

# Advanced Higher Chemistry Draft Course/Unit Support Notes



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Please refer to the note of changes at the end of this document for details of changes from previous version (where applicable).

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# Introduction

These support notes are not mandatory. They provide advice and guidance on approaches to delivering and assessing the Advanced Higher Chemistry Course. They are intended for teachers and lecturers who are delivering the Course and its Units. They should be read in conjunction with the *Course Specification*, the *Course Assessment Specification* and the *Unit Specifications* for the Units in the Course.

These support notes cover both the Advanced Higher Course and the Units in it.

Draft

# General guidance on the Course/Units

## Aims

The aims of the Course are to enable learners to:

- ◆ develop a critical understanding of the role of chemistry in scientific issues and relevant applications, including the impact these could make on the environment/society
- ◆ extend and apply knowledge, understanding and skills of chemistry
- ◆ develop and apply the skills to carry out complex practical scientific activities, including the use of risk assessments, technology, equipment and materials
- ◆ develop and apply inquiry and investigative skills, including planning and experimental design
- ◆ develop and apply scientific analytical thinking skills, including critical evaluation of experimental procedures
- ◆ extend and apply problem solving skills in a chemistry context
- ◆ further develop an understanding of scientific literacy, using a wide range of resources, in order to communicate complex ideas and issues and to make scientifically informed choices
- ◆ extend and apply skills of independent/autonomous working in chemistry

## Progression

In order to do this Course, learners should have achieved the Higher Chemistry Course.

Learners who have achieved this Advanced Higher Course may progress to further study, employment and/or training. Opportunities for progression include:

- ◆ Progression to further/higher education
  - For many learners a key transition point will be to further or higher education, for example to Professional Development Awards (PDAs), Higher National Certificates (HNCs) or Higher National Diplomas (HNDs) or degree programmes. Examples of further and higher education programmes that learners doing the Course might progress to include medicine, law, dentistry, veterinary medicine, engineering, environmental or health sciences.
  - Advanced Higher Courses provide good preparation for learners progressing to further and higher education as learners doing Advanced Higher Courses must be able to work with more independence and less supervision. This eases their transition to further/higher education. Advanced Higher Courses may also allow 'advanced standing' or partial credit towards the first year of study of a degree programme.

- Advanced Higher Courses are challenging and testing qualifications — learners who have achieved multiple Advanced Higher Courses are regarded as having a proven level of ability which attests to their readiness for education in higher education institutions (HEIs) in other parts of the UK as well as in Scotland.
- ◆ Progression to employment
  - For many learners progression will be directly to employment or work-based training programmes. Examples of employment opportunities and training programmes are careers in oil and gas exploration, renewable energy development, engineering, technology, pharmaceuticals, environmental monitoring, forensics, research and development, management, civil service, and education.

This Advanced Higher is part of the Scottish Baccalaureate in Science. The Scottish Baccalaureates in Expressive Arts, Languages, Science and Social Sciences consist of coherent groups of subjects at Higher and Advanced Higher level. Each award consists of two Advanced Highers, one Higher and an Interdisciplinary Project which adds breadth and value and helps learners to develop generic skills, attitudes and confidence that will help them make the transition into higher education or employment.

## Hierarchies

**Hierarchy** is the term used to describe Courses and Units which form a structured progression involving two or more SCQF levels.

It is important that any content in a Course and/or Unit at one particular SCQF level is not repeated if a learner progresses to the next level of the hierarchy. The skills and knowledge should be able to be applied to new content and contexts to enrich the learning experience. This is for centres to manage.

- ◆ Chemistry Courses from National 3 to Advanced Higher are hierarchical.
- ◆ Courses from National 3 to National 5 have Units with the same structure and titles.

## Skills, knowledge and understanding covered in this Course

Teachers and lecturers should refer to the *Course Assessment Specification* for mandatory information about the skills, knowledge and understanding to be covered in this Course.

# Approaches to learning and teaching

The purpose of this section is to provide you with advice on learning and teaching. It is essential that you are familiar with the mandatory information within the Advanced Higher Chemistry *Course Assessment Specification*.

Advanced Higher Courses place more demands on learners as there will be a higher proportion of independent study and less direct supervision. Some of the approaches to learning and teaching suggested for other levels (in particular, Higher) may also apply at Advanced Higher level but there will be a stronger emphasis on independent learning.

As with the Higher Chemistry Course, learning at Advanced Higher level is still expected to be experiential, active, challenging and enjoyable. It should include appropriate practical experiments/activities and could be learner led. A variety of active learning approaches is encouraged, including peer teaching and assessment, individual and group presentations, and game-based learning with learner-generated questions.

For Advanced Higher Courses, a significant amount of learning may be self-directed and require learners to demonstrate a more mature approach to learning and the ability to work on their own initiative. This can be very challenging for some learners, who may feel isolated at times, and teachers and lecturers should have strategies for addressing this. These could include, for example, planning time for regular feedback sessions/discussions on a one-to-one basis and on a group basis led by the teacher or lecturer (where appropriate).

Centres should be aware that although the mandatory knowledge and skillset may be similar in Higher and Advanced Higher Courses, there may be differences in the:

- ◆ depth of underpinning knowledge and understanding
- ◆ complexity and sophistication of the applied skills
- ◆ ways in which learners will learn: namely, they will take more responsibility for their learning at Advanced Higher and work more autonomously

All learning and teaching should offer opportunities for learners to work collaboratively. Practical activities and investigative work can offer opportunities for group work, which should be encouraged. Laboratory work should include the use of technology and equipment that reflects current scientific use in chemistry.

Learners, especially at Advanced Higher, would be expected to contribute a significant portion of their own time in addition to programmed learning time.

Effective partnership working can enhance the science experience. Where feasible, locally relevant contexts should be studied, with visits where this is possible. Guest speakers from eg industry, further and higher education could be used to bring the world of chemistry into the classroom.

An investigatory approach is encouraged in Chemistry, with learners actively involved in developing their skills, knowledge and understanding by investigating a range of relevant chemistry-related applications and issues. A holistic approach should be adopted to encourage simultaneous development of learners' conceptual understanding and skills. Where appropriate, investigative work/experiments, in Chemistry, should allow learners the opportunity to select activities and/or carry out extended study. Investigative and experimental work is part of the scientific method of working and can fulfil a number of educational purposes.

Teachers and lecturers should encourage learners to use an enquiring, critical and problem-solving approach to their learning. Learners should also be given the opportunity to practise and develop research and investigation skills and higher order evaluation and analytical skills.

The use of information and communications technology (ICT) can make a significant contribution to the development of these higher order skills as research and investigation activities become more sophisticated. ICT can make a significant contribution to practical work in Advanced Higher Chemistry, in addition to the use of computers as a learning tool. Computer interfacing equipment can detect and record small changes in variables allowing experimental results to be recorded over long or short periods of time. Results can also be displayed in real-time helping to improve understanding. Data-logging equipment and video cameras can be set up to record data and make observations over periods of time longer than a class lesson that can then be downloaded and viewed for analysis.

## **Skills of scientific experimentation, investigation and inquiry**

Learners should acquire scientific skills through a series of learning experiences, investigations and experimental work set in the contexts described in the content statements and supplementary notes of the Course specification. These skills should be developed throughout the Course using a variety of case studies, practical activities and other learning experiences as appropriate. Some activities and experiences will lend themselves to developing particular skills more than others. For example some practical activities will be particularly suitable for developing planning and designing skills, some for presenting and analysing data skills and others for the skill of drawing conclusions. In selecting appropriate activities and experiences teachers and lecturers should identify which skills are best developed in each activity to ensure the progressive development of all skills and to support candidates' learning.

Laboratory work should include the use of technology and equipment that reflects current scientific use in chemistry. Appropriate risk assessment must be undertaken. Learners should have the opportunity to become familiar with the apparatus, practical techniques and data-analysis strategies indicated below:

| Learners would benefit from being familiar with the following apparatus, practical techniques and activities  | Learners should be able to process experimental results by:  |
|---|--|
| <ul style="list-style-type: none"> <li>◆ Digital balance</li> <li>◆ Buchner or Hirsch or sintered glass funnel</li> <li>◆ Glassware with ground glass joints ('Quickfit' or similar)</li> <li>◆ Thin layer chromatography apparatus</li> <li>◆ Weighing by difference and gravimetric analysis</li> <li>◆ Preparing a standard solution</li> <li>◆ Using a reference or control or blank determination</li> <li>◆ Carrying out a complexometric titration</li> <li>◆ Carrying out a back titration</li> <li>◆ Using a colorimeter or visible spectrophotometer and carrying out dilution to prepare a calibration graph</li> <li>◆ Distilling</li> <li>◆ Refluxing</li> <li>◆ Using vacuum filtration methods</li> <li>◆ Recrystallising</li> <li>◆ Determining % yield experimentally</li> <li>◆ Using thin-layer chromatography</li> <li>◆ Using melting point apparatus and mixed melting point determination</li> <li>◆ Using a separating funnel and solvent extraction</li> </ul> | <ul style="list-style-type: none"> <li>◆ Representing experimental data using a scatter graph</li> <li>◆ Sketching lines or curves of best fit</li> <li>◆ Calculating mean values for experiments</li> <li>◆ Identifying and eliminating rogue points from the analysis of results</li> <li>◆ Qualitative appreciation of the relative accuracy of apparatus used to measure the volume of liquids. Learners would be expected to know that the volume markings on beakers provide only a rough indication of volume. While measuring cylinders generally provide sufficient accuracy for preparative work, for analytic work, burettes, pipettes and volumetric flasks are more appropriate</li> <li>◆ Appreciating that when a measurement has been repeated, any variations in the value obtained give an indication of the reproducibility of the technique</li> <li>◆ Knowing that the uncertainty associated with a measurement can be indicated in the form, <i>measurement ± uncertainty</i>. Learners are not expected to conduct any form of quantitative error analysis</li> <li>◆ Quantitative stoichiometric calculations</li> <li>◆ Interpretation of spectral data</li> </ul> |

Learners will engage in a variety of learning activities as appropriate to the subject, details of approaches and contexts are suggested in Appendix 1.

Teachers and lecturers should support learners by having regular discussions with them and giving regular feedback. Some learning and teaching activities may be carried out on a group basis and, where this applies, learners could also receive feedback from their peers.

Teachers and lecturers should, where possible, provide opportunities to personalise learning for learners, and to enable them to have choices in approaches to learning and teaching. The flexibility in Advanced Higher Courses and the independence with which learners carry out the work lend themselves to this. Teachers and lecturers should also create opportunities for, and use, inclusive approaches to learning and teaching. This can be achieved by encouraging the use of a variety of learning and teaching strategies which suit the needs of all learners. Innovative and creative ways of using technology can also be valuable in creating inclusive learning and teaching approaches.

Centres are free to sequence the teaching of the Course, Units, key areas and Outcomes in any order they wish. For example:

- ◆ Each Unit could be delivered separately in any sequence.  
**And/or**
- ◆ All Units may be delivered in a combined way as part of the Course. If this approach is used, the Outcomes within Units may either be partially or fully combined.

Learning about Scotland and Scottish culture will enrich the learners' learning experience and help them to develop the skills for learning, life and work they will need to prepare them for taking their place in a diverse, inclusive and participative Scotland and beyond. Where there may be opportunities to contextualise approaches to learning and teaching to Scottish contexts in this Course, this could be done through mini-projects or case studies.

## **Developing skills for learning, skills for life and skills for work**

It is important that learners are aware of the skills for learning, skills for life and skills for work that they are developing in the Course and the activities they are involved in that provide realistic opportunities to practise and/or improve these skills. Teachers and lecturers should ensure that learners have opportunities to develop these skills as an integral part of their learning experience.

At Advanced Higher level it is expected that learners will be using a range of higher order thinking skills. They will also develop skills in independent and autonomous learning.

Learners are expected to develop broad generic skills as an integral part of their learning experience. The *Course Specification* lists the skills for learning, skills for life and skills for work that learners should develop through this Course. These are based on SQA's *Skills Framework: Skills for Learning, Skills for Life and Skills for Work* and must be built into the Course where there are appropriate opportunities. The level of these skills will be appropriate to the level of the Course.

For this Course, it is expected that the following skills for learning, skills for life and skills for work will be significantly developed:

### **Literacy**

Writing means the ability to create texts which communicate ideas, opinions and information, to meet a purpose and within a context. In this context, 'texts' are defined as word-based materials (sometimes with supporting images) which are written, printed, Braille or displayed on screen. These will be technically accurate for the purpose, audience and context.

#### **1.1 Reading**

Learners will understand and interpret a variety of scientific texts.

#### **1.2 Writing**

Learners use skills to effectively communicate key areas of chemistry, make informed decisions and explain, clearly, chemistry issues in various media forms. Learners will have the opportunity to communicate applied knowledge and understanding throughout the Course.

There will be opportunities to develop the literacy skills of listening and reading, when gathering and processing information in Chemistry.

### **Numeracy**

This is the ability to use numbers in order to solve problems by counting, doing calculations, measuring, and understanding graphs and charts. This is also the ability to understand the results.

Learners will have opportunities to extract, process and interpret information presented in numerous formats including tabular and graphical. Practical work will provide opportunities to develop time and measurement skills.

#### **2.1 Number processes**

Number processes means solving problems through carrying out calculations, when dealing with data and results from experiments/investigations and everyday class work, making informed decisions based on the results of these calculations and understanding these results, for example stoichiometric calculations.

#### **2.2 Money, time and measurement**

The accuracy of measurements is important when handling data in a variety of chemistry contexts, including practical and investigative. Consideration should be given to uncertainties.

#### **2.3 Information handling**

Information handling means being able to gather and interpret chemistry data in tables, charts and other graphical displays to draw sensible conclusions throughout the Course. It involves interpreting the data and considering its reliability in making reasoned deductions and informed decisions. It also involves an awareness and understanding of the chance of events happening.

### **Thinking skills**

This is the ability to develop the cognitive skills of remembering and identifying, understanding and applying.

The Course will allow learners to develop skills of applying, analysing and evaluating. Learners can analyse and evaluate practical work and data by reviewing the process, identifying issues and forming valid conclusions. They can demonstrate understanding and application of key areas and explain and interpret information and data.

#### **5.3 Applying**

Applying is the ability to use existing information to solve chemistry problems in different contexts, and to plan, organise and complete a task such as an investigation.

#### **5.4 Analysing and evaluating**

This covers the ability to identify and weigh-up the features of a situation or issue in chemistry and to draw valid conclusions. It includes reviewing and considering any potential solutions.

#### **5.5 Creating**

This is the ability to design something innovative or to further develop an existing thing by adding new dimensions or approaches. Learners can demonstrate their creativity, in particular, when planning and designing chemistry experiments or investigations. Learners have the opportunity to be innovative in their approach. Learners also have opportunities to make, write, say or do something new.

In addition, learners will also have opportunities to develop working with others and citizenship.

### **Working with others**

Learning activities provide many opportunities, in all areas of the Course, for learners to work with others. Practical activities and investigations, in particular, offer opportunities for group work, which is an important aspect of chemistry and should be encouraged.

### **Citizenship**

Learners will develop citizenship skills, when considering the applications of chemistry on our lives, as well as the implications for the environment/society.

# Approaches to assessment

Assessment in Advanced Higher Courses will generally reflect the investigative nature of Courses at this level, together with high-level problem-solving and critical thinking skills and skills of analysis and synthesis.

This emphasis on higher order skills, together with the more independent learning approaches that learners will use, distinguishes the added value at Advanced Higher level from the added value at other levels.

There are different approaches to assessment, and teachers and lecturers should use their professional judgement, subject knowledge and experience, as well as understanding of their learners and their varying needs, to determine the most appropriate ones and, where necessary, to consider workable alternatives.

Assessments must be fit for purpose and should allow for consistent judgements to be made by all teachers and lecturers. They should also be conducted in a supervised manner to ensure that the evidence provided is valid and reliable.

## Unit assessment

Units will be assessed on a pass/fail basis. All Units are internally assessed against the requirements shown in the *Unit Specification*. Each Unit can be assessed on an individual Outcome-by-Outcome basis or via the use of combined assessment for some or all Outcomes.

Assessments must ensure that the evidence generated demonstrates, at the least, the minimum level of competence for each Unit. Teachers and lecturers preparing assessment methods should be clear about what that evidence will look like.

Sources of evidence likely to be suitable for Advanced Higher Units could include:

- ◆ meaningful contributions to group work and/or discussions (making use of log books, blogs, question and answer sessions to confirm individual learners have met the required standards)
- ◆ presentation of information to other groups and/or recorded oral evidence
- ◆ exemplification of concepts using (for example) a diagram
- ◆ interpretation of numerical data
- ◆ practical demonstration with commentary/explanation/narrative
- ◆ investigations
- ◆ answers to multiple choice questions
- ◆ short written responses
- ◆ extended response essay-type questions

Evidence should include the use of appropriate subject-specific terminology as well as the use of real-life examples where appropriate.

Flexibility in the method of assessment provides opportunities for learners to demonstrate attainment in a variety of ways and so reduce barriers to attainment.

The structure of an assessment used by a centre can take a variety of forms, for example:

- ◆ individual pieces of work could be collected in a folio as evidence for Outcomes and Assessment Standards
- ◆ assessment of each complete Outcome
- ◆ assessment that combines the Outcomes of one or more Units
- ◆ assessment that requires more than the minimum competence, which would allow learners to prepare for the Course assessment

Teachers and lecturers should note that learners' day-to-day work may produce evidence which satisfies assessment requirements of a Unit, or Units, either in full or partially. Such naturally-occurring evidence may be used as a contribution towards Unit assessment. However, such naturally-occurring evidence must still be recorded and evidence such as written reports, recording forms, PowerPoint slides, drawings/graphs, video footage or observational checklists provided.

## **Combining assessment across Units**

A combined approach to assessment will enrich the assessment process for the learner, avoid duplication of tasks and allow more emphasis on learning and teaching. Evidence could be drawn from a range of activities for a combined assessment. Care must be taken to ensure that combined assessments provide appropriate evidence for all the Outcomes that they claim to assess.

Combining assessment will also give centres more time to manage the assessment process more efficiently. When combining assessments across Units, teachers/lecturers should use e-assessment wherever possible. Learners can easily update portfolios, electronic or written diaries and recording sheets.

For some Advanced Higher Courses, it may be that a strand of work which contributes to a Course assessment method is started when a Unit is being delivered and is completed in the Course assessment. In these cases, it is important that the evidence for the Unit assessment is clearly distinguishable from that required for the Course assessment.

## **Preparation for Course assessment**

Each Course has additional time which may be used at the discretion of the teacher or lecturer to enable learners to prepare for Course assessment. This time may be used near the start of the Course and at various points throughout the Course for consolidation and support. It may also be used for preparation for Unit assessment, and, towards the end of the Course, for further integration, revision and preparation and/or gathering evidence for Course assessment.

For this Advanced Higher Course, the assessment methods for Course assessment are question paper and project. Learners should be given opportunities to practise these methods and prepare for them.

Examples of activities to include within this preparation time include:

- ◆ Preparing for the components of Course assessment, for example:
  - preparing for non-question paper components — selecting topics, gathering and researching information/data, evaluating and analysing findings, developing and justifying conclusions, presenting the information/data (as appropriate)
  - practising question paper techniques and revising for the question paper

In relation to preparing for the project, teachers and lecturers should explain requirements to learners and the amount and nature of the support they can expect. However, at Advanced Higher level it is expected that learners will work with more independence and less supervision and support.

## Authenticity

In terms of authenticity, there are a number of techniques and strategies to ensure that learners present work that is their own. Teachers and lecturers should put in place mechanisms to authenticate learner evidence.

In Advanced Higher Courses, because learners will take greater responsibility for their own learning and work more independently, teachers and lecturers need to have measures in place to ensure that work produced is the learner's own work.

For example:

- ◆ regular checkpoint/progress meetings with learners
- ◆ short spot-check personal interviews
- ◆ checklists which record activity/progress
- ◆ photographs, films or audio records

Group work approaches are acceptable as part of the preparation for assessment and also for formal assessment, where appropriate. However, there must be clear evidence for each learner to show that the learner has met the Evidence Requirements.

For more information, please refer to SQA's *Guide to Assessment*.

## Added Value

Advanced Higher Courses include assessment of added value which is assessed in the Course assessment.

Information given in the *Course Specification* and the *Course Assessment Specification* about the assessment of added value is mandatory.

In Advanced Higher Courses, added value involves the assessment of higher order skills such as high-level and more sophisticated investigation and research skills, critical thinking skills and skills of analysis and synthesis. Learners may be required to analyse and reflect upon their assessment activity by commenting on it and/or drawing conclusions with commentary/justification. These skills contribute to the uniqueness of Advanced Higher Courses and to the overall higher level of performance expected at this level.

In the assessment for this Course, added value will focus on the following:

- ◆ challenge — requiring greater depth or extension of knowledge and/or skills
- ◆ application — requiring application of knowledge and/or skills in practical or theoretical contexts as appropriate

In this Course, added value consists of a question paper and a project.

- ◆ The question paper is used to assess whether the learner can retain and consolidate the knowledge and skills gained in individual Units. It requires learners to demonstrate aspects of challenge and application. Learners will apply breadth and depth of skills, and the various applications of knowledge — such as reasoning, analysing, evaluating and solving problems from across the Course to answer questions in chemistry.
- ◆ The project is used to assess a wide range of high-order cognitive and practical skills and to bring them together, such as skills relating to planning, analysis, synthesis and evaluation. The project requires learners to apply skills of scientific inquiry, using related knowledge, to carry out a meaningful and appropriately challenging task in chemistry and communicate findings. The learner will carry out a significant part of the work for the project independently with minimal supervision.

# Equality and inclusion

It is recognised that centres have their own duties under equality and other legislation and policy initiatives. The guidance given in these *Course/Unit Support Notes* is designed to sit alongside these duties but is specific to the delivery and assessment of the Course.

It is important that centres are aware of and understand SQA's assessment arrangements for disabled learners, and those with additional support needs, when making requests for adjustments to published assessment arrangements. Centres will find more guidance on this in the series of publications on Assessment Arrangements on SQA's website: [www.sqa.org.uk/sqa/14977.html](http://www.sqa.org.uk/sqa/14977.html).

The greater flexibility and choice in Advanced Higher Courses provide opportunities to meet a range of learners' needs and may remove the need for learners to have assessment arrangements. However, where a disabled learner needs a reasonable adjustment/assessment arrangements to be made, you should refer to the guidance given in the above link.

The following should be taken into consideration:

| Situation  | Reasonable adjustment   |
|--|---|
| Carrying out practical activities  | Use could be made of practical helpers for learners with: <ul style="list-style-type: none"><li>◆ physical disabilities, especially manual dexterity, when carrying out practical activities</li><li>◆ visual impairment, who have difficulty distinguishing colour changes or other visual information</li></ul> |
| Reading, writing and presenting text, symbolic representation, tables, graphs and diagrams | Use could be made of ICT, enlarged text, alternative paper and/or print colour and/or practical helpers for learners with visual impairment, specific learning difficulties and physical disabilities   |
| Process information using calculations   | Use could be made of practical helpers for learners with specific cognitive difficulties (eg dyscalculia)   |
| Draw a valid conclusion, giving explanations and making generalisation/predictions         | Use could be made of practical helpers for learners with specific cognitive difficulties or autism  |

# Appendix 1: Further information on Units in the Course

## Inorganic and Physical Chemistry

- ◆ Electromagnetic radiation and atomic spectra
- ◆ Atomic orbitals, electronic configurations and the Periodic Table
- ◆ Shapes of molecules and polyatomic ions
- ◆ Transition metals
- ◆ Chemical equilibrium
- ◆ Reaction feasibility
- ◆ Kinetics

| Mandatory Course key areas  | Suggested learning activities   | Exemplification of key areas  |
|---|---|---|
| <b>Electromagnetic radiation and atomic spectra</b><br>Electromagnetic waves<br>The relationship $c = f\lambda$ | Education Scotland produced curriculum support staff notes for current Electronic Structure and the Periodic Table, and also for Principles of Chemical Reactions. These booklets have lots of suitable extra activities and teaching applications.<br>An internet search on CD or DVD spectroscope will produce many sites with simple instructions which allow learners to make individual spectroscopes from any unwanted CDs or CD-ROMs. For example, Arvind Gupta toys spectroscope.<br>An online and printable electromagnetic spectrum is available from the Royal Society of Chemistry (search RSC learnnet electromagnetic spectrum printable). The speed of light can be taken as $3.00 \times 10^8 \text{ m s}^{-1}$ (see Data Booklet). Frequency is often quoted in Hz, which is the same as $\text{s}^{-1}$ . | <b>Electromagnetic radiation and atomic spectra</b><br>Electromagnetic radiation may be described in terms of waves and can be characterised in terms of wavelength and/or frequency. The relationship between these quantities is given by $c = f\lambda$ where $c$ represents the speed of light, $f$ represents the frequency of the wave ( $\text{s}^{-1}$ ) and $\lambda$ represents the wavelength (m). When radiation in the visible part of the electromagnetic spectrum is being described, it is common to specify wavelength in nanometres (nm). |

| Mandatory Course key areas  | Suggested learning activities  | Exemplification of key areas   |
|---|--|--|
| <p>Dual nature of electromagnetic radiation — waves and particles</p> <p>The relationships <math>E = hf</math> and <math>E = Lhf</math></p> | <p>A video on the dual nature of light can be found on the internet (search Quantum mechanics: the dual nature of light — youtube). Use <math>h = 6.63 \times 10^{-34}</math> Js (see Data Booklet). For Avogadro's constant, use <math>L = 6.02 \times 10^{23}</math> mol<sup>-1</sup> (see Data Booklet). To get <math>E</math>, in kJ mol<sup>-1</sup>, it is more convenient to use <math>E = Lhf/1000</math> or <math>E = Lhc/1000</math>. <math>L</math> is the number of formula units in one mole of the substance. (Formula units can be atoms, molecules or groups of ions depending on how the formula is usually written and on the type of bonding structure present.)</p>  | <p>When electromagnetic radiation is absorbed or emitted by matter, it appears to behave more like a stream of particles than as a wave. These particles are known as photons. When a photon is absorbed or emitted, energy is gained or lost by electrons within the substance. The photons in high frequency radiation can transfer greater amounts of energy than photons in low frequency radiation. The energy associated with a single photon is given by <math>E = hf</math> where '<math>h</math>' represents Planck's constant. For chemists, it is more convenient to express the energy associated with a mole of photons which is given by <math>E = Lhf</math> giving the energy in J mol<sup>-1</sup> where <math>L</math> represents Avogadro's constant.</p> |
| <p>Atomic emission</p> <p>Evaluation of evidence for energy levels in atoms of elements</p>   | <p>Learners can observe atomic emission by carrying out flame tests. Methods for this can be found by searching for RSC flame test. The flames can be looked at through a spectroscope to show emission spectra. The RSC website gives more information.</p> <p>Spectacular demonstration versions in which an alcohol spray is used to produce coloured flames over a metre long could also be used. See the RSC website and in the RSC publication 'Classic Chemistry Demonstrations' No. 34 page 80. Search RSC flame colours — a demonstration.</p> <p>To view an atomic emission spectrum, a simple hand-held spectroscope can be used to view a vapour discharge lamp or, if good blackout conditions are available, from a flame test. Fluorescent tube lamps, commonly used for classroom lighting, contain mercury vapour. If a spectroscope is used to view an illuminated fluorescent</p> | <p>When energy is transferred to atoms, electrons within the atoms may be promoted to higher energy levels. To allow the electrons to return to their original levels, energy must be lost from the atom. This energy is released in the form of a photon. The spectrum of light emitted (atomic emission spectrum) is not continuous, but consists of a series of lines at discrete frequencies. This phenomenon provides direct evidence for the existence of discrete (quantised) energy levels for electrons. An atom can be considered as emitting a photon of light energy when an electron moves from a higher energy level to a lower energy level. Each element produces a unique pattern of frequencies of radiation in its emission spectrum.</p>                 |

| Mandatory Course key areas   | Suggested learning activities  | Exemplification of key areas  |
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|  | <p>lamp, a series of purple lines from the atomic emission spectrum of mercury can be observed.</p> <p>SSERC activity with filter paper soaked in brine to observe sodium spectrum. A useful resource on spectroscopy and the identification of elements from emission spectra can be found on the 800mainstreet.com website (search spectroscopy element identification and emission spectra 800 main street). SSERC is currently developing an instrument using a camera or phone with a diffraction grating attachment.</p>   |   |
| <p>Atomic spectroscopy<br/>Atomic emission spectroscopy and atomic absorption spectroscopy and how they are used to identify and quantify the elements present in a sample</p> | <p>Resources describing atomic absorption are available from the RSC (search RSC atomic absorption or CHP atomic absorption spectroscopy). Interesting anecdotes can be provided of the forensic uses of atomic absorption spectroscopy. For example, the investigation of toxic levels of heavy metals in Isaac Newton's hair due to his alchemical pastimes or the high levels of lead in men's hair treated with hair products to reduce greyness. Search RSC learnNet anecdotes lead in hair.</p> <p>A free science video by 'Brightstorm' on atomic emission spectra is available (search atomic emission spectra youtube brightstorm2).</p> <p>Videos on use of spectroscopy in astronomy, on the spectrum of stars and on the absorption and emission spectra of hydrogen are also available (search atomic emission spectra youtube brightstorm2).</p> <p>Astronomy-spectroscopy -1/3 youtube (spot the error on atomic size)</p> <p>Astronomy-spectroscopy -2/3 youtube (does show temp in °K (sic))</p> <p>Spectrum of stars 1/2 youtube</p> | <p>Atomic emission spectroscopy and atomic absorption spectroscopy are used to identify and quantify the elements present in a sample. In absorption spectroscopy, electromagnetic radiation is directed at an atomised sample. Radiation is absorbed as electrons are promoted to higher energy levels. An absorption spectrum can be produced by measuring how a sample's transmission of light varies with wavelength.</p> <p>In emission spectroscopy, high temperatures are used to excite the electrons within atoms. As the electrons drop to lower energy levels, photons are emitted. An emission spectrum can be produced by measuring how much light is emitted at different wavelengths.</p> <p>Each element produces a characteristic absorption/emission spectrum which can be used to identify that element. In atomic spectroscopy, the concentration of an element within a sample is related to the intensity of light emitted or absorbed.</p> |

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|   | <p>Forensic ink analysis (search <a href="#">forensic</a> ink analysis youtube).</p> <p>A very useful website from uoregon.edu has an applet which shows the absorption and emission spectra of most elements just by clicking on the appropriate element on a Periodic Table. Search for University of Oregon elements. Light from a sodium lamp passing through a sodium flame from, say, a sodium pencil produces a shadow when projected on to a white screen.</p>  |   |
| <p><b>Atomic orbitals, electronic configurations and the Periodic Table</b></p> <p>The four quantum numbers used to describe any electron within an atom</p> <p>The shapes of s, p and d orbitals</p> | <p>Electrons, behave as standing waves within the atom. Wave mechanics tells us that there are different shapes and sizes of standing waves possible around the nucleus, which are known as orbitals.</p> <p>The circumference of the standing wave is always equal to an integral number of wavelengths. The principal quantum number, n, is the circumference of the orbital in terms of the number of wavelengths.</p> <p>Revised Higher 2(a) atomic orbital notes page 28.</p> <p>The RSC website has pages which offer very clear and attractive representations of orbitals with accompanying text which refers to the wave nature of the electron. A free science video by 'Brightstorm' covers quantum numbers but this is beyond the level required and would need some previous teaching or learning. Search for Quantum numbers Brightstorm youtube.</p> | <p><b>Atomic orbitals</b></p> <p>The discrete lines observed in atomic emission spectra can be explained if electrons, like photons, display the properties of particles and waves. Within the atom, electrons behave as waves and there are different sizes and shapes of wave possible around the nucleus. These are known as orbitals and each can hold a maximum of two electrons. The four quantum numbers are:</p> <ul style="list-style-type: none"> <li>◆ the principal quantum number, n</li> <li>◆ the angular momentum quantum number, l</li> <li>◆ the magnetic quantum number, m</li> <li>◆ the spin magnetic quantum number, s</li> </ul> |

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|   | <p>A Sci-Comm video showing 3D models helping to visualise s, p and d orbitals is available. The RSC website has an animation which can be used to illustrate the absorption and emission of light by an atom. It can also be run set at 'Orbital Model' and shows a pictorial representation of the orbitals and labels them using the "1s" "2p" type of nomenclature, but search orbital diagrams Brightstorm youtube.</p>                 |  |
| <p>Electronic configuration including:</p> <ul style="list-style-type: none"> <li>◆ aufbau principle</li> <li>◆ Hund's rule</li> <li>◆ Pauli exclusion principle</li> </ul> | <p>A free science video by 'Brightstorm' covers orbital box diagrams and covers the aufbau principle, Pauli exclusion principle and Hund's rule. Another free science video by 'Brightstorm' (brightstorm.com) covers electronic configurations. Search the aufbau principle.</p> <p>Teachers/lecturers may wish to introduce only elements 1–20 at first and return to the remaining elements during the coverage of transition metals.</p> | <p><b>Electronic configurations of atoms in the ground state</b></p> <p>Any atom can only have a maximum of two electrons within any single orbital. The aufbau principle states that electrons fill orbitals in order of increasing energy. The relative energies corresponding to each orbital can be represented diagrammatically for the first four shells of a multi-electron atom. In an isolated atom the orbitals within each subshell are degenerate. Hund's rule states that when degenerate orbitals are available, electrons fill each singly, keeping their spins parallel before spin pairing starts. The Pauli exclusion principle states that no two electrons in the one atom can have the same set of four quantum numbers. As a consequence, no orbital can hold more than 2 electrons and the 2 electrons must have opposite spins. Electronic configurations using spectroscopic notation and orbital box notation can be written for elements of atomic numbers 1 to 36.</p> |

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| <p>Structure of the of the Periodic Table</p> <p>The Periodic Table is subdivided corresponding to electron configurations</p>   | <p>f-orbitals are not assessable</p>  | <p>The Periodic Table can be subdivided into four blocks (s, p, d and f) corresponding to the outer electronic configurations of the elements within these blocks.</p>   |
| <p>Ionisation energies as evidence for electron configurations</p> <p>The relative values of first, second and subsequent ionisation energies can be evaluated in terms of the stabilities of different subshell electron configurations</p> | <p>A graph of first ionisation energies against atomic number shows blips, which gives good evidence of s and p orbitals being filled.</p>  | <p>The variation in first, second and subsequent ionisation energies with increasing atomic number for the first 36 elements can be explained in terms of the relative stability of different electronic configurations, and so provides evidence for these electronic configurations.</p>   |
| <p>VSEPR rules</p> <p>Apply VSEPR rules to determine shapes of molecules and polyatomic ions</p>   | <p>Although valence shell electron pair repulsion (VSEPR) theory does not provide an accurate description of the actual molecular orbitals in a molecule, the shapes predicted are usually quite accurate. The RSC has links to sites allowing the 3D display of molecules with different numbers of bonding and non-bonding pairs. Search Cheml Ed home page then search for molecular orbitals.</p> <p>Alternatively, search:</p> <ul style="list-style-type: none"> <li>◆ davidson edu molecular orbitals (both need 3D java)</li> <li>◆ chemmy bear shapes of molecules gives animated shapes</li> <li>◆ beavon clara orbitals contents is an animation showing molecular shapes but has no commentary</li> </ul> | <p>The arrangement of electron pairs is linear, trigonal planar, tetrahedral, trigonal bipyramidal and octahedral when the total number of bonding and non-bonding electron pairs is 2, 3, 4, 5 and 6, respectively. Electron pair repulsions decrease in strength in the order: non-bonding pair/non-bonding pair &gt; non-bonding pair/bonding pair &gt; bonding pair/bonding pair. These different strengths of electron pair repulsion account for slight deviations from expected bond angles in molecules such as NH<sub>3</sub> and H<sub>2</sub>O.</p> |

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| <p><b>Transition metals</b><br/>Electronic configuration of transition metal atoms and ions and the anomalies of the model explained</p>  | <p>A striking display can be made by creating a set of sample bottles containing salts or compounds of the first 30 elements. If these are then positioned on an A1 or A2 sized Periodic Table poster it is striking that only the d-block compounds are coloured. Learners may also notice that zinc compounds are white — indicating that, although lying in the central region of the Periodic Table, zinc is different from the transition metals. Scandium is also different since it forms only the 3<sup>+</sup> ion which has no d electrons. A short 'Brightstorm' video on 'Exceptions to electron configurations' covers the electronic configurations of Cr and Cu.</p>  | <p><b>Transition metals</b><br/>The d-block transition metals are metals with an incomplete d subshell in at least one of their ions. The filling of the d orbitals follows, with the exception of chromium and copper atoms. These exceptions are due to a special stability associated with the d subshell being half filled or completely filled. When atoms from the first row of the transition elements form ions it is the 4s electrons which are lost first rather than the 3d electrons.</p>   |
| <p>Oxidation states of transition metals</p> <p>Oxidation numbers of transition metal ions</p> <p>Using changes in oxidation number of transition metal ions to determine whether oxidation or reduction has occurred</p> | <p>Zinc is used to reduce a solution of yellow ammonium vanadate(V) to a mauve solution containing vanadium(II) ions. The intermediate oxidation states of vanadium(IV) (blue) and vanadium(III) (green) are also seen. See the RSC website and also the RSC publication 'Classic Chemistry Demonstrations' No. 92 page 258.</p> <p>Another video resource can be found at Chemistry-oxidation of vanadium youtube.</p> <p>A similar experiment using zinc amalgam is also shown in a one-minute video produced by the Open University. Can also do similar experiment with oxidation states of Mn.</p> <p>Bromfield Honors Chemistry video 'Assigning Oxidation Numbers' covers all the main points for assigning oxidation numbers. Search blinkx.com assigning-oxidation-numbers.</p> <p>A website which is a series of questions and answers on oxidation numbers is available. It is good but fast. It is best done as revision after oxidation numbers have been</p> | <p>Oxidation states of transition metals</p> <p>An element is said to be in a particular oxidation state when it has a specific oxidation number. The oxidation number can be determined by following certain rules. Transition metals exhibit variable oxidation states of differing stability. Compounds of the same transition metal but in different oxidation states may have different colours. Oxidation can be considered as an increase in oxidation number and reduction can be considered as a decrease in oxidation number. Compounds containing metals in high oxidation states tend to be oxidising agents whereas compounds with metals in low oxidation states are often reducing agents.</p> |

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|  | taught. Search 9.1.2 assigning Oxidation Numbers youtube.   |   |
| <b>Ligands</b><br>Bonding of ligands in transition metal complexes<br><br>Classification of ligands<br>Coordination number<br>Naming complex ions according to IUPAC rules | Instructions for carrying out a microscale investigation into the chemistry of the transition elements, looking at their redox and precipitation reactions is available from the RSC website. Search RSC - learn Chemistry - microscale chemistry transition elements.  | <b>Ligands</b><br>Ligands may be negative ions or molecules with non-bonding pairs of electrons which they donate to the central metal atom/ion forming dative bonds. Ligands can be classified as monodentate, bidentate up to hexadentate. The total number of bonds from the ligands to the central transition metal atom/ion is known as the co-ordination number. Complexes are written and named according to IUPAC rules.                  |
| Explanation of colour in transition metal complexes  | An interesting introduction into colour in transition metal compounds is through the production of coloured glass. More can be found in the RSC publication 'Classic Chemistry Experiments' No.44 page 112 and on the RSC website. This allows learners to make glass and then colour some glass using transition metal oxides. RSC publication 'Classic Chemistry Demonstrations No. 93 page 261 shows different colours of nickel complexes with water and ethylenediamine as ligands in different ratios. The chemguide.co.uk website has pages which cover colours of transition metal complexes. Opportunity for learners to find out about the spectrochemical series and investigate how the position of ligand in the series may affect the colour and paramagnetism of the complex. Prepare solutions containing $\text{Cu}^{2+}(\text{aq})$ , $\text{Ni}^{2+}(\text{aq})$ , $\text{Co}^{2+}(\text{aq})$ . (Concentrations are not important but concentrated enough to have characteristic colours.) Add conc HCl to provide $\text{Cl}^-$ ions as ligands and concentrated $\text{NH}_3(\text{aq})$ to provide $\text{NH}_3$ molecules as ligands. See colour changes due to differences in energy levels between d orbitals. Original | In a complex of a transition metal the d orbitals are no longer degenerate. The energy difference between subsets of d orbitals depends on the ligand. Colours of many transition metal complexes can be explained in terms of d-d transitions. Light is absorbed when electrons in a lower energy d orbital are promoted to a d orbital of higher energy.<br>If light of one colour is absorbed, then the complementary colour will be observed. |

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|   | solutions have H <sub>2</sub> O molecules as ligands.  |  |
| UV and visible absorption of transition metal complexes   | A UV-visible spectrometer measures the intensity of radiation transmitted through a sample, and compares this with the intensity of incident radiation. Determination of Mn in steel (PPA from unrevised AH). The wavelength ranges are approximately 200–400 nm for ultra-violet and 400–700 nm for visible light.  | Ultra-violet and visible absorption spectroscopy involve transitions between electron energy levels in atoms and molecules where the energy difference corresponds to the ultra-violet and visible regions of the electromagnetic spectrum.  |
| Catalysis by transition metals<br><br>Transition metals and their compounds can act as catalysts  | Hydrogen peroxide oxidises potassium sodium tartrate (Rochelle salt) to carbon dioxide. The reaction is catalysed by cobalt(II) chloride. The colour of the cobalt(II) chloride turns from pink to green (an activated complex), returning to pink again as the reaction dies down. Details of the experiment are available from the RSC publication 'Classic Chemistry Demonstrations' page 1 and also from their website. Search for RSC Classic Chemistry Demonstrations a visible activated complex. (The experiment may have been done at Higher but at AH discussion would involve oxidation states.)  | It is believed that the presence of unpaired d electrons or unfilled d orbitals allows intermediate complexes to form, providing reaction pathways with lower activation energies compared to the uncatalysed reaction. The variability of oxidation states of transition metals is an important factor. Homogeneous and heterogeneous catalysts should be explained in terms of changing oxidation states with the formation of intermediate complexes and the adsorption of reactive molecules onto active sites respectively. |
| <b>Chemical equilibrium</b><br>Equilibrium expressions, factors affecting equilibria and calculation of the composition of the equilibrium mixtures | Try to ensure links to organic chemistry through pK <sub>a</sub> values and buffers are constantly reinforced as well as links within the Unit itself. Nclark.net and beckerdemos contain lots of good ideas for this Unit and other levels of Chemistry. They contain links to a variety of simulations, experiments and tutorials. Search n clark acids and bases website or becker demos (pH Rainbow tube). Strictly speaking, equilibrium constants are defined in terms of the activities of the reactants and products, but a good working approximation is achieved by using the concentration of solutions, in mol l <sup>-1</sup> , in place of activities. Because the concentrations of pure solids or pure liquids | A chemical reaction is in equilibrium when the composition of the reactants and products remains constant indefinitely. The equilibrium constant ( <i>K</i> ) characterises the equilibrium composition of the reaction mixture.<br>For the general reaction,<br>$aA + bB \rightleftharpoons cC + dD$<br>$K = \frac{[C]^c [D]^d}{[A]^a [B]^b}$<br>where [A], [B], [C] and [D] are the equilibrium concentrations of A, B, C and D respectively and a, b,   |

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|   | <p>are constant, by convention they can be given the value 1 in the equilibrium equation. The website <a href="http://chm.davidson.edu">chm.davidson.edu</a> has an equilibrium simulation showing the effect of temperature changes.</p> <p>Partition coefficients could be included as a specific example of an equilibrium constant.</p>  | <p>c and d are the stoichiometric coefficients in the balanced reaction equation.</p> <p>Equilibrium constants are independent of the concentrations or pressures of species in a given reaction. The numerical value of the equilibrium constant depends on the reaction temperature. For endothermic reactions a rise in temperature causes an increase in <math>K</math>, ie, the yield of the product is increased.</p> <p>For exothermic reactions a rise in temperature causes a decrease in <math>K</math>, ie, the yield of the product is decreased. The presence of a catalyst does not affect the value of the equilibrium constant.</p> <p>Equilibrium constants have no units.</p>  |
| <p>Ionic product of water and calculations of pH</p> $\text{pH} = -\log_{10}[\text{H}^+]$ $K_w = [\text{H}^+][\text{OH}^-]$ | <p>Point out that the equilibrium does not involve free protons but <math>\text{H}_3\text{O}^+(\text{aq})</math>. Use <math>K_w</math> to calculate pH of water and it can be used to show that the pH of water varies with temperature. The <a href="http://chemguide.co.uk">chemguide.co.uk</a> website gives good information on the ionic product of water, including variation of <math>K_w</math> at different temperatures. Unfortunately <math>K_w</math> has been given units. Search chemguide ionic product for water</p> <p>Calculations of <math>[\text{H}^+]</math> for different pH values. Quiz on calculating pH; quia pH pOH game</p> <p>A fun equilibrium applet can be found here: <a href="#">ChemConnections equilibrium</a>.</p> <p>Some useful Java animations can be found at <a href="#">davidson virtual chemistry experiments</a>.</p> <p>Another Equilibrium simulation can be found at <a href="#">davidson Dr Nut equin</a></p> | <p>In water and aqueous solutions there is an equilibrium between the water molecules and hydrogen and hydroxide ions.</p> <p>This ionisation of water can be represented by:</p> $\text{H}_2\text{O}(\ell) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{OH}^-(\text{aq}).$ <p>Water is amphoteric. The dissociation constant for the ionisation of water is known as the ionic product and is represented by <math>K_w</math>. The value of the ionic product varies with temperature.</p> <p>At 25 °C the value of <math>K_w</math> is approximately <math>1 \times 10^{-14}</math>.</p> <p>A shorthand representation of <math>\text{H}_3\text{O}^+(\text{aq})</math> is <math>\text{H}^+(\text{aq})</math>. Stoichiometric equations and equilibrium expressions can be written using <math>\text{H}^+(\text{aq})</math> instead of <math>\text{H}_3\text{O}^+(\text{aq})</math> where the meaning is clear. The relationship between pH and the hydrogen ion concentration is given by <math>\text{pH} = -\log_{10} [\text{H}^+]</math></p> <p><math>\text{pH} = -\log_{10}[\text{H}^+]</math> and conversely <math>[\text{H}^+] = 10^{-\text{pH}}</math>.</p> |

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|  |  | <p>In water and aqueous solutions with a pH value of 7 the concentrations of <math>\text{H}^+(\text{aq})</math> and <math>\text{OH}^-(\text{aq})</math> are both <math>10^{-7} \text{ mol l}^{-1}</math> at 25 °C. If the concentration of <math>\text{H}^+(\text{aq})</math> or the concentration of <math>\text{OH}^-(\text{aq})</math> is known, the concentration of the other ion can be calculated using <math>K_w</math> or by using <math>\text{pH} + \text{pOH} = 14</math>.</p>   |
| <p>Bronsted-Lowry acids/bases definitions<br/>pH of salt solutions<br/>Equilibria of the salt solutions</p>  | <p>Video by Mark Rosengarten video defines Bronsted/Lowry acids and bases. Search youtube chemistry tutorial 11.4a Bronsted Lowry. Videos by Papapodcasts go further, covering conjugate acids and bases. Search papapodcasts bronstead lowry</p>  | <p>The Bronsted-Lowry definitions of acid and base state that an acid is a proton donor and a base is a proton acceptor.<br/>For every acid there is a conjugate base, formed by the loss of a proton. For every base there is a conjugate acid, formed by the gain of a proton.<br/>A soluble salt of a strong acid and a strong base dissolves in water to produce a neutral solution. A soluble salt of a weak acid and a strong base dissolves in water to produce an alkaline solution. A soluble salt of a strong acid and a weak base dissolves in water to produce an acidic solution.<br/>Soaps are salts of weak acids and strong bases. The acidity, alkalinity or neutrality of the above kinds of salt solution can be explained by reference to the appropriate equilibria.</p> |
| <p><b>Strong and weak acids and bases</b><br/>Properties of strong and weak acids and bases.<br/>the acid dissociation constant, <math>K_a</math></p> $K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]}$ | <p>For a video of a simple animation showing the difference between the strong acid, HCl, and the weak acid, HF, in terms of ionisation, search mhhe chemistry demonstrations acid_ionization.<br/>Other Papapodcasts' videos cover strong/weak acids and strong/weak bases. Search papapodcasts strong and weak acids.<br/>Investigation of pH of strong and weak acids and bases using pH meter or indicators. Investigate pH of differing</p> | <p><b>Strong and weak acids and bases</b><br/>In aqueous solution, strong acids/bases are completely dissociated into ions but weak acids/bases are only partially dissociated. Examples of strong acids include hydrochloric acid, sulfuric acid and nitric acid. Ethanoic, carbonic and sulfurous acids are examples of weak acids. Solutions of metal hydroxides are strong bases. Ammonia and amines are examples of weak bases.<br/>The weakly acidic nature of solutions of carboxylic</p>  |

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| $pK_a = -\log_{10}K_a$  | <p>metal/non-metal hydroxide solutions.</p> <p>Look at titration curves for strong/weak acids and bases. Short videos of these are available at titration curve youtube. Some good reading can be found at: chem guide pH titration curves.</p> <p>A search for iastate greenbowe pH meter shows a simple simulation using a pH meter to test pH of various acids and alkalis of differing concentrations.</p> <p>Search thinkquest dissociation constant for information on strong and weak acids and on the acid dissociation constant.</p> <p>Calculate acidity/basicity of a given salt solution and confirm by measurement of pH. Test pH of various salt solutions including sodium carbonate, sodium sulfite, sodium stearate, ammonium chloride, ammonium nitrate etc.</p> <p>The Chem.iastate.edu website also shows a simple simulation using a pH meter to test pH of various salt solutions of differing concentrations. Search iastate greenbowe pH_meter.</p> | <p>acids, sulfur dioxide and carbon dioxide can be explained by reference to equations showing the equilibria. The weakly alkaline nature of a solution of ammonia or amines can be explained by reference to an equation showing the equilibrium.</p> <p>The acid dissociation constant is represented by <math>K_a</math> or by <math>pK_a</math> where <math>pK_a = -\log_{10}K_a</math></p> <p>Although equimolar solutions of weak and strong acids/bases differ in pH, conductivity, and reaction rates they do not differ in stoichiometry of reactions.</p> |
| <p><b>Calculation of pH for a weak acid</b></p> $pH = \frac{1}{2} pK_a - \frac{1}{2} \log_{10}c$  | <p>Calculate pH of a 0.1 mol l<sup>-1</sup> solution of a weak acid and confirm by measurement. Dilute it tenfold to show pH rises by 0.5 rather than by 1 as it would when diluting a strong acid such as 0.1 mol l<sup>-1</sup> HCl. Good opportunity for candidates to practise diluting accurately.</p>   | <p>The approximate pH of a weak acid can be calculated using <math>pH = \frac{1}{2} pK_a - \frac{1}{2} \log_{10}c</math> where <math>c</math> is the nominal concentration of the acid in the solution.</p>   |
| <p><b>Buffer solutions</b></p> <p>Composition of a buffer, how buffers work and calculation of the pH of buffers</p> $pH = pK_a - \log_{10} [\text{acid/salt}]$ | <p>Prepare buffer solution, measure pH and compare with calculated value. Opportunity to use pH meter and use buffer solution to calibrate it.</p> <p>pH of blood important. Small change in pH causes major problems. Need to explain to learners that acetic acid and</p>   | <p>A buffer solution is one in which the pH remains approximately constant when small amounts of acid or base are added. An acid buffer consists of a solution of a weak acid and one of its salts. In an acid buffer solution the weak acid can supply hydrogen</p>  |

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|   | <p>acetate are the same as ethanoic and ethanoate. Search mhhe essential chemistry buffer 12 for an animation of how a buffer solution resists change in pH when a strong acid or a strong base is added.</p> <p>Another animation of a buffer solution in which learners can prepare a buffer solution, test its pH, add acid or alkali and test the pH again can be found by searching for iastate greenbowe ph buffer solution. This can also be used to compare measured pH value of buffer against the calculated value. A search for chemcollective Concept Test acidbase yields shows an interesting but difficult quiz. Unfortunately, answers are not provided. An animation showing the difference in pH changes when adding an acid or alkali to a buffer solution compared with adding acid or alkali to water can be found by searching for michele usc acid baseOr nred.org titration web.</p> | <p>ions when these are removed by the addition of a small amount of base. The salt of the weak acid provides the conjugate base, which can absorb excess hydrogen ions produced by the addition of a small amount of acid. A basic buffer consists of a solution of a weak base and one of its salts. In a basic buffer solution the weak base removes excess hydrogen ions and the conjugate acid provided by the salt supplies hydrogen ions when these are removed. An approximate pH of an acid buffer solution can be calculated from its composition and from the acid dissociation constant,</p> $\text{pH} = \text{p}K_{\text{a}} - \log_{10} [\text{salt}]$   |
| <p><b>Indicators</b><br/>Weak acid indicators.</p> $K_{\text{in}} = \frac{[\text{H}_3\text{O}^+][\text{In}^-]}{[\text{H}_{\text{in}}]}$ <p>selection of an appropriate indicator for a particular reaction based on titration curves</p> <p>Colour change of a weak acid indicators</p> | <p>Determine the pH range over which indicator colour changes (possibly using natural indicator extracted from a plant). Select and use appropriate indicators for titration of: weak acid and strong base; strong acid and weak base. Use indicator for weak acid/weak base titration to show that a single indicator is not appropriate. Search chemguide.co.uk shows titration curves, for titration curves for different combinations of acids and alkalis. Animations (series of slides) showing colour change in phenolphthalein in various titrations can be found by searching for JCE chem. Ed xchange (by subscription only).</p>  | <p>Indicators are weak acids for which the dissociation can be represented as:</p> $\text{HIn}(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{In}^-(\text{aq})$ <p>The acid indicator dissociation constant is represented as <math>K_{\text{in}}</math> and is given by the following expression:</p> $K_{\text{in}} = \frac{[\text{H}_3\text{O}^+][\text{In}^-]}{[\text{H}_{\text{in}}]}$ <p>In aqueous solution the colour of the acid indicator is distinctly different from that of its conjugate base. The colour of the indicator is determined by the ratio of <math>[\text{H}_{\text{in}}]</math> to <math>[\text{In}^-]</math>. The theoretical point at which colour change occurs is when <math>[\text{H}^+] = K_{\text{in}}</math>.</p> |

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|  |  | <p>The colour change is assumed to be distinguishable when <math>[H_{in}]</math> and <math>[In^-]</math> differ by a factor of 10. The pH range over which a colour change occurs can be estimated by the expression: <math>pH = pK_{in} \pm 1</math></p>   |
| <p><b>Reaction feasibility</b><br/>Standard enthalpy of formation, definitions and relevant calculations<br/><math>\Delta H_f^{\circ} = \sum \Delta H_f^{\circ} (\text{products}) - \sum \Delta H_f^{\circ} (\text{reactants})</math>.</p> |  | <p><b>Enthalpy of formation</b><br/>The standard enthalpy of formation, <math>\Delta H_f^{\circ}</math>, is the enthalpy change when one mole of a substance is formed from its elements in their standard states. The standard enthalpy of a reaction can be calculated from the standard enthalpies of formation of the reactants and products.<br/><math>\Delta H_f^{\circ} = \sum \Delta H_f^{\circ} (\text{products}) - \sum \Delta H_f^{\circ} (\text{reactants})</math>.<br/>Knowledge of standard conditions is important.</p>  |
| <p><b>Entropy and prediction of value of entropy</b><br/><br/>Changes of entropy</p>   | <p>Investigate simple exothermic and endothermic reactions. Discuss in terms of entropy changes. A fun flash animation of entropy can be found by searching utoronto Einstein quote entropy flash.</p> | <p>The entropy (S) of a system is a measure of the degree of disorder of the system. The greater the degree of disorder, the greater the entropy. Entropy increases as temperature increases. Changes of state involve changes in entropy.</p>  |
| <p><b>Second and Third Laws of Thermodynamics</b></p>  | <p>Some information on the laws of thermodynamics can be found on the BBC website — laws of thermodynamics</p>   | <p>One version of the Second Law of Thermodynamics states that the total entropy of a reaction system and its surroundings always increases for a spontaneous process. Heat energy released by the reaction system into the surroundings increases the entropy of the surroundings, whereas heat absorbed by the reaction system from the surroundings decreases the entropy of the surroundings.<br/>One version of the Third Law of Thermodynamics states that the entropy of a perfect crystal at 0 K is zero. The standard entropy of a substance is the entropy value for the standard state of the substance.</p> |

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| <b>Calculations in changes in standard entropy</b><br>$\Delta S^\circ = \Sigma \Delta S^\circ (\text{products}) - \Sigma \Delta S^\circ (\text{reactants})$ .   | Experiment/demo of endothermic reaction of $\text{Ba}(\text{OH})_2$ with $\text{NH}_4\text{Cl}$ Examples of practical work which can be carried out on spontaneous endothermic reactions. Search leekhigh staffs chemistry Chemical reactions endothermic.   | The change in standard entropy for a reaction system can be calculated from the standard entropies of the reactants and products.<br>$\Delta S^\circ = \Sigma \Delta S^\circ (\text{products}) - \Sigma \Delta S^\circ (\text{reactants})$ .  |
| <b>Free energy</b><br><br>The concept of free energy<br><br>$\Delta G = \Delta H - T\Delta S$<br>Calculation of standard free energy change for a reaction<br>$\Delta G^\circ = \Sigma \Delta G^\circ (\text{products}) - \Sigma \Delta G^\circ (\text{reactants})$ . | Chemconnections.org has a little applet showing graph of $\Delta G$ v temperature. Learners can change values of $\Delta H^\circ$ and $\Delta S^\circ$ . Search chemconnections Gibbs applet.  | <b>Free energy</b><br>The change in free energy for a reaction is related to the enthalpy and entropy changes: $\Delta G = \Delta H - T\Delta S$ . If the change in free energy ( $\Delta G$ ) between reactants and products is negative, a reaction may occur. This is because the equilibrium composition favours the products over the reactants.<br>The standard free energy change for a reaction can be calculated from the standard free energies of formation of the reactants and products using the relationship,<br>$\Delta G^\circ = \Sigma \Delta G^\circ (\text{products}) - \Sigma \Delta G^\circ (\text{reactants})$ .   |
| <b>Applications of the concept of free energy</b><br><br>Prediction of the feasibility of a chemical reaction under standard and non-standard conditions<br>$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$   | Former AH PPA, verification of a thermodynamic prediction could be carried out here as an example of a theoretical prediction working out fairly closely to the observed experimental value. Suggest a larger quantity of $\text{NaHCO}_3(\text{s})$ be used to ensure bulb of thermometer is completely covered but this will produce a volume of $\text{CO}_2$ greater than $100 \text{ cm}^3$ so needs to be monitored carefully and heating stopped and syringe removed from the barrel before $100 \text{ cm}^3$ reached. Ellingham diagrams can be used to show how $G^\circ$ varies with temperature and they were useful in predicting temperatures at which reductions of metal oxides became feasible. | <b>Applications of the concept of free energy</b><br>The feasibility of a chemical reaction under standard conditions can be predicted from the calculated value of the change in standard free energy ( $\Delta G^\circ$ ). The temperatures at which a reaction may be feasible can be estimated from $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ by considering the range of values of $T$ for which $\Delta G^\circ < 0$ .<br>Under non-standard conditions any reaction is feasible if $\Delta G$ is negative. At equilibrium, $\Delta G = 0$ . A reaction will proceed spontaneously in the forward direction until the composition is reached where $\Delta G = 0$ . |

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| <p><b>Kinetics</b><br/>Determination of the order of a reaction (0, 1, 2, 3) from experimental data and rate equations. Calculation of rate constants and units of <math>k</math>.<br/>rate = <math>k[A]</math></p> | <p>Propanone/iodine reaction PPA from current AH.<br/>Decolourisation of blue food dye. See SSERC bulletin No. 225. Within the body, drug molecules are converted into a number of different molecules that are more easily excreted into the urine. These molecules are called metabolites and the whole process is called metabolism. The metabolism of the drug will begin as soon as it is administered and in many cases the process follows first order kinetics, ie the rate of metabolism is proportional to the concentration of the drug. The RSC have a case study from The Horseracing Forensic Laboratory (HFL). There is a learner worksheet and additional notes and answers for teachers. Search Royal Society of Chemistry, chemistry at the races.<br/>Saskschools.ca has an example on reaction rates in which learners can calculate the order of reaction and work out the rate law. Search for saskschools orders of reactions and the rate law.</p> | <p><b>Orders of reaction</b><br/>The rate of a chemical reaction normally depends on the concentrations of the reactants. For a first order reaction the rate of reaction is proportional to the concentration of one reactant and the rate can be expressed as: rate = <math>k[A]</math> where <math>k</math> is the rate constant and <math>[A]</math> is the concentration of reactant A in <math>\text{mol l}^{-1}</math>.<br/>The order of a reaction with respect to any one reactant is the power to which the concentration of that reactant is raised in the rate equation. The overall order of a reaction is the sum of the powers to which the concentrations of the reactants are raised in the rate equation. The order of a reaction can only be determined from experimental data.<br/>The rate constant can be determined from initial rate data for a series of reactions in which the initial concentrations of reactants are varied. Integral orders of reaction from zero order to third order should be covered.</p> |
| <p><b>Reaction mechanisms</b><br/>The rate determining step in a reaction<br/><br/>From the rate equation predict the rate determining step and possible mechanism</p>  | <p><math>S_N1</math> and <math>S_N2</math> reaction mechanisms can be discussed here but will also be covered in the Organic Chemistry Unit. Saskschools.ca has lots of information on reaction mechanisms including examples. Search saskschools reaction mechanisms.</p>   | <p><b>Reaction mechanisms</b><br/>Reaction mechanisms usually occur by a series of steps. The rate of reaction is dependent on the slowest step which is called the 'rate determining step'. Experimentally determined rate equations can provide evidence for a proposed reaction mechanism.</p>  |

## Organic Chemistry

- ◆ Molecular orbitals
- ◆ Molecular structure
- ◆ Stereochemistry
- ◆ Synthesis
- ◆ Experimental determination of structure
- ◆ Pharmaceutical Chemistry

| Mandatory Course key areas  | Suggested learning activities   | Exemplification of key areas  |
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| <p><b>Molecular orbitals</b><br/>Formation of bonding molecular orbitals</p>  | <p>Chem.purdue.edu has information about atomic orbitals becoming molecular orbitals</p>  | <p><b>Molecular orbitals</b><br/>When atoms approach each other, their separate sets of atomic orbitals merge to form a single set of molecular orbitals. Some of the molecular orbitals, known as 'bonding molecular orbitals', occupy the region between two nuclei. The attraction of positive nuclei to negative electrons occupying bonding molecular orbitals is the basis of bonding between atoms. Each molecular orbital can accommodate a maximum of two electrons.</p>   |
| <p>Hybridisation <math>sp^3</math>, <math>sp^2</math> hybrid orbitals and their role in the formation of sigma and pi bonds</p> | <p>mhhe.com has pages which cover hybridisation including an animation. Consider effect that the different types of bonds have on the shapes of molecules, eg shape of <math>CH_4</math> v <math>C_2H_4</math> v <math>C_2H_2</math>.<br/>As an extension, bonding in alkynes can be described in terms of <math>sp</math> hybridisation with both sigma and pi bonds. The website <a href="http://ibchem.com">ibchem.com</a> has information on sigma bonds, pi bonds and hybridisation.<br/>There are also other videos on the internet covering hybridisation.</p> | <p>Hybridisation is the process of mixing atomic orbitals within an atom to generate a set of new atomic orbitals called hybrid orbitals. Bonding in alkanes can be described in terms of <math>sp^3</math> hybridisation and sigma bonds. Bonding in alkenes can be described in terms of <math>sp^2</math> hybridisation and both sigma and pi bonds. A sigma bond is a covalent bond formed by end-on overlap of two atomic orbitals lying along the axis of the plane.<br/>A pi bond is a covalent bond formed by the sideways overlap of two parallel atomic orbitals lying perpendicular to the axis of the bond.</p> |

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| <p><b>The bonding continuum</b><br/>The symmetry and position of bonding orbitals between atoms determines types of bonding<br/>Ionic, polar and non-polar covalent bonding</p> | <p>Markrosengarten.com has a fun song and video covering covalent, polar covalent and ionic bonding. Useful as revision of Higher bonding.</p>   | <p><b>The bonding continuum</b><br/>In a non-polar covalent bond, the bonding molecular orbital is symmetrical about the midpoint between two atoms. Polar covalent bonds result from bonding molecular orbitals which are asymmetric about the midpoint between two atoms. Ionic compounds represent an extreme case of asymmetry with the bonding molecular orbitals being almost entirely located around just one atom.</p>  |
| <p><b>Molecular structure</b><br/>Conversion between molecular, structural and skeletal formulae with no more than 10 carbon atoms in their longest chain</p>                   | <p>Molecular drawing packages such as ChemSketch can be set to display structures in skeletal representation if required. 3D representations of relatively small molecules (less than 10 carbon atoms) containing common functional groups can be created and manipulated by learners using molymods or similar. Wireframe, stick, ball and stick and space-filling representations should all be familiar. Learners can rotate molecules around the x, y and z axes to align any chosen bond horizontally or vertically, to align any three atoms in a given plane, to zoom in and out, and to switch on and off atom labels. Molecules sketched in 2D mode can be converted into 3D representations in Chems sketch. CHIME (a free plugin for web browsers) can also display a huge range of molecules in 3D.<br/>Extensive free libraries of 3D molecules are available to be downloaded from the internet. The structures of aliphatic compounds can be drawn on a Chems sketch type system. The functional groups -OH, -COOH, -C=O, -NH<sub>2</sub>, -CONH-, -COO- can also be drawn and added to these compounds using a Chems sketch type system. A free alternative to Chemdraw is Chems sketch, which is available from ACD</p> | <p><b>Molecular structure</b><br/>Learners should be able to draw structural formulae and skeletal formulae and to interconvert between molecular, structural and skeletal formulae for organic molecules with no more than 10 carbon atoms in their longest chain. In a skeletal formula neither the carbon atoms, nor any hydrogens attached to the carbon atoms, are shown. The presence of a carbon atom is implied by a 'kink' in the carbon backbone, and at the end of a line.</p> |

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|  | <p>labs or ISIS Draw. The structural formulae of aliphatic compounds can be represented in skeletal form using a Chemdraw type system. Molecular drawing packages such as ChemSketch can be set to display structures in skeletal representation if required. Learners may learn how to interconvert between full and shortened structural formulae and skeletal formulae using the Chems sketch type system. Tutorials on using Chems sketch and drawing skeletal formulae are available on the internet.</p>   |  |
| <p><b>Stereo chemistry</b><br/>stereoisomerism</p>   | <p>Videos on different forms of isomerism by Dr Chris Arthur and 'Brightstorm' are available on the internet.</p>  | <p><b>Stereo chemistry</b><br/>Stereoisomers are molecules with the same molecular formula with a different spatial arrangement of their atoms.</p>  |
| <p><b>Geometric isomerism</b><br/><i>cis</i> and <i>trans</i></p> <p>Physical and chemical properties of geometric isomers</p> | <p>Make molecular models of <i>cis</i> and <i>trans</i> isomers. The influence of geometric isomerism on chemical properties can be illustrated by the fact that <i>cis</i>-butenedioic acid is more readily dehydrated than <i>trans</i>-butenedioic acid. Melting points and densities of <i>cis</i>-butenedioic and <i>trans</i>-butenedioic acid can also be compared. Health issues associated with <i>trans</i> fatty acids. Also, the <i>cis</i> geometry of combretastatin is crucial to anticancer activity. Alkenes are often used to rigidify structures into active conformations.</p> | <p><b>Geometric isomerism</b><br/>Geometric isomerism is one type of stereoisomerism. It arises due to the lack of free rotation around a bond, frequently a carbon-carbon double bond, but not always. Geometric isomers are labelled <i>cis</i> and <i>trans</i> according to whether the substituent groups are on the same side or on different sides of the carbon-carbon double bond. Geometric isomers display differences in some physical properties. Geometric isomerism can also influence chemical properties.</p> |
| <p><b>Optical isomerism</b><br/>non-superimposable mirror image,<br/>chiral/enantiomers</p>                                    | <p>The Thalidomide story could be discussed here. Limonene exists in two isomeric forms. One has the scent of oranges, and the other of pine. A microscale investigation of the isomers of limonene is available from the RSC.</p>   | <p><b>Optical isomerism</b><br/>Optical isomers are non-superimposable mirror images of asymmetric molecules and such molecules can be described as chiral molecules</p>   |

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| <p>Racemic mixture and effect on polarised light</p> <p>Physical and chemical properties of optical isomers</p> | <p>Chm.bris.ac.uk has more information about limonene. Ibuprofen is normally sold as a mixture of two optical isomers, one of which is an effective pain-killing drug and the other of which is inactive. This gives a low atom economy for the desired product. Recent research has produced a more efficient synthetic route to produce only the desired isomer. More information from the RSC. Chiral drugs are often sold as racemates despite the fact that activity is due mainly to one of the enantiomers. However, there are cases where the pure enantiomer is sold if there is a clear clinical advantage (for example if the other enantiomer has toxic side effects). An example is esomeprazole which is the active enantiomer of omeprazole — an antiulcer agent. R- and S- enantiomers can be discussed but will not be assessed. Can discuss chirality in drugs such as ibuprofen. S-Naproxen is a pain reliever and its enantiomer R- Naproxen is a liver toxin. Use a polarimeter, if one is available, to demonstrate the rotation of plane polarised light by optical isomers. Many links show the number of synthetic steps involved in making an asymmetric compound. Enzymes are now being used to produce asymmetric compounds in fewer synthetic steps. A simple polarimeter can be made from polaroid sun glasses using the instructions from the RSC Classic Chemistry Demonstrations No.13, page 26 (also available on the internet). Colby.edu has a video which covers chirality, stereoisomerism and optical activity. Also covers R- and S- enantiomers.</p> | <p>or enantiomers. Optical isomerism occurs in substances in which four different substituent groups are arranged around a central 'chiral' carbon atom. Optical isomers, in general, have identical physical and chemical properties, except when they are in a chiral environment. However, they have an opposite and equal effect on the direction of rotation of plane-polarised light, and are therefore said to be optically active. Racemic mixtures contain equal amounts of both optical isomers, and are optically inactive. In biological systems, only one optical isomer of each asymmetric organic compound is usually present.</p> |

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| <p><b>Synthesis</b><br/>From given equations identify: substitution, addition, elimination, condensation, hydrolysis, oxidation, reduction reactions</p> <p>Devise synthetic routes, with no more than three steps, from a given reactant to a final product</p> <p>Deduce possible reactions from molecular structures</p> | <p>It is important that many, varied, real-life contexts for these reactions are provided. Similarities/parallels between the different reaction types should be constantly reinforced and opportunities to make connections frequently provided.</p> <p>RSC website Learn Chemistry has a program Investigating Organic Reaction Mechanisms which is an online tutorial on reaction mechanisms.</p>  | <p><b>Synthesis</b><br/>Recognising and using types of reaction in organic synthesis. Given equations, the following reaction types can be identified: substitution, addition, elimination, condensation, hydrolysis, oxidation, reduction.</p> <p>Learners should be able to devise synthetic routes, with no more than three steps, from a given reactant to a final product.</p> <p>Learners should be able to look at molecular structures and deduce the reactions it can undergo.</p>   |
| <p><b>Bond fission</b><br/>homolytic and heterolytic fission</p>  | <p>Free radical chain reaction mechanism is covered at Higher. Chemguide.co.uk has information which covers free radical substitution reaction mechanism in more detail than at Higher.</p> <p>Tutorvista provides more information on homolytic and heterolytic fission. Pi bonds are easier to break than sigma due to weaker overlap of orbitals. This can be used to explain why carbonyls are important in synthesis (pi bond and polarity).</p> | <p><b>Bond fission</b><br/>When an organic reaction takes place, bonds are broken and formed. If, when the bond between atoms breaks, each atom retains one electron from the former covalent bond, then two free radicals are formed. This is known as homolytic fission. Reactions involving free radicals tend to result in formation of very complex mixtures of products, thus making them unsuitable for synthesis. If, when the bond between atoms breaks, one atom retains both of the electrons from the former covalent bond, then an ion pair is formed. This is known as heterolytic fission.</p> |

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|  |   | <p>Reactions proceeding via heterolytic fission tend to produce far fewer products and are therefore better suited for synthesis. Heterolytic fission will be favoured when the bond between the atoms is polar.</p>  |
| <p><b>Electrophiles and nucleophiles</b><br/>Reactions involving heterolytic bond fission</p> <p>Nucleophiles or electrophiles as attacking groups</p>                           | <p>Avogadro.co.uk provides definitions and examples of nucleophiles and electrophiles.</p>  | <p><b>Electrophiles and nucleophiles</b><br/>In reactions involving heterolytic bond fission, attacking groups are classified as 'nucleophiles' or 'electrophiles'. Nucleophiles are atoms or groups of atoms which are attracted towards atoms bearing a (partial) positive charge. Nucleophiles are capable of donating and sharing an electron pair to form a new bond. Electrophiles are atoms or groups of atoms which are attracted towards atoms bearing a (partial) negative charge. Electrophiles are capable of accepting an electron pair.</p>   |
| <p><b>Curly arrow notation</b><br/>Use of double-headed and single-headed arrows to show electron movement. The curly arrow shows source and destination of the electron (s)</p> | <p>Chemguide.co.uk has information on use of curly arrows. The website abdn.ac.uk also has a brief introduction to using curly arrows with some animations and examples of specific mechanisms.</p> | <p><b>Curly arrow notation</b><br/>Use of double-headed and single-headed arrows to show electron movement. The head and tail of the arrow indicates the destination of the pair of electrons. An arrow starting at the middle of a covalent bond indicates that heterolytic bond fission is occurring. When an arrow is drawn with the head pointing to the space between two atoms, this indicates that a covalent bond will be formed between the two atoms. A double-headed arrow indicates the movement of an electron pair and a single-headed arrow indicates the movement of a single electron.</p> |

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| <p><b>Haloalkanes</b><br/>Classification of monohaloalkanes as primary, secondary or tertiary</p> <p>Monohaloalkanes undergo nucleophilic substitution reactions:</p> <ul style="list-style-type: none"> <li>◆ alkalis to form alcohols</li> <li>◆ alcoholic alkoxides to form ethers</li> <li>◆ ethanolic cyanide to form nitriles which can be hydrolysed to carboxylic acids</li> </ul> <p>Monohaloalkanes can also undergo elimination reactions to form alkenes</p> | <p>Alkaline hydrolysis of a bromoalkane. Experiment on nucleophilic substitution reactions of haloalkanes — See 'Chemistry in Context Laboratory Manual, fifth edition' by Graham Hill and John Holman, published by Nelson Thornes. React monohaloalkanes with aqueous alkali and test for halide ion using silver nitrate solution. React monohaloalkanes with ethanolic potassium hydroxide and test for alkene produced. Some haloalkanes are used as anticancer agents and are called alkylating agents. Associated with toxic side effects.</p> | <p><b>Haloalkanes</b><br/>Haloalkanes (alkyl halides) are named according to IUPAC rules. Monohaloalkanes can be classified as primary, secondary or tertiary. Monohaloalkanes undergo nucleophilic substitution reactions.</p> <p>They react with:</p> <ul style="list-style-type: none"> <li>◆ alkalis to form alcohols</li> <li>◆ alcoholic alkoxides to form ethers</li> <li>◆ ethanolic cyanide to form nitriles which can be hydrolysed to carboxylic acids (chain length increased by one carbon atom)</li> </ul> <p>Monohaloalkanes can also undergo elimination reactions to form alkenes. For example: Ethanolic KOH.</p> |
| <p><b>The reaction mechanism for S<sub>N</sub>1 and S<sub>N</sub>2 reactions</b></p> <p>S<sub>N</sub>1 and S<sub>N</sub>2 reactions using curly arrows and mechanisms with particular attention</p>  | <p>Not necessary to go into inductive stabilisation in great detail. Mechanisms and animations for S<sub>N</sub>1 and S<sub>N</sub>2 are available on the internet. Chemguide.co.uk gives information on nucleophilic substitution reactions. Abdn.ac.uk covers a variety of reaction mechanisms including nucleophilic substitution reactions.</p>   | <p><b>The reaction mechanism for S<sub>N</sub>1 and S<sub>N</sub>2 reactions</b></p> <p>The reaction mechanisms for S<sub>N</sub>1 and S<sub>N</sub>2 reactions can be represented using curly arrows. The dominance of an S<sub>N</sub>1 or S<sub>N</sub>2 mechanism for a particular haloalkane can be explained in terms of steric hindrance and the inductive stabilisation of an intermediate carbocation. An S<sub>N</sub>2 reaction</p>  |

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| given to the transition state/intermediate   |   | proceeds via a single five-centred transition state, whereas an S <sub>N</sub> 1 reaction occurs in two steps via a carbocation.  |
| <p><b>The preparation properties, and reactions of alcohols</b></p> <p>Preparation from alkenes haloalkanes and reduction of carbonyl compounds using lithium aluminium hydride</p> <p>Physical properties related to bonding</p> <p>Dehydration, reaction with metals</p> <p>Reactions with carboxylic acids and acid chlorides</p> | <p>Preparation of esters, ethanol reacting with Na to form sodium ethoxide, oxidation of ethanol, ethanal and propan-2-ol by acidified dichromate, etc. Dehydration of ethanol to ethene using aluminium oxide. Alcohol groups present in a lot of drugs since they are involved in hydrogen bonding with protein binding sites (for example blockers and anti-asthmatics).</p> | <p><b>The, preparation, properties and reactions of alcohols</b></p> <p>Alcohols exhibit hydrogen bonding and as a result have anomalously high boiling points compared to many other organic compounds of comparable relative formula mass and shape. The shorter chain alcohols are miscible with water, but their solubility in water decreases as chain length increases. Alcohols can be prepared from:</p> <ul style="list-style-type: none"> <li>◆ alkenes by acid-catalysed hydration;</li> <li>◆ haloalkanes by substitution</li> </ul> <p>Alcohols react with some reactive metals to form alkoxides. Alcohols can be dehydrated to alkenes. Alcohols undergo condensation reactions with carboxylic acids and react more vigorously with acid chlorides to form esters. Aldehydes and ketones can be reduced to primary and secondary alcohols respectively, by reaction with lithium aluminium hydride in ethoxyethane.</p> |

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| <p><b>Ethers</b><br/>Naming and general structure</p> <p>Boiling point related to bonding</p> <p>Preparation using haloalkanes with alkoxides</p> <p>Chemical and physical properties of ethers linked to molecular size and uses</p> | <p>Ethers were the first anaesthetics. Williamson ether synthesis, eg synthesis of 1-ethoxy butane from 1-bromo butane and ethanol — can also be done as a kinetic experiment. Ethoxyethane is not fully miscible in water, having the same solubility as n-butanol. Methoxymethane and methoxyethane are more soluble in water than ethoxyethane, but they are not fully miscible. This is due to the formation of hydrogen bonds between the ether molecules and water molecules. Ethers, of low relative molecular mass are highly flammable and on exposure to air may form explosive peroxides. Ether runway experiment can be demonstrated.</p> | <p><b>Ethers</b><br/>Ethers have the general structure R'-O-R'' where R' and R'' are alkyl groups. Ethers are named according to IUPAC rules. Due to the lack of hydrogen bonding between ether molecules, they have lower boiling points than the corresponding isomeric alcohols. Ethers can be prepared by the reaction of haloalkanes with alkoxides. Ethers are commonly used as solvents since they are relatively inert chemically and will dissolve many organic compounds. The solubility of ethers in water decreases as the molecular size increases.</p> |
| <p><b>Alkenes</b><br/>Preparation:</p> <ul style="list-style-type: none"> <li>◆ dehydration of alcohols</li> <li>◆ base-induced elimination of hydrogen halides from monohaloalkanes</li> </ul>                                       | <p>Preparation of cyclohexene from cyclohexanol.</p>  | <p><b>Preparation of alkenes</b><br/>Alkenes can be prepared in the laboratory by:</p> <ul style="list-style-type: none"> <li>◆ dehydration of alcohols using aluminium oxide, concentrated sulfuric acid or orthophosphoric acid</li> <li>◆ base-induced elimination of hydrogen halides from monohaloalkanes</li> </ul>  |
| <p><b>Electrophilic addition reactions</b></p> <ul style="list-style-type: none"> <li>◆ catalytic addition of hydrogen to form alkanes</li> <li>◆ including</li> </ul>  | <p>abdn.ac.uk covers a variety of reaction mechanisms including reactions of alkenes such as addition of H-X to an alkene and also Markovnikov's rule (with a different spelling).</p>  | <p><b>Electrophilic addition to alkenes</b><br/>Alkenes can undergo the following electrophilic addition reactions:</p> <ul style="list-style-type: none"> <li>◆ catalytic addition of hydrogen to form alkanes</li> <li>◆ addition of halogens to form dihaloalkanes</li> <li>◆ addition of hydrogen halides according to</li> </ul>  |

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| <p>mechanisms for addition of halogens to form dihaloalkanes</p> <ul style="list-style-type: none"> <li>◆ addition of hydrogen halides according to Markovnikov's rule, to form monohaloalkanes</li> <li>◆ acid-catalysed addition of water according to Markovnikov's rule, to form alcohols</li> </ul>  |  | <p>Markovnikov's rule, to form monohaloalkanes</p> <ul style="list-style-type: none"> <li>◆ acid-catalysed addition of water according to Markovnikov's rule, to form alcohols.</li> </ul> <p>The mechanism for both the addition of hydrogen halides and the acid-catalysed addition of water involves a carbocation intermediate.</p> <p>The mechanism for addition of a halogen involves a cyclic ion intermediate.</p> <p>Both mechanisms can be written using curly arrows.</p>   |
| <p><b>Carboxylic acids</b></p> <p>Preparation by:</p> <ul style="list-style-type: none"> <li>◆ oxidising primary alcohols and aldehydes;</li> <li>◆ hydrolysing nitriles, esters, amides.</li> </ul> <p>Reactions:</p> <ul style="list-style-type: none"> <li>◆ formation of salts by reactions with metals or bases</li> <li>◆ condensation reactions with alcohols to form esters in the presence of an acid</li> </ul> | <p>Preparation of benzoic acid from ethyl benzoate (previously a PPA). Carboxylic acids are weak acids, neutralisation with alkalis to form salts, reaction with Mg — covered in Physical Chemistry Unit.</p> <p>Carboxylic acids are often ionised in drugs and form ionic interactions with binding sites. Penicillins contain a carboxylate ion that plays a crucial binding role. Consider role of carboxyl functional group in polymerisation the formation of polyesters, polyamides and proteins.</p> | <p>Preparation and reactions of carboxylic acids</p> <p>Carboxylic acids can be prepared by:</p> <ul style="list-style-type: none"> <li>◆ oxidising primary alcohols and aldehydes;</li> <li>◆ hydrolysing nitriles, esters or amides.</li> </ul> <p>Reactions of carboxylic acids include:</p> <ul style="list-style-type: none"> <li>◆ formation of salts by reactions with metals or bases;</li> <li>◆ condensation reactions with alcohols to form esters in the presence of an acid catalyst;</li> <li>◆ reaction with amino groups to form amide links;</li> <li>◆ reduction with lithium aluminium hydride to form primary alcohols.</li> </ul> |

| Mandatory Course key areas  | Suggested learning activities   | Exemplification of key areas  |
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| catalyst<br>♦ reaction with amino groups to form amide links<br>♦ reduction with lithium aluminium hydride to form primary alcohols                                       |   |   |
| <b>Amine classification</b> as primary, secondary or tertiary<br><br>Physical properties related to structure<br><br>Amines as weak bases and their use in salt formation | Solubility of lower amines in water, test pH of solutions formed. Compare pH of ethylamine solution with pH of ammonia. Neutralise solutions of amines with mineral acids. chem.purdue.edu provides some information about amines in drugs.<br>Indiana.edu also provides information about amines and their salts in medicines. Elmhurst.edu has some homework ideas on amines but need to be selective.  | <b>Amine classification and reactions</b><br>Amines are organic derivatives of ammonia and can be classified as primary, secondary or tertiary. Primary and secondary amines, but not tertiary amines, associate by hydrogen bonding. As a result, primary and secondary amines have higher boiling points than isomeric tertiary amines. Amine molecules can hydrogen-bond with water molecules thus explaining the appreciable solubility of the shorter chain length amines in water. The nitrogen atom in amines has a lone pair of electrons which can accept a proton from water, producing hydroxide ions. Amines are weak bases which react with aqueous mineral or carboxylic acids to form salts. |
| <b>Aromatic hydrocarbons and reactions of benzene</b><br>Structure, bonding and stability of the benzene ring   | Many everyday consumer products have very distinctive smells as a result of the presence of key aromatic compounds. A brief interest raising activity can be a display of household products containing these products. Examples would include well known antiseptics and disinfectants containing trichlorophenol or 4-chloro-3,5-dimethylphenol, permanent markers containing xylene or toluene etc. An | <b>Aromatic hydrocarbons and reactions of benzene</b><br>Benzene C <sub>6</sub> H <sub>6</sub> is the simplest member of the class of aromatic hydrocarbons. The benzene ring has a distinctive structural formula. The stability of the benzene ring is due to the delocalisation of electrons. A benzene ring in which one hydrogen   |

| <b>Mandatory Course key areas</b>  | <b>Suggested learning activities</b>  | <b>Exemplification of key areas</b>   |
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| <p>Substitution reactions of benzene (phenyl); alkylation, nitration, sulfonation and halogenation as examples of electrophilic substitution in benzene and other aromatic compounds</p>                                   | <p>internet search using these compounds as key words will return the names of several well known products. Benzene and its related compounds are important as feedstocks in the dyes and pigments industry, the pharmaceuticals industry and the detergents industry. Many drugs contain aromatic rings. They play a crucial role in binding as a result of their planar shape and hydrophobic character. Mechanism not necessary but should be able to work out the product formed from benzene and the electrophile/reaction mixture. Information about mechanisms is available on the internet.</p> | <p>atom has been substituted by another group is known as the phenyl group. The phenyl group has the formula <math>-C_6H_5</math>. The benzene ring resists addition reactions. One or more hydrogen atoms of a benzene molecule can be substituted to form a range of consumer products. Bonding in benzene can be described in terms of <math>sp^2</math> hybridisation, sigma and pi bonds and electron delocalisation. Consider only alkylation, nitration, sulfonation and halogenation as examples of electrophilic substitution in benzene and other aromatic compounds.</p> |
| <p><b>Experimental determination of structure</b></p> <p>Elemental microanalysis</p> <p>Determination of the masses of C, H, O, S and N in a sample of an organic compound in order to determine its empirical formula</p> | <p><math>SnI_4</math> or CuO empirical formula experiment can be done again here but is probably not necessary. Opportunity to practise empirical formula calculations from results of elemental microanalysis experiments. Other elements in organic compounds can also be determined by elemental microanalysis.</p>  | <p><b>Experimental determination of structure</b></p> <p>In organic chemistry, a number of experimental techniques are carried out to verify that the correct chemical structure has been synthesised.</p> <p><b>Elemental microanalysis</b></p> <p>Elemental microanalysis can be used to determine the masses of C, H, O, S and N in a sample of an organic compound in order to determine its empirical formula.</p>   |
| <p><b>Spectroscopy</b></p>   | <p>The RSC has produced 'Spectroscopy in a suitcase' which is an outreach activity giving school students the chance to learn about spectroscopy through hands-on experience. As well as covering the principles of spectroscopic techniques,</p>   |   |

| Mandatory Course key areas  | Suggested learning activities  | Exemplification of key areas  |
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|   | <p>the activities use real-life contexts to demonstrate the applications of the techniques. This can be used to teach mass spectrometry, infra-red spectroscopy and proton nmr spectroscopy.</p> <p>The RSC 'spectraschool' is also very useful and as well as providing useful background information, it also gives learners the opportunity to print their own spectra for a range of compounds.</p>  |   |
| <p><b>Mass spectrometry</b><br/>Interpretation of fragmentation data to gain structural information</p> | <p>In mass spectrometry, the sample is first vaporised and ionised, and fragmentation occurs when excessive energy is used to ionise the molecules. The ion fragments are separated according to their mass-to-charge ratio using an electric or magnetic field. Many types of mass spectrometer will automatically compare the mass spectrum of the sample against a large database of known organic compounds to look for an exact match and to allow identification. The mass spectrum is like a fingerprint for a particular compound.</p> | <p><b>Mass spectrometry</b><br/>Mass spectrometry can be used to determine the accurate molecular mass and structural features of an organic compound. Fragmentation takes place producing parent ion and ion fragments. A mass spectrum is obtained showing a plot of the relative abundance of the ions detected against the mass-to-charge ratio. The molecular formula can be confirmed from a high accuracy determination of the mass of the parent ion. The fragmentation pattern can also be interpreted to gain structural information.</p> |
| <p><b>Infra-red spectroscopy</b><br/>Interpretation of spectral data to gain structural information</p> | <p>IR is still widely used as it is cheaper than NMR and can be used to follow reaction progress (ie carbonyl group present or absent). It also has many specialist applications in forensics, polymer chemistry and quality control. Chemguide.co.uk provides much background information on infra-red spectroscopy.</p>  | <p><b>Infra-red spectroscopy</b><br/>Infra-red spectroscopy can be used to identify certain functional groups in an organic compound. Infra-red radiation causes parts of a molecule to vibrate. The wavelengths which are absorbed to cause the vibrations will depend on the type of chemical bond and the groups or atoms at the ends of these bonds. In infra-red spectroscopy,</p>   |

| Mandatory Course key areas   | Suggested learning activities  | Exemplification of key areas  |
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|  |  | <p>infra-red radiation is passed through a sample of the organic compound and then into a detector which measures the intensity of the transmitted radiation at different wavelengths. Infra-red absorbances are measured in wavenumbers, the reciprocal of wavelength, in units of <math>\text{cm}^{-1}</math>.</p>  |
| <p><b>Interpretation of <math>^1\text{H}</math> NMR spectra</b><br/>Understand how a proton NMR spectrum is produced</p> <p>Interpretation of spectral data to gain structural information</p> <p>Draw and analyse low resolution proton NMR spectra and to analyse high resolution proton NMR spectra</p> | <p>Hydrogen nuclei behave like tiny magnets and in a strong magnetic field some are aligned with the field (lower energy) whilst the rest are aligned against it (higher energy). Absorption of radiation in the radio-frequency region of the electromagnetic spectrum will cause the hydrogen nuclei to 'flip' from the lower to the higher energy alignment. As they fall back from the higher to the lower level, the emitted radiation is detected. The standard reference substance used in NMR spectroscopy is tetramethylsilane (TMS) which is assigned a chemical shift value equal to zero.</p> <p>The RSC website provides online NMR spectroscopy resources with video, tutorials and spectra databases. There is also a large RSC resource providing background theory for nmr and simple correlation information. Chemguide.co.uk provides background information on NMR spectroscopy as well as information on interpreting both low resolution and high resolution nmr spectra. Application of NMR in medical body scanners can be discussed here.</p> | <p><b>Interpretation of <math>^1\text{H}</math> NMR spectra</b><br/>Proton nuclear magnetic resonance spectroscopy (proton NMR) can give information about the different environments of hydrogen atoms in an organic molecule, and about how many hydrogen atoms there are in each of these environments. In the proton NMR spectrum the peak position (chemical shift) is related to the environment of the H atom. The area under the peak is related to the number of H atoms in that environment. An interaction with H atoms on a neighbouring carbon atom can result in the splitting of NMR peaks into 'multiplets'. The number of H atoms on the neighbouring carbon will determine the number of lines within a multiplet. Learners would be expected to be able to draw and analyse low resolution proton NMR spectra and to analyse high resolution proton NMR spectra.</p> |
| <p><b>Absorption of visible light by organic molecules</b><br/>An explanation of why</p>   | <p>Students can examine information on a number of molecules comparing the absorptions of conjugated and non-conjugated dienes. Vitamin A very clearly exhibits a conjugated structure (retinol). They can also look at the</p>  | <p><b>Absorption of visible light by organic molecules</b><br/>Most organic molecules appear colourless because the energy difference between the</p>   |

| <b>Mandatory Course key areas</b>  | <b>Suggested learning activities</b>  | <b>Exemplification of key areas</b>  |
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| <p>organic compounds are colourless or coloured with reference to molecular orbital theory or conjugated systems</p> | <p>structure of natural compounds such as beta-carotene. When ninhydrin reacts with amino acids a highly conjugated product is formed which absorbs light in the visible region and an intense purple colour (max 750 nm) is observed. This is used in the detection of amino acids. Students can prepare a variety of dyes themselves and examine the structures to locate the chromophore. Examples would include the preparation of azo dye from aminobenzene (aniline), sodium nitrite and 2-naphthol at low temperatures. The azo dye can be used to dye a piece of cotton. Synthetic indigo can also be prepared using a microscale method.</p> | <p>highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) is relatively large resulting in the absorption of light in the ultraviolet region of the spectrum. Coloured organic compounds contain delocalised electrons within molecular orbitals which extend across several atoms. This is known as a conjugated system. The more atoms the delocalised molecular orbital spans, the smaller the energy gap between the delocalised orbital and the next unoccupied orbital and hence the lower the frequency of light (or longer the wavelength or lower the energy of radiation) absorbed by the compound. When the wavelength of the light absorbed is in the visible region, the organic substance will appear coloured. Molecules in which the structural formula contains alternate double bonds will exhibit molecular orbitals containing delocalised electrons which will extend the conjugated section of the molecule.</p> |
| <p><b>Chromophores</b><br/>Describe a chromophore and explain its role in the colour exhibited by the compound</p>   | <p>For example, a compound in which the chromophore absorbs blue light will appear yellow. Complementary colours can be demonstrated very effectively using online resources which will allow colour mixing to be demonstrated on a computer screen or interactive whiteboard. An internet search using 'RGB colour mixing' will produce suitable simulations and animations. Simple spectrometers made from DVDs can be used to view light transmitted or reflected by coloured compounds.</p>   | <p><b>Chromophores</b><br/>The chromophore is the group of atoms within a molecule which is responsible for the absorption of light in the visible region of the spectrum. Light can be absorbed when electrons in a chromophore are promoted from one molecular orbital to another. If the chromophore absorbs light of one colour, the compound will exhibit the complementary colour.</p>   |

| Mandatory Course key areas  | Suggested learning activities   | Exemplification of key areas  |
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| <p><b>Pharmaceutical chemistry</b><br/>Effect of drugs on the body</p> <p>Lipinski rule of five</p> | <p>Discuss paracetamol which taken according to the correct dosage is beneficial but is very dangerous when taken in larger quantities and may lead to liver failure and death. Most drugs bind to a protein target by intermolecular binding forces and do not undergo any reaction. An induced fit normally leads to the effects observed.</p> <p>'The Design Studio' is a useful, interactive RSC resource to introduce the topic of drugs and medicines. The resource gives learners the opportunity to learn about the causes and effects of diseases such as cancer, HIV and asthma using their knowledge of chemistry. It then challenges the learner to design an 'optimal' drug to treat one of the diseases using their knowledge of organic chemistry.</p> <p>Another interactive resource from the RSC is the 'Masterminding Molecules' package. This resource combines learning with game-play and involves cracking a code to reveal hidden chemical concepts involved in design of drugs and medicines. Clinical trials allow safety and efficacy data to be collected for new drugs or devices. Depending on the nature of the study, healthy volunteers or patients may be used in a small pilot study. If the safety and efficacy data is satisfactory, the scale of the study will be increased. In randomised drug trials a group of patients are divided with some being given the drug.</p> <p>RSC learn chemistry has a bank of resources in challenging medicine. Not all will be suitable.</p> | <p><b>Pharmaceutical chemistry</b></p> <p>Drugs are substances which alter the biochemical processes in the body. Drugs which have beneficial effects are used in medicines. A medicine usually contains the drug plus other ingredients.</p> <p>Lipinski rule of five (multiples of 5).<br/>Molecular mass less than 500 amu.<br/>Not more than 5 hydrogen bond donors.<br/>Not more than 10 hydrogen bond acceptors.<br/>An octanol/water partition coefficient log p not greater than 5.</p> |
| <p><b>Classification of drugs</b><br/>Classification of drugs as agonists or as antagonists</p>     | <p>Andanamide (also known as the bliss molecule) is a recently discovered messenger molecule that plays a role in pain, depression, appetite, memory, and fertility. Frostburg.edu provides more information about andanamide. The resource also describes the way in which</p>   | <p><b>Classification of drugs</b></p> <p>Many drugs can be classified as agonists or as antagonists at receptors, according to whether they enhance or block the body's natural responses. An agonist will produce a response</p>   |

| Mandatory Course key areas  | Suggested learning activities   | Exemplification of key areas  |
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|   | <p>nerve cells communicate, through molecular keys and receptors.</p> <p>There are other drug targets apart from receptors and enzymes, such as DNA and RNA.</p>  | <p>similar to the body's natural active compound. An antagonist produces no response but prevents the action of the body's natural active compound.</p>   |
| <p><b>How drugs work</b><br/>Identify the types of interaction between drug functional groups and receptor sites</p> <p>Recognise the pharmacophore in drug molecules</p> | <p>Emphasise importance of shape. Binding of the active molecule to the binding site initiates a series of chemical events which results in a change in the cell chemistry. This can lead to an observable effect such as a muscle cell contracting. Protein databanks offer a huge number of PDB files containing examples of proteins with various drug molecules bound to a receptor site. Learners can use CHIME, PYMOL or Chem3D to explore the interactions between the functional group and the receptor site. Some computer packages allow H-bonding interactions to be displayed or electrostatic potential surfaces to be examined. Design Studio and Masterminding Molecules (RSC) can be used to illustrate these concepts. Excellent opportunity to investigate structural fragments common to different medicines using websites given above.</p> | <p><b>How drugs work</b><br/>Most drugs work by binding to receptors. Receptors are usually protein molecules on the surface of cells where they interact with small biologically active molecules, or are enzymes that catalyse chemical reactions (catalytic receptors). The structural fragment of a drug molecule which confers pharmacological activity upon it normally consists of different functional groups correctly orientated with respect to each other. The overall shape and size of the drug has to be such that it fits a binding site. The functional groups on both the drugs and the receptor are positioned such that the drugs can interact with and bind to the receptor. Learners should be able to identify the types of interaction between drugs and binding sites.</p> <p>By comparing the structures of drugs that have similar effects on the body, the structural fragment that is involved in the drug action can be identified.</p> <p>Many drugs act as enzyme inhibitors by binding to the enzyme's active site and blocking the reaction normally catalysed there.</p> |

## Researching Chemistry

*Unit title: Researching Chemistry (SCQF level 7)*

This Unit requires the application of different teaching methods/techniques to the other Advanced Higher Chemistry Units; the following guidance on learning and teaching approaches for this Unit are suggested methods for teachers/lecturers.

### Outcome 1 and Outcome 2

The *Researching Chemistry (AH)* Unit develops the skills required to undertake investigative work in Chemistry. As part of this Unit, candidates are required to become familiar with commonly used experimental techniques and data-analysis skills. Within the further education context this Unit may well be delivered as a free-standing Unit, but in schools, parts of this Unit can be very effectively run concurrently with the other Course Units. The advantage of such an approach is that each technique can be developed and practised within the real-life contexts provided by the other Course Units. For example, carrying out a practical laboratory exercise on the hydrolysis of ethyl benzoate involving refluxing, distillation, vacuum filtration, recrystallisation and melting point determination, which are some of the techniques specified in the *Researching Chemistry* Unit, could be undertaken when studying carboxylic acids in the *Organic Chemistry* Unit.

It is advisable that candidates begin the Investigation part of the *Researching Chemistry* Unit only after they have covered many of the skills and techniques within the Unit and have also covered some of the theory in at least one of the other Units. This may help the candidates make better informed choices on the subject of their Investigation and help them understand the Underlying Chemistry more effectively.

### Outcome 1 (1.1)

The teacher/lecturer should encourage creativity and originality in the choice of topic for research by the candidate. The investigation is not required to be original research but should be new to the candidate. The topic for research should be generated by the candidate and be of interest and relevance to them. The topic need not be drawn from the chemistry in the Advanced Higher Course; topics previously encountered by the candidate or from outside their direct learning experience can be suitable. The teacher/lecturer should support the candidate by advising on realistic and suitable procedures that will be achievable within the given time scale. This may involve consideration of laboratory facilities and equipment and the necessary control measures required as a result of risk assessment.

Candidates should be supported in identifying suitable topics for research and in devising experimental designs but should not be given excessive direction or support. Rather the candidate should be encouraged and directed to reflect on the learning in this Unit and supported to apply that learning to their investigation through open ended discussion with their teacher/lecturer. Suitable sources for initial reading include school and undergraduate textbooks, newspaper and media items, scientific journals such as *School Science Review*, *New Scientist* and *Scientific American* and internet websites.

### **Outcome 1 (1.2)**

Learners are required to record the details of the planning cycle. Planning experimental work is likely to involve a certain amount of trialling, with subsequent amendments being made to the initial plan; at Advanced Higher level learners are expected to maintain a record of their work including the planning stages and any issues and challenges met, together with reasons for proposed amendments. Formal statements and diagrams of the experimental procedures adopted should be included in the investigation report, and therefore are not needed in the work record or diary. Candidates should be encouraged to understand that producing a risk assessment is a natural part of the planning process for any practical activity. In this context candidates would be expected to produce a full written risk assessment themselves, as part of the planning process before undertaking the practical work in their Investigation. As a result of the risk assessment, candidates should become aware of how to minimise risks by taking necessary precautions and appropriate control measures which may lead to using alternative and safer procedures. They should maintain a brief record of their discussions and dialogue with their teacher/lecturer.

### **Outcome 1 (1.3)**

Learners should have regular discussions with teachers/lecturers on the difficulties and challenges of carrying out the practical work. By observation and discussion, teachers/lecturers should attest that the learner has carried out the experimental procedures effectively. The following may contribute to their judgement:

- ◆ Learners should use equipment properly, taking account of any precautions in setting up the equipment.
- ◆ Learners should take responsibility for collecting and putting away equipment as appropriate.

While learners can record experimental data in any suitable format – paper based or electronic. Learners who maintain an on-going record of work (and they should be strongly advised to do so) may present this as their evidence for a record of experimental data.

All measurements should be recorded. If a mean value is calculated, the data used to calculate that mean should also be available. Tables should normally include headings and units as appropriate. The uncertainties associated with measurements should be included in the record. Whereas the analysis and combination of uncertainties is not required in the record.

It is good practice for the assessor to check the record of work of each learner on a regular basis and sign and date any part which is to be used as evidence. Learners should use the record of work to record aims, planning, risk assessments, observations and results of the research. It is also good practice for the assessor to write appropriate comments and advice in the learner's work record.

### **Outcome 2**

Outcome 2 assesses the knowledge and understanding from the Advanced Higher Units.

## Researching Chemistry

### Key areas

- ◆ Gravimetric Analysis
- ◆ Volumetric Analysis
- ◆ Practical skills and Techniques
- ◆ Carrying out Stoichiometric Calculations

### Overarching principles

Throughout each of the key areas the learners must be able to apply the following principles:

- ◆ Precision
- ◆ Accuracy
- ◆ Uncertainties
- ◆ Units

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| Mandatory Course key areas   | Suggested learning activities | Exemplification of key areas   |
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| <p><b>Gravimetric analysis</b><br/>Analytical determination of composition of a substance's mass by chemically changing the substance</p> <p>Understanding of key techniques including 'weighing by difference' and 'heating to constant mass'</p>             |                               | <p><b>Use of an accurate electronic balance</b><br/>In gravimetric analysis, the mass of an element or compound present in a substance is determined by chemically changing that substance into some other substance of known chemical composition, which can be readily isolated, purified and weighed to constant mass.</p> <p>Learners should be aware of the techniques of weighing by difference and heating to constant mass. Possible experiments include:</p> <ul style="list-style-type: none"> <li>◆ gravimetric determination of water in hydrated barium chloride</li> <li>◆ gravimetric determination of water in hydrated magnesium sulfate</li> <li>◆ determination of Ni using butanedioxime (dimethylglyoxime)</li> </ul>   |
| <p><b>Volumetric analysis</b><br/>Appreciation of the characteristics of substances that can be used as a primary standard</p> <p>Good practice in preparation of a standard solution and their use in determination of a solution's unknown concentration</p> |                               | <p><b>Preparation of a standard solution / primary standard / standardising solutions</b><br/>A solution of accurately known concentration is known as a standard solution. A standard solution can be prepared directly from a primary standard. A primary standard must have, at least, the following characteristics:</p> <ul style="list-style-type: none"> <li>◆ high state of purity</li> <li>◆ stability in air and in solution</li> <li>◆ solubility</li> <li>◆ reasonably high formula mass</li> </ul> <p>Examples of primary standards include:</p> <ul style="list-style-type: none"> <li>◆ sodium carbonate, <math>\text{Na}_2\text{CO}_3</math></li> <li>◆ oxalic acid, <math>\text{H}_2\text{C}_2\text{O}_4 \cdot 2\text{H}_2\text{O}</math></li> <li>◆ potassium hydrogen phthalate, <math>\text{KH}(\text{C}_8\text{H}_4\text{O}_4)</math></li> <li>◆ silver nitrate, <math>\text{AgNO}_3</math></li> <li>◆ potassium iodate, <math>\text{KIO}_3</math></li> <li>◆ potassium dichromate, <math>\text{K}_2\text{Cr}_2\text{O}_7</math></li> </ul> <p>Learners should appreciate why certain compounds such as sodium hydroxide are not acceptable as primary standards. Learners should also be aware that, where practicable, titrations should be repeated until concordant results are obtained.</p> |

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|  |  | <p>Possible experiments include:</p> <ul style="list-style-type: none"> <li>◆ Prepare a standard solution of 0.1 mol l<sup>-1</sup> oxalic acid</li> <li>◆ Standardisation of approx 0.1 mol l<sup>-1</sup> NaOH(aq)</li> <li>◆ Determination of the ethanoic acid content of vinegar</li> <li>◆ Preparation of a standard solution of 0.1 mol l<sup>-1</sup> sodium carbonate solution</li> <li>◆ Standardisation of approximately 0.1 mol l<sup>-1</sup> HCl(aq)</li> <li>◆ Determination of the purity of marble by back titration</li> </ul> <p>Animation of titration and titrations with corresponding calculations can be found on the internet.</p> <p>□</p> |
| Understanding the role of a control in experiments to validate techniques                                      |  | <p><b>Use of a control</b></p> <p>A control validates a technique and may consist of carrying out a determination on a solution of known concentration.</p> <p>Possible experiments include:</p> <ul style="list-style-type: none"> <li>◆ Determination of the percentage acetyl salicylic acid in a commercial tablet, using 'pure' aspirin as a control</li> <li>◆ Determination of vitamin C in a fruit juice using pure ascorbic acid as a control</li> </ul>  |
| Understanding the use of complexometric titration in quantitative analysis of solutions containing a metal ion |  | <p><b>Complexometric titration</b></p> <p>Complexometric titrations are based on reactions in which complexes are formed. EDTA is an important complexometric reagent and can be used to determine the concentration of metal ions in solution.</p> <p>A possible experiment could be the determination of the percentage of Ni in a nickel salt using EDTA.</p>   |
| Understanding of back titrations and associated calculations   |  | <p><b>Back titration</b></p> <p>Back titration is used to find the number of moles of a substance by reacting it with an excess volume of reactant of known concentration. The resulting mixture is then titrated to work out the number of moles of the reactant in excess. From the initial number of moles of that reactant the number of moles used in the reaction can be determined, making it possible to work back to calculate the initial number of moles of the substance</p>   |

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|  |   | <p>under test. A back titration is useful when trying to work out the quantity of substance in an insoluble solid.</p> <p>Possible experiments include:</p> <ul style="list-style-type: none"> <li>◆ Determination of aspirin</li> <li>◆ Determination of purity of marble by back titration</li> </ul>  |
| <p><b>Practical skills and techniques</b></p> <p>Preparation of standard solutions using accurate dilution technique</p> <p>Formation and use of calibration curves to determine an unknown using solutions of appropriate concentration</p> |   | <p><b>Colorimetry/accurate dilution</b></p> <p>Colorimetry uses the relationship between colour intensity of a solution and the concentration of the coloured species present. A calibration curve must be prepared using solutions of known concentrations (standard solutions). The concentration of the 'unknown' solution is determined from its absorbance and by referring to the calibration curve. The straight line section of the calibration graph should cover the dilution range likely to be used in the determination.</p> <p>Possible experiments include:</p> <ul style="list-style-type: none"> <li>◆ Colorimetric determination of manganese in steel</li> <li>◆ Determination of nickel using colorimetric analysis</li> </ul>   |
| <p>Knowledge of the appropriate use of distillation, reflux, vacuum filtration, recrystallisation and use of a separating funnel in the preparation and purification of an experimental product</p>  | <p>A video showing simple, fractional and steam distillation is available on the internet</p> | <p><b>Distillation</b></p> <p>In the modern organic chemistry laboratory, distillation is a powerful tool, both for the identification and the purification of organic compounds. The boiling point of a compound — determined by distillation — is well-defined and thus is one of the physical properties of a compound by which it is identified.</p> <p>Distillation is used to purify a compound by separating it from a non-volatile or less-volatile material.</p> <p>This technique provides opportunities for learners to become familiar with glassware containing ground glass joints.</p> <p>Possible experiments include:</p> <ul style="list-style-type: none"> <li>◆ Preparation of benzoic acid by hydrolysis of ethyl benzoate</li> <li>◆ Preparation of ethyl ethanoate</li> <li>◆ Preparation of cyclohexene from cyclohexanol</li> </ul> |

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|  | <p>Different videos showing heating under reflux are available on the internet.</p>   | <p><b>Refluxing</b></p> <p>Refluxing is a technique used to apply heat energy to a chemical reaction mixture over an extended period of time. The liquid reaction mixture is placed in a round-bottomed flask along with anti-bumping granules with a condenser connected at the top. The flask is heated vigorously over the course of the chemical reaction; any vapours given off are immediately returned to the reaction vessel as liquids when they reach the condenser. This technique provides opportunities for learners to become familiar with glassware containing ground glass joints.</p> <p>Possible experiments include:</p> <ul style="list-style-type: none"> <li>◆ Preparation of benzoic acid by hydrolysis of ethyl benzoate</li> <li>◆ Preparation of ethyl ethanoate</li> </ul> |
|  | <p>A video on vacuum filtration showing use of a Buchner funnel and a Hirsch funnel is available on the internet.</p>                         | <p><b>Vacuum filtration</b></p> <p>Using a Buchner, Hirsch or sintered glass funnel. These methods are carried out under reduced pressure and provide a faster means of separating the precipitate from the filtrate. The choice of filtering medium depends on the quantity and nature of the precipitate.</p> <p>Possible experiments include:</p> <ul style="list-style-type: none"> <li>◆ Preparation of potassium trioxalatoferrate(III)</li> <li>◆ Preparation of aspirin</li> <li>◆ Preparation of benzoic acid by hydrolysis of ethyl benzoate</li> <li>◆ Identification by derivative formation</li> </ul>  |
|  | <p>Videos on recrystallisation are available on the internet.</p> <p>Videos on melting point determination are available on the internet.</p> | <p><b>Recrystallisation</b></p> <p>Recrystallisation is a laboratory technique used to purify solids, based upon solubility. The solvent for recrystallisation must be carefully selected such that the impure compound is insoluble at lower temperatures, yet completely soluble at higher temperatures. The impure compound is dissolved gently in the minimum volume of hot solvent then filtered to remove insoluble impurities. The filtrate is allowed to cool slowly to force crystallisation. The more soluble impurities are left behind in the solvent.</p>   |

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|  |  | <p>Possible experiments include:</p> <ul style="list-style-type: none"> <li>◆ Preparation of benzoic acid by hydrolysis of ethyl benzoate</li> <li>◆ Preparation of potassium trioxalatoferrate(III)</li> <li>◆ Preparation of acetylsalicylic acid</li> </ul>  |
|  | <p>For example, supercritical CO<sub>2</sub> is used in the preparation of decaffeinated coffee. Videos on solvent extraction are available on the internet.</p> | <p><b>Use of a separating funnel</b></p> <p>Solvent extraction can be an application of the partition of a solute between two liquids. It is based on the relative solubility of a compound in two different immiscible liquids, usually water and an organic solvent. The partition coefficient is expressed as the concentration of a solute in the organic layer over that in the aqueous layer. The two solvents form two separate layers in the separating funnel and the lower layer is run off into one container and the upper layer is poured out into another container. The quantity of solute extracted depends on the partition coefficient and on the number of times that the process is repeated. Selection of suitable solvents can be discussed.</p> <p>Possible experiments include:</p> <ul style="list-style-type: none"> <li>◆ Preparation of ethyl ethanoate</li> <li>◆ Extraction of caffeine from tea</li> </ul> |
| <p>Knowledge of the appropriate uses of thin-layer chromatography, melting point and mixed melting point determination in evaluating the purity of an experimental products</p> <p>Calculation of R<sub>f</sub> values from relevant data and its use in following the course of a reaction.</p> | <p>Videos of thin-layer chromatography are available on the internet.</p>  | <p><b>Use of thin-layer chromatography to assess product purity</b></p> <p>Instead of chromatography paper, thin-layer chromatography (TLC) uses a fine film of silica or aluminium oxide spread over glass or plastic. R<sub>f</sub> values can be calculated and under similar conditions a compound will always have the same R<sub>f</sub> value within experimental error. Since a pure substance will show up as only one spot on the developed chromatogram, TLC can be used to assess the purity of a product prepared in the lab.</p> <p>Possible experiments include:</p> <ul style="list-style-type: none"> <li>◆ Preparation of aspirin</li> <li>◆ Hydrolysis of ethyl benzoate</li> </ul>  |

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|   |  | <p><b>Determination of melting point and mixed melting point</b></p> <p>The melting point of an organic compound is one of several physical properties by which it can be identified. A crystalline substance has a sharp melting point falling within a very small temperature range. Determination of the melting point can also give an indication of the purity of an organic compound, as the presence of impurities lowers the melting point and extends its melting temperature range.</p> <p>Since impurities lower the melting point, the technique of mixed melting point determination can be used as a means of identifying the product of a reaction</p> <p>Possible experiments include:</p> <ul style="list-style-type: none"> <li>◆ Preparation of benzoic acid by hydrolysis of ethyl benzoate</li> <li>◆ Identification by derivative formation</li> <li>◆ Preparation of aspirin</li> </ul>   |
| <p><b>Carrying out stoichiometric calculations</b></p> <p>Calculations from balanced equations, including multi-step reactions, reactant excess, and empirical formulae from given data</p> <p>Calculations and explanations comparing theoretical and actual yield</p> |  | <p><b>Carrying out stoichiometric calculations</b></p> <p>Stoichiometry is the study of quantitative relationships involved in chemical reactions. The ability to balance and interpret equations enabling calculations to be carried out involving any of the above skills/techniques is an important part of chemistry at this level and is examinable in the course assessment.</p> <p><b>Experimental determination of percentage yield</b></p> <p>Theoretical percentage yields can be calculated and compared with actual yield . Mass transfer or mechanical losses, purification of product, side reactions, equilibrium position and purity of reactants, inevitably lowers the percentage yield.</p> <p>Possible experiments include:</p> <ul style="list-style-type: none"> <li>◆ Preparation of aspirin</li> <li>◆ Preparation of potassium trioxalatoferrate(III)</li> <li>◆ Preparation of benzoic acid by hydrolysis of ethyl benzoate</li> <li>◆ Preparation of ethyl ethanoate</li> </ul> |

# Skills and techniques which need to be covered through experimentation on the Course

| Advanced Higher Chemistry  |                        |                              |                                    |                          | Skills/techniques to be covered in the Researching Chemistry Unit |                     |                  |                             |                          |                |            |                                       |                             |                                       |
|----------------------------|------------------------|------------------------------|------------------------------------|--------------------------|---|---------------------|------------------|-----------------------------|--------------------------|----------------|------------|---------------------------------------|-----------------------------|---------------------------------------|
| (a)<br>Use of a<br>Balance | (b)<br>Standardisation | (c)<br>Control/<br>Reference | (d)<br>Complexometric<br>titration | (e)<br>Back<br>titration | (f)<br>Colorimetry/<br>serial dilution                            | (g)<br>Distillation | (h)<br>Refluxing | (i)<br>Vacuum<br>filtration | (j)<br>Recrystallisation | (k)<br>% yield | (l)<br>TLC | (m)<br>Melting point<br>determination | (n)<br>Separating<br>funnel | (o)<br>Stoichiometric<br>Calculations |
| 1                          | 1                      |                              |                                    | 1                        |   |                     |                  |                             |                          |                |            |                                       |                             | 1                                     |
| 2                          | 2                      |                              |                                    |                          |   |                     |                  |                             |                          |                |            |                                       |                             | 2                                     |
| 3                          |                        |                              | 3                                  |                          |   |                     |                  |                             |                          |                |            |                                       |                             | 3                                     |
| 4                          |                        |                              |                                    |                          |   |                     |                  |                             |                          |                |            |                                       |                             | 4                                     |
| 5                          |                        |                              |                                    |                          |   |                     |                  | 5                           | 5                        | 5              |            |                                       |                             | 5                                     |
| 6                          | 6                      | 6                            |                                    |                          |   |                     |                  |                             |                          |                |            |                                       |                             | 6                                     |
| 7                          |                        | 7                            |                                    | 7                        |   |                     |                  | 7                           | 7                        | 7              | 7          | 7                                     |                             | 7                                     |
| 8                          |                        |                              |                                    |                          |   | 8                   | 8                | 8                           | 8                        | 8              | 8          | 8                                     |                             | 8                                     |
| 9                          |                        |                              |                                    |                          |   | 9                   | 9                |                             |                          | 9              |            |                                       | 9                           | 9                                     |
| 10                         |                        | 10                           |                                    |                          | 10  |                     |                  |                             |                          |                |            |                                       |                             | 10                                    |
| 11                         |                        |                              |                                    |                          |   | 11                  |                  |                             |                          | 11             |            |                                       | 11                          | 11                                    |

## Possible experiments to cover these skills

### Experiment 1

- ◆ Prepare a standard solution of 0.1 mol l<sup>-1</sup> oxalic acid
- ◆ Standardisation of approx 0.1 mol l<sup>-1</sup> NaOH(aq)
- ◆ Determination of the ethanoic acid content of vinegar

### Experiment 2

- ◆ Preparation of a standard solution of 0.1 mol l<sup>-1</sup> sodium carbonate solution
- ◆ Standardisation of approximately 0.1 mol l<sup>-1</sup> HCl(aq)
- ◆ Determination of purity of marble by back titration

### Experiment 3

- ◆ Determination of Ni<sup>2+</sup> in a nickel(II) salt

### Experiment 4

- ◆ Determination of water in hydrated barium chloride
- ◆ Gravimetric determination of nickel using butanedioxime

### Experiment 5

- ◆ Preparation of trioxalatoferrate(III)

### Experiment 6

- ◆ Determination of vitamin C in a tablet

### Experiment 7

- ◆ Preparation of aspirin (acetyl salicylic acid)
- ◆ Determination of acetyl salicylic acid in a commercial tablet, using prepared aspirin as a control

### Experiment 8

- ◆ Hydrolysis of ethyl benzoate

### Experiment 9

- ◆ Preparation of ethyl ethanoate

### Experiment 10

- ◆ Colorimetric determination of manganese in steel

### Experiment 11

- ◆ Preparation of cyclohexene from cyclohexanol

Candidates should be exposed to these skills/techniques by carrying out a variety of experiments such as those suggested above. For example, doing experiments 1, 3 and 10 followed by 8 and 11 would cover all the skills/techniques. However, the list above is neither prescriptive nor exhaustive.

Candidates may also carry out experiments based on these skills/techniques as part of their Chemical Investigation. There will be no formal internal assessment of these skills but candidates should be given opportunities to become secure in each skill. Questions in the examination paper relating to these techniques, including calculations, will be the means of external assessment.

## Appendix 2: Reference documents

The following reference documents will provide useful information and background.

- ◆ Assessment Arrangements (for disabled candidates and/or those with additional support needs) — various publications are available on SQA's website at: [www.sqa.org.uk/sqa//14977.html](http://www.sqa.org.uk/sqa//14977.html).
- ◆ Building the Curriculum 4: Skills for Learning, Skills for Life and Skills for Work
- ◆ Building the Curriculum 5: A Framework for Assessment
- ◆ [Course Specifications](#)
- ◆ [Design Principles for National Courses](#)
- ◆ [Guide to Assessment](#)
- ◆ [Overview of Qualification Reports](#)
- ◆ Principles and practice papers for curriculum areas
- ◆ [SCQF Handbook: User Guide](#) and [SCQF level descriptors](#)
- ◆ [SQA Skills Framework: Skills for Learning, Skills for Life and Skills for Work](#)
- ◆ [Skills for Learning, Skills for Life and Skills for Work: Using the Curriculum Tool](#)
- ◆ [Coursework Authenticity: A Guide for Teachers and Lecturers](#)

## Administrative information

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### History of changes to Advanced Higher draft Course/Unit Support Notes

| Course details | Version | Description of change | Authorised by | Date |
|----------------|---------|-----------------------|---------------|------|
|                |         |                       |               |      |
|                |         |                       |               |      |
|                |         |                       |               |      |
|                |         |                       |               |      |

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