thomas Graham House,
Science Park, Milton Road,
Cambridge CB4 0WF
Tel 01223 420066

Nuffield Curriculum Centre

www.nuffieldcurriculumcentre.org

The Nuffield Curriculum Centre explores new approaches to teaching and learning by developing, managing and supporting curriculum projects such as Twenty First Century Science (in partnership with the Science Education Group at the University of York). The Nuffield Foundation also offers bursaries for students to experience real research.

Secondary National Strategy

www.standards.dfes.gov.uk/secondary

The strategy has developed many resources and materials for Key stage 3 and Key stage 4 that will be relevant to teaching and learning for Triple Science. Many of these are available online.

Science Enhancement Programme

www.sep.org.uk

The Science Enhancement Programme (SEP) supports science education in the UK by developing innovative, high-quality resources for secondary science at low cost, making them affordable and accessible to schools. It also offers development opportunities to improve classroom practice.

STEMNET

www.stemnet.org.uk

STEMNET aims to ensure that more young people in the UK make a choice to enter careers related to science, technology, engineering and mathematics (STEM) at all levels and that future generations are properly informed about the science and technology that surround them. With the support of a wide range of partners, the organisation brings STEM activities, experiences and excitement into classrooms throughout the UK, enhancing and enriching the curriculum. Its science and engineering ambassadors are available to work with schools to inspire young people. STEMNET is particularly strong on linking those companies and other organisations that employ STEM-educated people with schools, in such a way that young people can get a clear idea of the diverse and exciting range of careers available to them.

Research Councils UK

www.rcuk.ac.uk/sis/linksci.htm

Research Councils UK is a strategic partnership between the eight UK Research Councils. Its 'Science in society' programme has several different strands to support teachers in bringing contemporary research and researchers into the classroom. Of note are the 'Researchers in residence' initiative and the Nuffield bursaries.

Annex 1
GCSE Chemistry specifications at a glance

The following tables show at a glance how the content of GCSE Science, GCSE Additional Science and GCSE Chemistry (Extension) is broken down in each of the specifications offered by the awarding bodies.

AQA

Chemistry	Science Chemistry 1	Additional Science Chemistry 2	Extension Science Chemistry 3
Atomic structure, properties and bonding	• Atoms and molecules • Elements and compounds • Metals	• Electronic structure • Covalent, ionic and metallic bonding and structures • Introduction to Group 1 and Group 7 • Allotropes of carbon	• Periodic table and its development • Group 1 and Group 7 • Transition metals
Changing materials and chemical reactions	• Conservation of mass • Combustion • Reactivity of metals	• Reversible reactions • Equilibria • Rates of reaction • Catalysts • Energy changes • Electrolysis • Salts and solutions • Acids and bases	• Strong acids and bases • Solubility • Food, fuel and energy changes (quantitative)
Obtaining and using materials	• Limestone, quicklime and concrete • Rocks and metals: iron, steel, (smart) alloys, copper, aluminium and titanium. Recycling. • Crude oil, alkanes, alkenes, polymers, ethanol • Plant oils	• Developing new materials, eg nanoscience • Haber process	• Water
Earth and environ-mental sciences	• Earth and its atmosphere		
Chemical detection	• Chemical analysis for additives in food		• Ion detection, organic compounds (elemental analysis, unsaturated bonds) • Instrumental methods: gas-liquid chromatography, spectroscopy: atomic absorption, infrared, UV, NMR. Mass spectrometry • Titrations
Chemical calculations		• Relative atomic/formula masses, Moles • Chemical equations, percentage yield, atom economy	

Note that AQA offers two specifications (A and B). There are differences in the assessment structure but no differences in the content.

Edexcel360

	Science	Additional Science	Extension Science
Chemistry	5: Patterns in properties 6: Making changes 7: There's one Earth 8: Designer products	5: Synthesis 6. In your element 7: Chemical structures 8: How fast? How furious?	3: Chemical detection 4: Chemistry working for us
Atomic structure, properties and bonding	• Group 1, Group 7, Group 0, Transition metals • Periodic table and its development • Metals, non-metals • Atomic structure	• Covalent bonding – carbon, giant molecular structures • Metals and metallic bonding • Atomic structure and reactivity • Ionic bonding, giant ionic structures • Isotopes • Allotropes of carbon including fullerenes and nanotubes • Intermolecular forces	• Transition metals • Alkali metals
Changing materials and chemical reactions	• Alkali metals and water • Halide ion displacement • Rates of reaction • Energy changes • Neutralisation • Making salts • Dilute strong acids with metal oxides, carbonates and hydroxides • Oxidation and reduction • Reactivity of metals • Heating (hydrogen)carbonates • Combustion	• Cracking • Alloys • Electrolysis • Energy changes • Rates of reaction	• Electrolysis
Obtaining and using materials	• Extracting metals from ores and oxides • Uses of common compounds, hydrocarbons, burning • Precautionary principle • Recycling • Fuels: bio and fossil • Crude oil • Rock salt and sea water, and their products • Modern and smart materials and their properties • Nanoscience • Fermentation • Intelligent packaging • Emulsifiers	• Alkanes and alkenes • Making ethanol • Polymers: thermosetting and thermoplastics, cross linking • Stage synthesis in drug development • Haber process and fertilisers	• Water • Organic acids, alcohols and esters • Copper • Sodium carbonate and hydroxide • Sulphuric acid • Soap and detergent
Earth and environmental sciences	• Global warming models • Evolution of the atmosphere • Composition of air		
Chemical detection	• Flame tests • Using analytical data • Tests for gases	• Test for alkenes	• Tests for ions • Titrations
Chemical calculations		• Atom economy • Relative formula mass • Mass of products and reactants • Percentage yields	• Moles, masses and volumes in reactions

OCR Twenty First Century Science

	Science	Additional Science	Extension Science
Chemistry	C1: Air quality C2: Material choices C3: Food matters	C4: Chemical patterns C5: Chemicals in the natural environment C6: Chemical synthesis	C7: Further chemistry
Atomic structure, properties and bonding	• Small molecules	• Atomic structure • Periodic table • Metals and non-metals • Group 1, Group 7 • Ionic bonding and crystal lattices • Molecules and covalent bonding • Intermolecular forces • Giant covalent structures • Metallic structure and bonding	
Changing materials and chemical reactions	• Combustion • Chemical reactions: conservation and rearrangement of atoms • Polymerisation	• Alkali metals with water, chlorine and air • Oxidation • Reduction • Reactivity of metals • Electrolysis • Acids and bases/alkalis • Reactions of acids with metals, oxides, hydroxides and carbonates • Neutralisation • Rates of reaction	• Energy changes in reactions • Activation energy • Reversible reactions and equilibria • Strong and weak acids
Obtaining and using materials	• Fuels • Sulphur dioxide, carbon oxides, nitrogen oxides • Reducing atmospheric pollution • Polymers: natural and synthetic. Properties • Crude oil • Lifecycle assessment • Intensive and organic farming • Carbohydrates, proteins • Food additives and their properties inc. emulsifiers • Precautionary principle • Biochemistry of digestion	• Extracting metals from ores/oxides • Aluminium • Uses of metals and impact on the environment • Salts from the ocean • Silicon dioxide • Chemical synthesis	• Alcohols – production of ethanol • Carboxylic acids and esters • Fats and oils • (Un)saturated bonds • Green chemistry
Earth and environmental sciences	• Composition of the atmosphere • Pollutants • Nitrogen cycle	• Composition of the hydrosphere • Composition of the lithosphere • Composition of the biosphere • Oxygen and carbon cycles	
Chemical detection		• Flame tests • Atomic emission spectroscopy • Titrations	• Analytical procedures • Chromatography (paper, thin layer, gas) • Titrations • Test for ions
Chemical calculations		• Balancing equations • Ionic equations • Relative atomic/formula mass • Percentage yields	• Moles, masses and volumes in reactions

OCR Gateway

	Science	Additional Science	Extension Science
Chemistry	C1: Carbon chemistry C2: Rocks and metals	C3: The periodic table C4: Chemical economics	C5: How much? C6: Chemistry out there
Atomic structure, properties and bonding	• Covalent bonding	• Elements and compounds • Atomic structure • Ionic, covalent and metallic bonding • Periodic table • Giant ionic structures • Small molecules • Intermolecular forces • Group 1 • Group 7 • Transition metals • Allotropes of carbon inc. fullerenes	
Changing materials and chemical reactions	• Chemical changes in cooking • Heating $NaHCO_3$ and proteins • Oxidation • Solutes, solvents and solubility • Combustion – complete and partial • Energy changes • Heating carbonates • Electrolysis • Rusting • Rates of reaction	• Conservation of atoms in reactions • Reactions of alkali metals with water and with halogens • Oxidation as loss of electrons, reduction as gain of electrons • Electrolysis • Thermal decomposition of carbonates • Precipitation reactions • Acids and bases, pH • Neutralisation • Reactions of acids with metal oxides, metal hydroxides and carbonates • Solubility • Reversible reactions	• Oxidation and reduction • Water of crystallisation • Electrolysis • Strong and weak acids • Neutralisation • Reversible reactions and equilibria • Rates of reaction
Obtaining and using materials	• Food and food additives • Emulsifiers • Cosmetics: esters from alcohols and acids • Crude oil • Cracking • Fossil fuels • Alkanes and alkenes • Polymers • Fuels • Paints and pigments: colloids and emulsions • Marble, limestone and granite, glass, brick, aluminium and iron • Metals and alloys – copper, smart alloys, iron and aluminium	• Aluminium extraction • Uses of sulphuric acid • Fertiliser properties and preparation • Ammonia and the Haber process • Detergents • Batch and continuous processes • Drugs development and production • Nanochemistry • Purity of water	• Production of sulphuric acid • Fuel cells • Rust protection • Alcohols – production of ethanol • Salt • Ozone layer and CFCs • Water chemistry • Natural fats and oils • Analgesics
Earth and environmental sciences	• Earthquakes and volcanoes • Lithosphere and plate tectonics, igneous rock • Composition of air and pollutants		
Chemical detection	• Test for unsaturation	• Flame tests • Gas tests • Transition metal ion tests	• Quantitative analysis • Titrations
Chemical calculations		• Balanced equations • Relative atomic/formula masses • Percentage yield • Product and reactant masses	• Moles, masses and volumes in reactions • Empirical formulae

WJEC

	Science Chemistry 1	Additional Science Chemistry 2	Extension Science Chemistry 3
Atomic structure, properties and bonding	• Atomic structure • Periodic table (Mendeleev) • Metals and non-metals • Group 1 and Group 7 • Group 0 • Compounds	• Atomic structure • Metallic, ionic, simple molecular and giant covalent structures and bonding • Allotropes of carbon including nanoscience	
Changing materials and chemical reactions	• Chemical reactions for new materials • Energy changes • Rates of reaction • Catalyst • Combustion	• Reactivity series of metals • Oxidation and reduction • Electrolysis • Reversible reaction • Solubility	• Fuels • Strong and weak acids (vs. concentration) • Neutralisation • Thermal decomposition of carbonates
Obtaining and using materials	• Reactions of acids with metals, bases (alkalis), carbonates • Chemical industry • Nanoscience • Production and use of fuels: crude oil, combustion of fuels, acid rain	• Developing new materials • Production and use of metals: aluminium, iron, steel. Recycling – energy and greenhouse gases • Ammonia and Fertilisers. Haber Process • Alkanes, Alkenes and polymers • Smart materials: thermochromic/ photochromic paints, shape memory alloys and polymers, polymer gels • Water: treatment, temporary and permanent hardness	• Alkanes, alkenes • Ethanol production and uses • Ethanoic acid • Sulphuric acid: Contact process, reactions • Limestone, quicklime, slaked lime and cement
Earth and environmental sciences	• Atmosphere: origin, evolution, respiration, combustion, photosynthesis • Global warming • Geological processes: continental drift, earthquakes and volcanoes, lithosphere, plate tectonics, rock cycle, rock formation		
Chemical detection	• Flame tests, detection of halides • Test for carbonates	• Ammonium salts and ammonia	• Tests for alkenes, carboxylic acids • Flame tests, precipitation reactions for metal ions, tests for anions, tests for gases • Techniques: chromatography, distillation, filtration • Titrations
Chemical calculations		• Balanced equations • Relative atomic/ formula mass • Percentage yield • Atom economy	• Moles, masses and volumes in reactions

Annex 2
Teaching and learning models: bibliography and further reading

DfES (2004). *Pedagogy and practice: teaching and learning in secondary schools – Unit 2: Teaching models*, Department for Education and Skills (Ref: DfES 0425-2004 G).

DfES (2006). *Science subject leader development materials: Summer 2006*. Secondary National Strategy, Department for Education and Skills (Ref: 0274-2006DOC-EN).

DfES (2007). *Pedagogy and personalisation*, Department for Education and Skills (Ref: 00126-2007DOM-EN).

Joyce B, Calhoun E and Hopkins D (2002). *Models of learning: tools for teaching*, Open University Press (ISBN: 0335210155).

Gloucestershire LA (2007). *Pedagogy and practice – using different teaching models to support How Science Works*, Gloucestershire Local Authority (Ref: www.gloucestershire.gov.uk/schoolsnet/index.cfm?articleid=92914).

Secondary National Strategy (2006). *Theories of learning – a summary paper*, SNS Science Consultant Days 1 and 2, September 2006.

Annex 3
Assessment of How Science Works in different GCSE Science courses

AQA

AQA assesses How Science Works by means of written papers, practical skills assessment and an investigative skills assignment. It isn't, therefore, necessary to look for, select and run lesson activities for the purpose of assessing How Science Works objectives (although it will be necessary to deliver lessons that prepare students for their assessment).

Edexcel

Edexcel's Extension Chemistry C3 can be assessed either by a structured examination paper or a centre-devised internal assessment, which may be one integrated piece of work or several portfolio items. These pieces will be centre assessed and externally moderated by an examiner appointed by Edexcel. Candidates will be assessed on their ability to:

1 distinguish between and use primary and/or secondary data

2 demonstrate understanding of topics 'Chemical Detection' and 'Chemistry Working for Us'

3 discuss and evaluate evidence and data

4 consider the ethical, contemporary and social issues.

OCR Twenty First Century Science

OCR's Twenty First Century Science course has the Extension Chemistry in unit C7, which is assessed by means of terminal examination. Students also conduct (as part of GCSE Chemistry, but not necessarily drawing on contexts from Extension Chemistry) either a practical investigation or a practical data analysis task and a case study. It is likely that, at least to start with, students will be asked to use contexts drawn from the modules common to Science or Additional Science to ease internal standardisation practices. Nevertheless contexts could be drawn from those in C7 and so possibilities will be identified.

- In the **data analysis task**, candidates either singly or collaboratively take part in a practical procedure in order to collect primary data. Candidates are assessed on their ability to analyse and evaluate the data collected and the limitations of the techniques used.
- The **case study** should arise naturally from work on the course or from an issue that arises while candidates are following the course. It should be related to an aspect of science that involves an element of controversy, in terms either of the interpretation of evidence, or of the acceptability of some new development. Topics for study should be selected by candidates in discussion with teachers, and should be seen as an extension or consolidation of studies undertaken as a normal part of the course.
- The **practical investigation**, in addition to confirming the predicted effect of a variable on a system over a range, also includes more speculative investigation of systems where no clear prediction can be made in advance; for example, where there is little relevant explanatory theory available in the course, or where the experimental material is likely to be variable (eg in surveys of distribution of species). It will be assessed on the strategy deployed, the collection and interpretation of data, evaluation and presentation.

OCR Gateway

OCR's Gateway course has the Extension Chemistry in units C5 and C6, which are assessed by means of terminal examination. Students also conduct (as part of GCSE Chemistry, but not necessarily drawing on contexts from Extension Chemistry) either 'can-do' tasks and 'Science in the news' or a research study, data tasks and practical skills. It is likely that, at least to start with, students will be asked to use contexts drawn from the modules common to Science or Additional Science to ease internal standardisation practices. Nevertheless contexts could be drawn from those in C5 and C6 and so possibilities will be identified.

- **'Can-do' tasks** provide opportunities to demonstrate practical capabilities and explore the ways in which scientific evidence is collected. These are monitored and recorded throughout the course as the candidate fulfils them.
- The report on **'Science in the news'** aims to give candidates an insight into how science is reported to the public, the validity of underlying research and claims or recommendations made based on the research. Candidates are required to use stimulus material provided by OCR and other sources of information to research the way in which scientific data and ideas are dealt with by the media. The number of reports attempted is at the discretion of the centre, but the results of only one may be submitted.
- In the **research study**, candidates are required to use stimulus material provided by OCR and other sources of information to research scientific ideas.
- In the **data task**, candidates are required to analyse and evaluate data and to plan further work (which will not be carried out).
- For **practical skills**, the ability to carry out practical tasks safely and skilfully is assessed holistically.

WJEC

WJEC's Extension Chemistry, Chemistry 3, is assessed by a terminal examination. The internal assessment for GCSE Science and GCSE Additional Science consists either of practical work provided by WJEC or work written by centres for completion wholly during class time and marked by teachers according to a mark scheme provided/approved by WJEC or of a centre-assessed extended report. In addition, candidates for GCSE Chemistry may, as an alternative, submit a written 'investigatory planning exercise', marked by the centre using board criteria. For each of the separate science qualifications, Biology, Chemistry and Physics, no more than one extended report or investigatory planning exercise may be submitted. It is likely that, at least to start with, students will be asked to use contexts drawn from the modules common to Science or Additional Science to ease internal standardisation practices. Nevertheless, contexts could be drawn from those in C3 and so possibilities will be identified.

In the **assessment of the practical task**, the candidate is guided through a practical activity, which could be laboratory- or field-based and which arises from the relevant subject content of the specification. The awarding body provides a range of such activities for each of the specifications, including a specific candidate worksheet, a list of laboratory or field requirements, teacher guidance and a marking scheme.

A second aspect of the internal assessment scheme is the **extended report**. Various aspects of the specifications lend themselves to a different style of enquiry-based approach, with students investigating, discussing and reporting. This is especially, but not exclusively, the case with those areas of the specification that involve social, ethical and political issues and effects, such as GM technology, the siting of wind farms or mobile phone masts, for which science informs but does not determine the debate.

The **investigatory planning exercise** recognises the greater experience of these candidates in scientific investigatory work and takes the form of a paper exercise in which the candidate plans an experimental activity involving either an investigation into the relationship between variables or a forensic-style investigation. The stimulus for this activity arises out of the experience of Sc1 investigations and is included to enable candidates to demonstrate their scientific competence arising from carrying out their own investigations previously.

Annex 4
LSN science publications

Triple Science GCSEs: collaborative approaches

The Triple Science Support Programme (TSSP) provides advice and guidance on models of effective collaborative delivery between providers, in the form of a booklet that deals with science at Key stage 4. The booklet is essential reading for all who have an interest in developing and sustaining partnerships.

Learning and Skills Network, 2007
Free
Tel 0845 071 0800
www.triplescience.org.uk

Triple Science GCSEs: curriculum planning and design

This publication provides managers and others with practical advice on how to plan, develop and model the Triple Science requirement – taking into account all the critical factors that need to be considered.

Learning and Skills Network, 2007
Free
Tel 0845 071 0800
www.triplescience.org.uk

Resources for your Triple Science courses

LSN's guide lists many of the resources available for delivering Triple Science courses. Sections cover books; non-books, such as multimedia packs and CD-ROMs; websites; national organisations; and nationally available continuing professional development programmes.

Learning and Skills Network, 2007
ISBN 9781845726472
Free
Tel 0845 071 0800
www.triplescience.org.uk

Teaching Triple Science: GCSE Biology
Teaching Triple Science: GCSE Physics

LSN has commissioned another two subject-specific publications aimed at helping practitioners tackle some of the main issues in delivering the separate sciences. Written by acknowledged experts in these subject areas, the books provide practitioners with up-to-date and useful guidance on:

- the major differences between Double and Triple Science
- teaching and learning modules, particularly focusing on areas known to be delivered poorly in schools
- teaching resources and assignments to promote student-centred problem-solving activities.

Learning and Skills Network, 2007
Teaching Triple Science:
GCSE Biology ISBN 9781845726485
Teaching Triple Science:
GCSE Physics ISBN 9781845726508
Free
Tel 0845 071 0800
www.triplescience.org.uk

Annex 5
TSSP frequently asked questions

What is Triple Science?

Triple Science is a combination of three GCSEs in biology, chemistry and physics. It will normally be a course of study for students in Years 10 and 11. It provides the fullest coverage of biology, chemistry and physics at Key stage 4, including all of the compulsory Programme of Study for science, provided all three GCSEs are taken during the Key stage.

What's new about Triple Science?

In September 2006, new science GCSEs, including Biology, Chemistry and Physics, were introduced. These incorporated a new Programme of Study for Key stage 4 and included a wider range of science GCSEs (see below). Since September 2007, there has been a new statutory entitlement for all students to study science courses leading to at least two GCSEs. From September 2008, all students achieving at least level 6 at Key stage 3 will be entitled to study Triple Science. This need not all be in their own school, for example, it could be through collaborative arrangements with other schools, FE colleges and universities. Also from September 2008, all specialist science schools will be required to offer Triple Science at least to all students achieving level 6+ at the end of Key stage 3.

How does Triple Science relate to other science GCSEs?

Awarding bodies (examination boards) have devised suites of qualifications that can be studied to three different extents. The minimum required science (sometimes called 'the core'), which covers the required Programme of Study, is a single science GCSE including some biology, chemistry, physics, astronomy, environmental and Earth sciences. The expected normal extent of science study (previously 'double award') includes a second 'Additional Science' GCSE, with more of all these areas of science. The separate GCSEs in biology, chemistry and physics add further content to this. This enables science classes to be taught common content and then for some students to cover additional material.

What are the differences between Triple Science and other science GCSEs?

The difference is only one of extent of coverage of the subject. There are differences between GCSE suites in the content to be covered and the nature and timing of the assessment, but these apply to the single science and Additional Science GCSEs as well as the separate sciences. Features that were emphasised in the 2006 revision of Key stage 4 science, such as 'How Science Works' and a requirement for contemporary applications of science, apply to all courses. All GCSEs have a common grading system for standards.

What are the advantages of studying Triple Science?

The courses cover a more extensive range of subject matter and provide the best preparation for entry to A-level in the respective subjects. The Government is encouraging the take-up of Triple Science because there is evidence that the students are more likely to continue to study science at the post-compulsory stage. This is an important element in the Government's economic strategy.

What extra science do students study compared with a two-science GCSE course?

Awarding bodies are free to select the additional content for these courses and therefore the content varies widely. Full details are available on their websites (see below). Here are some examples:

- **Biology**: Micro-organisms (AQA, OCR Gateway, WJEC); Biotechnology (Edexcel, OCR C21st, WJEC); Behaviour (Edexcel); Transport in plants and animals (AQA, WJEC); Human physiology (OCR C21st).
- **Chemistry**: Analysis (most); Chemical production (Edexcel, OCR Gateway, WJEC); Energy changes (AQA, OCR C21st); Organic (OCR C21st, WJEC).
- **Physics**: Electromagnetic induction (AQA, WJEC); Motion (AQA, WJEC); Particle and nuclear physics (Edexcel, WJEC); Astronomy (AQA, OCR C21st); Satellite technology (OCR Gateway); Medical physics (Edexcel); Electronics (OCR Gateway).

What ways are there of timetabling the study of Triple Science?

Most schools and colleges run the three separate subjects in parallel through Years 10 and 11. This can be partially combined with a course leading to a single or two-science GCSE because of the common content (see above). Where the subjects are taught in collaboration between centres, other arrangements may be needed.

Can students study a single separate science (ie only biology, chemistry or physics)?

All Key stage 4 students (Years 10 and 11, aged 14–16) are required to cover the Programme of Study for science. A single science subject, other than GCSE Science itself, will not do this. However, it can be studied in conjunction with the single 'core' science, or by a student over the age of 16.

Who offers Triple Science qualifications?

The following awarding bodies offer the full range of science GCSEs:

AQA www.aqa.org.uk

Edexcel www.edexcel.com

OCR www.ocr.org.uk

WJEC www.wjec.co.uk

Any centre can register for any course but because of the interconnected way that suites of qualifications are offered (see above), centres may prefer to choose the same suite for single science, Double Science and Triple Science.

What about entry level?

These are qualifications, usually called 'Certificate of Science', suitable for those who are not likely to gain GCSE passes at either grades A*–C (Level 2) or D–G (Level 1). They are covering the Programme of Study for Key stage 4 but have a very different assessment system.

What help is available to introduce Triple Science?

The DCSF has contracted with LSN to raise awareness of, and provide support for, increased take-up of Triple Science GCSEs, through the Triple Science Support Programme.

What is LSN?

The Learning and Skills Network is an independent, not-for-profit organisation committed to making a difference in post-14 education and training. We support schools, colleges and other learning providers. We do this through delivering government-funded quality improvement and staff development programmes; through research, training and consultancy; and through providing high-quality resources for teachers and lecturers.

What is the Triple Science Support Programme (TSSP)?

The Triple Science Support Programme has been set up to support the following DCSF policy objectives:

- to enable all young people with level 6 and above in science at Key stage 3 to study Triple Science GCSEs from September 2008
- to help specialist science schools offer Triple Science to their students from September 2008.

These aims arise directly from the 'Science and innovation investment framework 2004–2014: next steps' discussion paper, which outlines strategies to halt the decline in young people doing Physics and Chemistry A-level and therefore increase the numbers of professional scientists in the UK. This programme has been funded by the DCSF. All publications, networks and newsletters will be delivered without charge to maintained secondary schools. The training and consultancy will be available to targeted Triple Science schools only.

When is it available?

The programme is being prepared now and should be up and running from September 2008. Detailed information will be added to the website as it becomes available.

What does TSSP offer?

The TSSP comprises the following:

- the programme website: www.triplescience.org.uk
- a programme newsletter
- publications on: collaboration and partnership; raising attainment in Triple Science; curriculum modelling, timetabling and Triple Science
- three subject-specific resources on the separate sciences
- Triple Science networks of support for practitioners
- an audit of resources for Triple Science
- an offer of three days' consultancy per targeted school (around the topics above)
- a marketing campaign around Triple Science for schools.

If you wish to register an interest in the programme information, please contact the LSN helpline on 0845 071 0800 or e-mail triplescience@lsnlearning.org.uk

How will LSN target schools for training and consultancy?

LSN will be offering training and consultancy to a set of 300 schools that seem particularly suited to offering the full Triple Science but currently do not. Among the criteria being used to identify the potential schools will be whether they:

- offer one or two of the three science GCSEs
- have a critical mass of students attaining level 6+ science but not offering all three science GCSEs.

LSN will also consult with its partners on the selection.

What's on the TSSP website?

- Triple Science content
- How Science Works
- Teaching and learning
- Managing Triple Science
- The Triple Science community
- LSN support.

What other forms of support are available?

Events and CPD opportunities from the Secondary National Strategy, ASE, Science Learning Centres and the awarding bodies may help in implementing your choices and developing a greater understanding of 'How Science Works'. An overview of information about these can be found on the ASE website. QCA has also set up a forum, allowing you to raise questions and share ideas, that can be accessed online at www.qca.org.uk/qca_8058.aspx Other groups are identifying resources that support the new approaches and, within the ASE, some are looking at existing materials (such as Science upd8 and SATIS) to see how these can be matched to the new specifications.

Where is further information available on current developments in science at Key stage 4?

Association for Science Education
www.ase.org.uk

The Royal Society
royalsociety.org

Institute of Physics
www.iop.org

Royal Society of Chemistry
www.rsc.org/education

Institute of Biology
www.iob.org

Qualifications and Curriculum Authority
www.qca.org.uk/qca_8058.aspx

Twenty First Century Science Project
www.21stcenturyscience.org/home

OCR www.ocr.org.uk

AQA www.aqa.org.uk

Edexcel www.edexcel.com

WJEC www.wjec.co.uk

CCEA www.ccea.org.uk

This is a subject-specific publication to support teachers in the delivery of the new Triple Science GCSEs. It focuses on GCSE Chemistry, and particularly on the content that extends Additional Science to the Triple Science GCSEs. For science teachers, those teaching outside their specialism and subject leaders responsible for implementing Triple Science GCSEs in their departments. The book includes: effective teaching and learning approaches; ideas for delivering key topics through investigations, demonstrations and other activities; and comparisons of awarding body specifications for Science, Additional Science and Extension Science (Chemistry).

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Making learning work
lsnlearning.org.uk