Education Scotland
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Advanced Higher Chemistry

Resource Guide

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Advanced Higher Chemistry Resources Guide

This resource guide has been produced in response to requests from staff who attended the NQ Sciences events at Hampden Stadium in December 2013. Those attending felt it would be useful to have a document which helped them navigate to the most relevant resources quickly.

The following pages show the mandatory course key areas table from the SQA Advanced Higher Chemistry Course and Unit Support Notes. An additional fourth column has been included which contains hyperlinks to useful resources. **Please note: Staff are not required to use the resources listed – they are only included as helpful suggestions. Staff should also refer to the SQA website for the most up-to-date course and unit support notes.**

To further assist staff content links to useful SQA documentation have been included at the beginning of each unit along with resources for the Researching Chemistry Unit.

SQA documents	**Web link**
Course specification	http://bit.ly/13xROgY
Course assessment specification	http://bit.ly/1vZ38Iw
Course and unit support notes	http://bit.ly/1vZ3grF
Assessment overview published June 2014	http://bit.ly/1AbCbaM

Education Scotland learning materials	
Higher Sciences website	http://bit.ly/HigherSciences

Inorganic and Physical Chemistry			**Unit specification http://bit.ly/13ao2hh**
Mandatory course key areas	**Suggested learning activities**	**Exemplification of key areas**	**Useful resources**
Electromagnetic radiation and atomic spectra Electromagnetic waves The relationship c = f λ	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. 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 spectrascope. 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 × 108 m s^{-1} (see Data Booklet). Frequency is often quoted in Hz, which is the same as s^{-1} .	Electromagnetic radiation and atomic spectra. 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 = fλ where c represents the speed of light, f represents the frequency of the wave (s^{-1}) and λ 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).	Education Scotland resources – Electronic structure and the periodic table. ChemWiki resources – Electromagnetic radiation.
Dual nature of electromagnetic radiation — waves and particles	A video on the dual nature of light can be found on the internet (search Quantum mechanics: the dual nature of light — YouTube).	When electromagnetic radiation is absorbed or emitted by matter, it appears to behave more like a stream of particles than as a wave.	New Chemistry Teaching resources – Wave particle duality

The relationships E = hf and E = Lhf	Use h = 6·63 × 10^{-34} J s (see Data Booklet). For Avogadro's constant, use L = 6·02 × 10^{23} mol^{-1} (see Data Booklet). To get E, in kJ mol^{-1}, it is more convenient to use E = Lhf/1000 or E = Lhc/1000. L 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.)	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 E = hf where 'h' represents Planck's constant. For chemists, it is more convenient to express the energy associated with a mole of photons which is given by E = Lhf giving the energy in J mol^{-1} where L represents Avogadro's constant.	PhET animation – Waves on a string PhET animation- Quantum wave interference
Atomic emission Evaluation of evidence for energy levels in atoms of elements	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. 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	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	McGraw-Hill Education animation – Line spectra Learn Chemistry activity – Flame tests PhET animation – Neon lights and other discharge lamps

	demonstration. 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 lamp, a series of purple lines from the atomic emission spectrum of mercury can be observed. 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.	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.	SSERC experiment – Sodium absorption spectrum with a white Lumiled 800mainstreet resources – Spectroscopy: Element identification and emission spectra

Atomic spectroscopy Atomic emission spectroscopy and atomic absorption spectroscopy and how they are used to identify and quantify the elements present in a sample	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. A free science video by 'Brightstorm' on atomic emission spectra is available (search atomic emission spectra YouTube brightstorm2). 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). Astronomy-spectroscopy -1/3 YouTube (spot the error on atomic size) Astronomy-spectroscopy -2/3 YouTube (does show temp in °K (sic)) Spectrum of stars 1of2 YouTube Forensic ink analysis (search forensic ink analysis YouTube).	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. 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. 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.	RSC resource – Atomic absorption spectrometry Learn Chemistry resources – Measuring lead levels in hair YouTube video – Atomic emission spectra University of Oregon animation – Create absorption or emission spectra for various elements

	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.		
Atomic orbitals, electronic configurations and the Periodic Table The four quantum numbers used to describe any electron within an atom. The shapes of s, p and d orbitals	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. 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. Revised Higher 2(a) atomic orbital notes page 28. 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'	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: • the principal quantum number, n • the angular momentum quantum number, l • the magnetic quantum number, m • the spin magnetic quantum number, s	MyRSC animation – Electron orbitals University of Sheffield animation – The Orbitron

	covers quantum numbers but this is beyond the level required and would need some previous teaching or learning. Search for Quantum numbers Brightstorm YouTube. 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.		
Electronic configuration including: • aufbau principle • Hund's rule • Pauli exclusion principle	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. Teachers/lecturers may wish to introduce only elements 1–20 at first and return to the remaining elements during the coverage of transition metals.	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.	Brightstorm animation – Orbital Diagrams - Concept

		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.	
The Periodic Table is subdivided corresponding to electron configurations	f-orbitals are not assessable	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.	
Ionisation energies as evidence for electron Configurations The relative values of first, second and subsequent ionisation energies can be evaluated in terms of the stabilities of different subshell electron configurations	A graph of first ionisation energies against atomic number shows blips, which gives good evidence of s and p orbitals being filled.	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.	
Shapes of Molecules and Polyatomic Ions VSEPR rules Apply VSEPR rules to determine shapes of	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	Shapes of Molecules and Polyatomic Ions The arrangement of electron pairs is linear, trigonal planar, tetrahedral, trigonal bipyramidal and octahedral when the total	PhET animations - Molecule shapes

molecules and polyatomic ions	of molecules with different numbers of bonding and non-bonding pairs. Search Cheml Ed home page then search for molecular orbitals. Alternatively, search: • davidson edu molecular orbitals (both need 3D java) • chemmy bear shapes of molecules gives animated shapes • beavon clara orbitals contents is an animation showing molecular shapes but has no commentary	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 > non-bonding pair/bonding pair > bonding pair/bonding pair. These different strengths of electron pair repulsion account for slight deviations from expected bond angles in molecules such as NH_3 and H_2O.	
Transition metals Electronic configuration of transition metal atoms and ions and the anomalies of the model explained	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 dblock 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+ ion which has no d electrons. A short 'Brightstorm' video on 'Exceptions to electron configurations' covers the electronic configurations of Cr and Cu.	Transition metals 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.	Brightstorm video – Exceptions to electron configurations Education Scotland activity – Preparation of potassium trioxolatoferrate(III)
Oxidation states of transition Metals	Zinc is used to reduce a solution of yellow ammonium vanadate(V) to a	Oxidation states of transition metals An element is said to be in a	RSC experiment – The oxidation states of vanadium

Oxidation numbers of transition metal ions Using changes in oxidation number of transition metal ions to determine whether oxidation or reduction has occurred	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. Another video resource can be found at Chemistry oxidation of vanadium YouTube. 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. Bromfield Honors Chemistry video 'Assigning Oxidation Numbers' covers all the main points for assigning oxidation numbers. Search blinkx.com assigning-oxidation-numbers. 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 taught. Search 9.1.2 assigning Oxidation Numbers YouTube	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.	ChemGuide resources – Oxidation states

Ligands Bonding of ligands in transition metal complexes Classification of ligands Coordination number 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.	Ligands may be negative ions or molecules with nonbonding 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.	Learn Chemistry experiment – Reactions of transition elements
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.	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. If light of one colour is absorbed, then the complementary colour will be observed.	Learn Chemistry experiment – Making glass RSC experiment – Complexes of nickel(II) with ethylenediamine

	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 $Cu^{2+}(aq)$, $Ni^{2+}(aq)$, $Co^{2+}(aq)$. (Concentrations are not important but concentrated enough to have characteristic colours.) Add conc HCl to provide Cl^- ions as ligands and concentrated $NH_3(aq)$ to provide NH_3 molecules as ligands. See colour changes due to differences in energy levels between d orbitals. Original solutions have H_2O 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.	RSC experiment – Investigating commercial sunscreens Chemistry Teaching Resources activity – Determination of manganese in steel (Unit 1 PPA 2)
Catalysis by transition metals Transition metals and their compounds can acts 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	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	RSC experiment – A visible activated complex Iowa State University animation – Cobalt chloride catalysis

	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.)	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.	
Chemical equilibrium Equilibrium expressions, factors affecting equilibria and calculation of the composition of the equilibrium mixtures	Try to ensure links to organic chemistry through pKa 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 animations, 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^{-1} , in place of activities. Because the concentrations of pure solids or pure liquids are constant, by convention they can be given the value 1 in the equilibrium equation. The website chm.davidson.edu has an equilibrium animation showing	A chemical reaction is in equilibrium when the composition of the reactants and products remains constant indefinitely. The equilibrium constant (K) characterises the equilibrium composition of the reaction mixture. For the general reaction, $aA + bB \rightleftharpoons cC + dD$ $K = \frac{[C]^c[D]^d}{[A]^a[B]^b}$ where [A], [B], [C] and [D] are the equilibrium concentrations of A, B, C and D respectively and a, b, c and d are the stoichiometric coefficients in the balanced reaction equation. Equilibrium constants are independent of the concentrations or pressures of species in a given reaction. The numerical value of the	ChemConnections animation – Equilibrium Beckerdemos experiment – pH rainbow tube Nancy Clark resources – Acids and Bases Learn Chemistry experiment – Challenging medicines: physiochemical properties Nuffield Foundation experiments – Dynamic equilibria Learn Chemistry resources – Starter for ten equilibria Quia animation – Rags to riches

	the effect of temperature changes. Partition coefficients could be included as a specific example of an equilibrium constant.	equilibrium constant depends on the reaction temperature. For endothermic reactions a rise in temperature causes an increase in K, i.e., the yield of the product is increased. For exothermic reactions a rise in temperature causes a decrease in K, i.e., the yield of the product is decreased. The presence of a catalyst does not affect the value of the equilibrium constant. Equilibrium constants have no units.	
Ionic product of water and calculations of pH $pH = -\log_{10}[H^+]$ $K_w = [H+][OH^-]$	Point out that the equilibrium does not involve free protons but $H_3O^+(aq)$. Use K_w to calculate pH of water and it can be used to show that the pH of water varies with temperature. The chemguide.co.uk website has useful information on the ionic product of water, including variation of K_w at different temperatures. Unfortunately K_w has been given units. Search chemguide ionic product for water Calculations of $[H^+]$ for different pH values. Quiz on calculating pH; quia pH pOH game A fun equilibrium applet can be found here called ChemConnections equilibrium.	In water and aqueous solutions there is an equilibrium between the water molecules and hydrogen and hydroxide ions. This ionisation of water can be represented by: $H_2O(\ell) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + OH(aq)$ Water is amphoteric. The dissociation constant for the ionisation of water is known as the ionic product and is represented by K_w. The value of the ionic product varies with temperature.	ChemConnections animation – Equilibrium Davidson College experiment – Chemical equilibrium

	Some useful Java animations can be found at Davidson virtual chemistry experiments. Another Equilibrium animation can be found at Davidson Dr Nut equkin.	At 25 °C the value of Kw is approximately 1×10^{-14}. A shorthand representation of $H_3O^+(aq)$ is $H^+(aq)$. Stoichiometric equations and equilibrium expressions can be written using $H^+(aq)$ instead of $H_3O^+(aq)$ where the meaning is clear. The relationship between pH and the hydrogen ion concentration is given by $pH = -\log_{10}[H^+]$ $pH = -\log_{10}[H^+]$ and conversely $[H+] = 10^{-pH}$. In water and aqueous solutions with a pH value of 7 the concentrations of $H^+(aq)$ and $OH^-(aq)$ are both 10-7 mol l^{-1} at 25 °C. If the concentration of $H^+(aq)$ or the concentration of $OH^-(aq)$ is known, the concentration of the other ion can be calculated using K_w or by using pH + pOH = 14.	
Bronsted-Lowry acids/bases definitions pH of salt solutions Equilibria of the salt solutions	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.	The Bronsted-Lowry definitions of acid and base state that an acid is a proton donor and a base is a proton acceptor. For every acid there is a conjugate base, formed by the loss of a proton.	YouTube video – Bronsted-Lowry Theory of acids and bases University of Nebraska activities – Bronsted/Lowry Acids and bases

		For every base there is a conjugate acid, formed by the gain of a proton. 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. 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.	YouTube video – Bronsted-Lowry acids/bases.
Strong and weak acids and bases Properties of strong and weak acids and bases. the acid dissociation constant, K_a or pKa where $pKa = -\log_{10}K_a$	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. Other Papapodcasts' videos cover strong/weak acids and strong/weak bases. Search papapodcasts strong and weak acids.	Strong and weak acids and bases 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	Iowa State University animation – Solutions of acid, base and salt Learn Chemistry animation – Strong/weak acids and bases RSC resources – Indicators and titration curves Nuffield Foundation activities – pH of oxides

	Investigation of pH of strong and weak acids and bases using pH meter or indicators. Investigate pH of differing metal/non-metal hydroxide solutions. 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. A search for iastate greenbowe pH meter shows a simple animation using a pH meter to test pH of various acids and alkalis of differing concentrations. Search thinkquest dissociation constant for information on strong and weak acids and on the acid dissociation constant. 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. The Chem.iastate.edu website also shows a simple animation using a pH	bases. The weakly acidic nature of solutions of carboxylic 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. The acid dissociation constant is represented by K_a or by pK_a where $pK_a = -\log_{10}K_a$ Although equimolar solutions of weak and strong acids/bases differ in pH, conductivity, and reaction rates they do not differ in stoichiometry of reactions.	

	meter to test pH of various salt solutions of differing concentrations. Search iastate greenbowe pH_meter.		
Calculation of pH for a weak acid $pH = ½ pK_a – ½ \log_{10}c$	Calculate pH of a 0·1 mol l^{-1} 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^{-1} HCl. Good opportunity for candidates to practise diluting accurately.	The approximate pH of a weak acid can be calculated using $pH = ½ pK_a – ½ \log_{10}c$ where c is the nominal concentration of the acid in the solution.	
Buffer solutions Composition of a buffer, how buffers work and calculation of the pH of buffers $pH = pK_a – \log_{10}$ [acid/salt]	Prepare buffer solution, measure pH and compare with calculated value. Opportunity to use pH meter and use buffer solution to calibrate it. pH of blood important. Small change in pH causes major problems. Need to explain to learners that acetic acid and 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. 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	Indicators are weak acids for which the dissociation can be represented as: $HIn(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + In^-(aq)$ The acid indicator dissociation constant is represented as K_{In} and is given by the following expression: $K_{In} = \frac{[H_3O^+][In^-]}{[HIn]}$ 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 [HIn] to $[In^-]$. The theoretical point at which colour change occurs is when $[H^+]$ = KIn.	McGraw-Hill Education animation – Buffers University of Southern California animation – Acid base titration ChemCollective animation – Acid Base chemistry and buffers concept test

	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 base or nred.org titration web.	The colour change is assumed to be distinguishable when [HIn] and [In^-] differ by a factor of 10. The pH range over which a colour change occurs can be estimated by the expression: pH = pKIn ±1	
Reaction feasibility Standard enthalpy of formation, definitions and relevant calculations ΔHof = ΣΔHof (products) – ΣΔHo f (reactants).	Enthalpy of formation The standard enthalpy of formation, ΔHof, 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.	ΔHof = ΣΔHof (products) – ΣΔHof (reactants). Knowledge of standard conditions is important.	Dartmouth College activity – Enthalpy of formation of magnesium oxide
Entropy and prediction of value of entropy Changes of entropy	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.	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.	University of Toronto animation – Entropy Nuffield Foundation activity – A colourful clock reaction
Second and Third Laws of Thermodynamics	Experiment/demo of endothermic reaction of $Ba(OH)_2$ with NH_4Cl Examples of practical work which can be carried out on spontaneous	The change in standard entropy for a reaction system can be calculated from the standard entropies of the reactants and products.	Leek High School activities – Endothermic reactions

	endothermic reactions. Search leekhigh staffs chemistry Chemical reactions endothermic.	ΔSo = ΣΔSo (products) – ΣΔSo (reactants).	
Calculations in changes in standard entropy $\Delta S^o = \Sigma\Delta S^o$ (products) – $\Sigma\Delta S^o$ (reactants).	Experiment/demo of endothermic reaction of $Ba(OH)_2$ with NH_4Cl 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. $\Delta S^o = \Sigma\Delta S^o$ (products) – $\Sigma\Delta S^o$ (reactants).	Nuffield Foundation activity – Endothermic solid-solid reactions
Free energy The concept of free energy ΔG = ΔH – TΔS Calculation of standard free energy change for a reaction $\Delta G^o = \Sigma \Delta G^o$ (products) – $\Sigma \Delta G^o$ (reactants).	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 $NaHCO_3(s)$ be used to ensure bulb of thermometer is completely covered but this will produce a volume of CO_2 greater than 100 cm^3 so needs to be monitored carefully and heating stopped and syringe removed from the barrel before 100 cm^3 reached. Ellingham diagrams can be used to show how G^o varies with temperature and they were useful in predicting temperatures at which reductions of metal oxides became feasible.	Applications of the concept of free energy The feasibility of a chemical reaction under standard conditions can be predicted from the calculated value of the change in standard free energy (ΔG^o). The temperatures at which a reaction may be feasible can be estimated from $\Delta G^o = \Delta H^o - T\Delta S^o$ by considering the range of values of T for which $\Delta G^o < 0$. Under non-standard conditions any reaction is feasible if ΔG is negative. At equilibrium, $\Delta G = 0$. A reaction will proceed spontaneously in the forward direction until the composition is reached where $\Delta G = 0$.	Education Scotland activity – Verification of a thermodynamic prediction (Unit 2 PPA 4)

Kinetics Determination of the order of a reaction (0, 1, 2, 3) from experimental data and rate equations. Calculation of rate constants and units of k. rate = *k*[A]	Propanone/iodine reaction PPA from current AH. 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, i.e. 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.	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 = *k*[A] where *k* is the rate constant and [A] is the concentration of reactant A in mol l^{-1}. 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. 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.	Chemistry Teaching Resources activity – Verification of a thermodynamic prediction (Unit 2 PPA 5) SSERC activity – Determining the rate constant and order of reaction RSC case study – Horse racing forensic laboratory

Reaction mechanisms The rate determining step in a reaction From the rate equation predict the rate determining step and possible mechanism.	S_N1 and S_N2 reaction mechanisms can be discussed here but will also be covered in the Organic Chemistry Unit.	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.	Learn Chemistry activity – Iodination of propanone

Organic Chemistry and Instrumental Analysis			**Unit specification: http://bit.ly/1yYkeIX**
Mandatory course key areas	**Suggested learning activities**	**Exemplification of key areas**	**Useful resources**
Molecular orbitals Formation of bonding molecular orbitals	Chem.purdue.edu has information about atomic orbitals becoming molecular orbitals	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	Purdue University resources – Molecular orbital theory University of Sheffield animation – The orbitron
Hybridisation sp^3, sp^2 hybrid orbitals and their role in the formation of sigma and pi bonds	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 CH_4 v C_2H_4 v C_2H_2. As an extension, bonding in alkynes can be described in terms of sp hybridisation with both sigma and pi bonds. The website ibchem.com has information on sigma bonds, pi bonds and hybridisation.	Hybridisation is the process of mixing atomic orbitals within an atom to generate a set of new hybrid orbitals. As an extension, bonding in alkynes can be described in terms of sp hybridisation with both sigma and pi bonds. The website ibchem.com has information on sigma bonds, pi bonds and hybridisation. There are also other videos on the internet covering hybridisation.	McGraw-Hill Education animation – Hybridisation IB Chemistry resources – Orbitals

	There are also other videos on the internet covering hybridisation.	atomic orbitals called hybrid orbitals. Bonding in alkanes can be described in terms of sp^3 hybridisation and sigma bonds. Bonding in alkenes can be described in terms of sp^2 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. 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.	
The bonding continuum The symmetry and position of bonding orbitals between atoms determines types of bonding - ionic, polar or non-polar covalent bonding.	Markrosengarten.com has a fun song and video covering covalent, polar covalent and ionic bonding. Useful as revision of Higher bonding.	The bonding continuum 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	PhET animation – Molecule polarity YouTube video – What kind of bonds are these?

		compounds represent an extreme case of asymmetry with the bonding molecular orbitals being almost entirely located around just one atom.	
Molecular structure Convertion between molecular, structural and skeletal formulae with no more than 10 carbon atoms in their longest chain	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 Chemsketch. CHIME (a free plugin for web browsers) can also display a huge range of molecules in 3D. Extensive free libraries of 3D molecules are available to be downloaded from the internet. The	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.	ACD resources – ChemSketch Cambridgesoft resources – ChemDraw Chemdoodle resources – Chemdoodle YouTube video – Introduction to line drawings in organic chemistry

	structures of aliphatic compounds can be drawn on a Chemsketch type system. The functional groups -OH, -COOH, -C=O, -NH_2, -CONH-, -COO- can also be drawn and added to these compounds using a Chemsketch type system. A free alternative to Chemdraw is Chemsketch, which is available from ACD 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 Chemsketch type system. Tutorials on using Chemsketch and drawing skeletal formulae are available on the internet.		
Stereochemistry stereoisomerism	Videos on different forms of isomerism by Dr Chris Arthur and 'Brightstorm' are available on the internet.	Stereoisomers are molecules with the same molecular formula with a different spatial arrangement of their atoms.	YouTube video – Introduction to stereoisomerism

Geometric isomerism *cis* and *trans.* Physical and chemical properties of geometric isomers.	Make molecular models of cis and trans isomers. The influence of geometric isomerism on chemical properties can be illustrated by the fact that cis-butenedioic acid is more readily dehydrated than trans-butenedioic acid. Melting points and densities of cis-butenedioic and transbutenedioic acid can also be compared. Health issues associated with trans fatty acids. Also, the cis geometry of combretastatin is crucial to anticancer activity. Alkenes are often used to rigidify structures into active conformations.	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 cis and trans 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.	Boston College activity – Bromination of stilbene Yteach animation – Cis- and trans-isomers of compounds with a double carbon-carbon bond Learn Chemistry resources – Chemistry olympiad support booklet
Optical isomerism non-superimposable mirror image, chiral/ enantiomers Racemic mixture and effect on polarised light Physical and chemical properties of optical isomers	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. 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.	Optical isomers are non-superimposable mirror images of asymmetric molecules and such molecules can be described as chiral molecules 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	YouTube video – Optical isomerism Learn Chemistry activity – Extracting limonene from oranges University of Bristol resources – Optical isomerism In thalidomide YouTube video – Naming enantiomers R and S Learn Chemistry activity – Synthesis of

	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	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.	Nurofen

	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.		
Synthesis From given equations identify: substitution, addition, elimination, condensation, hydrolysis, oxidation, reduction reactions Devise synthetic routes, with no more than three steps, from a given reactant to a final product. Deduce possible reactions from molecular structures	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. RSC website Learn Chemistry has a program Investigating Organic Reaction Mechanisms which is an online tutorial on reaction mechanisms.	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. Learners should be able to devise synthetic routes, with no more than three steps, from a given reactant to a final product. Learners should be able to look at molecular structures and deduce the reactions it can undergo.	Learn Chemistry animations – Investigate organic reaction mechanisms HKEdCity animations – Reaction mechanism animation CompoundChem resources – Explorations of everday chemical compounds
Bond fission homolytic and heterolytic fission	Free radical chain reaction mechanism is covered at Higher. Chemguide.co.uk has information which covers free radical substitution reaction mechanism in more detail	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	ChemGuide resources – Free radical mechanisms menu Avogadro resources – Bond fission, radicals and photochemical reactions

	than at Higher. 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).	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. 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.	
Electrophiles and nucleophiles Reactions involving heterolytic bond fission. Nucleophiles or electrophiles as attacking groups.	Avogadro.co.uk provides definitions and examples of nucleophiles and electrophiles.	Electrophiles and nucleophiles 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.	Avogadro resources – Introducing chemical kinetics rate equations

		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.	
Curly arrow notation Use of double-headed and single-headed arrows to show electron movement. The curly arrow shows source and destination of the electron (s)	Chemguide.co.uk has information on use of curly arrows.	Use of double-headed and single-headed arrows to show electron movement. The head and tail of the arrow indicates the destination and origin 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	ChemGuide resources – Curly arrow mechanisms University of Oxford animations – Interactive organic reaction mechanisms Kirsop Labs animations – How to draw mechanisms using curly arrows

		electron.	
Haloalkanes Classification of monohaloalkanes as primary, secondary or tertiary. Monohaloalkanes undergo nucleophilic substitution reactions: • alkalis to form alcohols alcoholic alkoxides to form ethers • ethanolic cyanide to form nitriles which can be hydrolysed to carboxylic acids • Monohaloalkanes can also undergo elimination reactions to form alkenes	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.	Haloalkanes (alkyl halides) are named according to IUPAC rules. Monohaloalkanes can be classified as primary, secondary or tertiary. Monohaloalkanes undergo nucleophilic substitution reactions. They react with: • alkalis to form alcohols • alcoholic alkoxides to form ethers • ethanolic cyanide to form nitriles which can be hydrolysed to carboxylic acids (chain length increased by one carbon atom) Monohaloalkanes can also undergo elimination reactions to form alkenes. For example: Ethanolic KOH.	
The reaction mechanism for S_N1 and S_N2 reactions S_N1 and S_N2 reactions using curly arrows and mechanisms with particular attention given to the transition state/ intermediate	Not necessary to go into inductive stabilisation in great detail. Mechanisms and animations for S_N1 and S_N2 are available on the internet. Chemguide.co.uk gives information on nucleophilic substitution reactions.	The reaction mechanisms for S_N1 and S_N2 reactions can be represented using curly arrows. The dominance of an S_N1 or S_N2 mechanism for a particular haloalkane can be explained in terms of steric hindrance and the inductive stabilisation of an intermediate carbocation. An S_N2	University of Surrey animation – S_N1 mechanism University of Surrey animation – S_N2 mechanism Kirsop animations – Looking for Curly Arrows?

		reaction proceeds via a single five-centred transition state, whereas an S_N1 reaction occurs in two steps *via* a carbocation.	
The preparation properties, and reactions of alcohols Preparation from alkenes haloalkanes and reduction of carbonyl compounds using lithium aluminium hydride Physical properties related to bonding Dehydration, reaction with metals Reactions with carboxylic acids and acid chlorides	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 antiasthmatics).	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: • alkenes by acid-catalysed hydration; • haloalkanes by substitution 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.	Learn Chemistry experiment – Preparation of esters Education Scotland activity – preparation of benzoic acid by the hydrolysis of ethyl benzoate Learn Chemistry experiment – Microscale oxidation of alcohols Education Scotland activity – Preparation of aspirin Learn Chemistry experiment – Dehydration of ethanol to form ethene

Ethers Naming and general structure Boiling point related to bonding. Preparation using haloalkanes with alkoxides. Chemical and physical properties of ethers linked to molecular size and uses	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 ethoxyethane 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 experiment can be demonstrated.	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.	
Alkenes Preparation: • dehydration of alcohols • base-induced elimination of hydrogen halides from monohaloalkanes	Preparation of cyclohexene from cyclohexanol.	Preparation of alkenes Alkenes can be prepared in the laboratory by: • dehydration of alcohols using aluminium oxide, concentrated sulfuric acid or orthophosphoric acid • base-induced elimination of	Education Scotland activity – Preparation of benzoic acid by the hydrolysis of ethyl benzoate Kirsop Labs animations – Looking for Curly Arrows?

		hydrogen halides from monohaloalkanes	
• Electrophilic addition reactions: catalytic addition of hydrogen to form alkanes • addition of halogens to form dihaloalkanes • addition of hydrogen halides according to Markovnikov's rule, to form monohaloalkanes • acid-catalysed addition of water according to Markovnikov's rule, to form alcohols.	Chem. 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).	Alkenes can undergo the following electrophilic addition reactions: • catalytic addition of hydrogen to form alkanes • addition of halogens to form dihaloalkanes • addition of hydrogen halides according to Markovnikov's rule, to form monohaloalkanes • acid-catalysed addition of water according to Markovnikov's rule, to form alcohols. The mechanism for both the addition of hydrogen halides and the acid-catalysed addition of water involves a carbocation intermediate. The mechanism for addition of a halogen involves a cyclic ion intermediate. Both mechanisms can be written using curly arrows.	Kirsop Labs animations – Looking for Curly Arrows?
Carboxylic acids Preparation by: • oxidising primary alcohols and aldehydes;	Preparation of benzoic acid from ethyl benzoate (previously a PPA).	Preparation and reactions of carboxylic acids	Education Scotland activity – Preparation of benzoic acid by the hydrolysis of ethyl benzoate

• hydrolysing nitriles, esters, amides. Reactions: • formation of salts by reactions with metals or bases • condensation reactions with alcohols to form esters in the • presence of an acid catalyst reaction with amino groups to form amide links • reduction with lithium aluminium hydride to form primary alcohols	Carboxylic acids are weak acids, neutralisation with alkalis to form salts, reaction with Mg — covered in Physical Chemistry Unit. Carboxylic acids are often ionised in drugs and form ionic interactions with binding sites. Penicillin contains a carboxylate ion that plays a crucial binding role. Consider role of carboxyl functional group in polymerisation the formation of polyesters, polyamides and proteins.	Carboxylic acids can be prepared by: • oxidising primary alcohols and aldehydes; • hydrolysing nitriles, esters, amides. Reactions of carboxylic acids include: • formation of salts by reactions with metals or bases • condensation reactions with alcohols to form esters in the • presence of an acid catalyst reaction with amino groups to form amide links • reduction with lithium aluminium hydride to form primary alcohols	Learn Chemistry resources – Information on carboxylic acids and carboxylic acid derivatives McGraw-Hill Education resources – Reaction of carboxylic acids Learn Chemistry experiment – Synthesis of nylon
Amine classification as primary, secondary or tertiary. Physical properties related to structure. 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. Indiana.edu also provides information about amines and their salts in medicines.	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	Learn Chemistry resources – Structure and reactions of amines ChemGuide resources – Introducing amines Purdue University resources – Amines, Alkaloids, and Amides YouTube video – Amines experiment

	Elmhurst.edu has some homework ideas on amines but need to be selective.	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.	
Aromatic hydrocarbons and reactions of benzene Structure, bonding and stability of the benzene ring. Substitution reactions of benzene (phenyl); alkylation, nitration, sulfonation and halogenation as examples of electrophilic substitution in benzene and other aromatic compounds	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 tricholorophenol or 4-chloro-3,5-dimethylphenol, permanent markers containing xylene or toluene. An 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.	Aromatic hydrocarbons and reactions of benzene Benzene C_6H_6 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 atom has been substituted by another group is known as the phenyl group. The phenyl group has the formula - C_6H_5. 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 sp^2	Learn Chemistry resources – Substance: List of aromatic hydrocarbons YTeach animation – Halogenation of a benzene ring Learn Chemistry experiment – Organic molecules day Shell resource – Benzene-containing feedstocks product stewardship summary

	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.	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.	
Experimental determination of structure Elemental microanalysis 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	SnI_4 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.	In organic chemistry, a number of experimental techniques are carried out to verify that the correct chemical structure has been synthesised. 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.	Elemental Microanalysis videos – How to videos
Spectroscopy	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		Learn Chemistry resources – Introduction to spectroscopy Learn Chemistry resources – Spectroscopy in a suitcase

	experience. As well as covering the principles of spectroscopic techniques, 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. 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.		RSC resources – SpectraSchool
Mass spectrometry Interpretation of fragmentation data to gain structural information	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	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.	RSC animation –Mass Spectrometry ChemGuide resources – Information on the workings of a Mass Spectrometer

	compound.		
Infra-red spectroscopy Interpretation of spectral data to gain structural information	IR is still widely used as it is cheaper than NMR and can be used to follow reaction progress (i.e. 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.	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 that 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, 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 cm^{-1}.	Learn Chemistry resources – Information on IR Spectroscopy ChemGuide resources – Information on IR Spectroscopy RSC animation –Infra-Red Spectrometer

Interpretation of ^{1}H NMR spectra. Understand how a proton NMR spectrum is produced Interpretation of spectral data to gain structural information Draw and analyse low resolution proton NMR spectra and to analyse high resolution proton NMR spectra.	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. 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.	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.	ChemGuide resources – information on proton NMR Learn Chemistry resources – Spectra school RSC animation – NMR spectrometer Learn Chemistry activity – Nuclear Magnetic Resonance

	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.		
UV Spectroscopy Absorption of visible light by organic molecules. An explanation of why organic compounds are colourless or coloured with reference to molecular orbital theory or conjugated systems.	When ninhydrin reacts with amino acids, a highly conjugated product is formed which absorbs light in the visible region. 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.	Most organic molecules appear colourless because the energy difference between the 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	ChemGuide resources – UV-Visible absorption spectra Learn Chemistry resources –UV Visible spectroscopy YouTube video – How does a spectrophotometer work? Learn Chemistry activity – The microscale synthesis of azo dyes

	Synthetic indigo can also be prepared using a microscale method.	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.	
Chromophores Describe a chromophore and explain its role in the colour exhibited by the compound.	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 animations and animations. Simple spectroscopes made from DVDs can be used to view light transmitted or reflected by coloured compounds.	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.	ChemGuide resources – UV-Visible Absorption Spectra PhysClips animations – Colouring mixing and colour vision

Pharmaceutical Chemistry Effect of drugs on the body Lipinski rule of five	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. '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. Another interactive resource from the RSC is the 'Masterminding Molecules' package. This resource combines learning with game-play and involves cracking a code to	Drugs are substances which alter the biochemical processes in the body. Drugs that have beneficial effects are used in medicines. A medicine usually contains the drug plus other ingredients. Lipinski rule of five (multiples of 5). • Molecular mass less than 500 amu. • Not more than 5 hydrogen bond donors. • Not more than 10 hydrogen bond acceptors. • An octanol/water partition coefficient log P not greater than 5.	RSC resources – Breaking the rules Learn Chemistry activity – Masterminding Molecules

	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. RSC learn chemistry has a bank of resources in challenging medicine. Not all will be suitable for the AH course.		
Classification of drugs Classification of drugs as agonists or as antagonists	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	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 similar to the body's natural active compound. An antagonist produces no response but prevents the action of the	The Merck Manual resources – Drug–receptor interactions Frostburg State University learner resource – Andanamide University of Bristol resources – Andanamide

	which nerve cells communicate, through molecular keys and receptors. There are other drug targets apart from receptors and enzymes, such as DNA and RNA.	body's natural active compound.	
How drugs work Identify the types of interaction between drug functional groups and receptor sites. Recognise the pharmacophore in drug molecules.	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	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 that 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	Learn Chemistry resource – Molecules against malaria Design of a structure activity Relationship study of antimalarial 4-aminoquinolines RSC quiz – 'Masterminding molecules' YouTube video – Computer Aided Drug Discovery Pipeline

	Molecules (RSC) can be used to illustrate these concepts. Excellent opportunity to investigate structural fragments common to different medicines using websites given above.	drugs and binding sites. 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. Many drugs act as enzyme inhibitors by binding to the enzyme's active site and blocking the reaction normally catalysed there.	

Researching Chemistry			**Unit specification: http://bit.ly/1AbDN4p**
Mandatory course key areas	**Suggested learning activities**	**Exemplification of key areas**	**Useful resources**
Gravimetric analysis Analytical determination of composition of a substance's mass by chemically changing the substance Understanding of key techniques including 'weighing by difference' and 'heating to constant mass'		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. Learners should be aware of the techniques of weighing by difference and heating to constant mass. Possible experiments include: • gravimetric determination of water in hydrated barium chloride • gravimetric determination of water in hydrated magnesium sulfate • determination of Ni using butanedioxime (dimethylglyoxime)	Education Scotland activity – Gravimetric analysis
Volumetric analysis Appreciation of the characteristics of substances that can be used as a primary standard		Preparation of a standard solution / primary standard / standardising solutions	Learn Chemistry resources – volumetric analysis background information and experiments

Good practice in preparation of a standard solution and their use in determination of a unknown solution's concentration		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: • high state of purity • stability in air and in solution • solubility • reasonably high formula mass Examples of primary standards include: • sodium carbonate, Na_2CO_3 • oxalic acid, $H_2C_2O_4.2H_2O$ • potassium hydrogen phthalate, $KH(C_8H_4O_4)$ • silver nitrate, $AgNO_3$ • potassium iodate, KIO_3 • potassium dichromate, $K_2Cr_2O_7$ 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.	

		Possible experiments include: • Prepare a standard solution of 0·1 mol l^{-1} • oxalic acid • Standardisation of approx 0·1 mol l^{-1} NaOH(aq) • Determination of the ethanoic acid content of vinegar • Preparation of a standard solution of 0·1 mol l^{-1} sodium carbonate solution • Standardisation of approximately 0·1 mol l^{-1} HCl(aq) • Determination of the purity of marble by back titration Animation of titration and titrations with corresponding calculations can be found on the internet.	Learn Chemistry animations – acid/base titration Education Scotland activity – the purity of marble *via* a back titration Labskills animation – Titration set up Labskills animation –Titration end points
Understanding the role of a control in experiments to validate techniques		Use of a control A control validates a technique and may consist of carrying out a determination on a solution of known concentration. Possible experiments include: • Determination of the percentage acetylsalicylic acid in a commercial tablet, using 'pure' aspirin as a control	Learn Chemistry experiment – Aspirin Nuffield Foundation experiment – Measuring the vitamin C content of fruit and juices

		• Determination of Vitamin C in a fruit juice using pure ascorbic acid as a control	
Understanding the use of complexometric titration in quantitative analysis of solutions containing a metal ion		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. A possible experiment could be the determination of the percentage of Ni in a nickel salt using EDTA.	Education Scotland activity – Gravimetric analysis
Understanding of back titrations and associated calculations		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 under test. A back titration is useful when trying to work out the quantity of substance	ChemGuide resources – Finding orders of reaction experimentally Education Scotland experiment – The purity of marble *via* a back titration

		in an insoluble solid. Possible experiments include: • Determination of aspirin • Determination of purity of marble by back titration	
Practical Skills and Techniques Preparation of standard solutions using accurate dilution technique Formation and use of calibration curves to determine an unknown using solutions of appropriate concentration		Colorimetry/accurate dilution 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. Possible experiments include: • Colorimetric determination of manganese in steel • Determination of nickel using colorimetric analysis	Vernier experiment – The synthesis and analysis of Aspirin Education Scotland activity – determination of Mn in steel Education Scotland activity – determination of nickel using EDTA

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	A video showing simple, fractional and steam distillation is available on the internet	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. Distillation is used to purify a compound by separating it from a non-volatile or less volatile material. This technique provides opportunities for learners to become familiar with glassware containing ground glass joints. Possible experiments include: • Preparation of benzoic acid by hydrolysis of ethyl benzoate • Preparation of ethyl ethanoate • Preparation of cyclohexene from cyclohexanol	ChemGuide resources – Fractional distillation of ideal mixtures and liquids Learn Chemistry experiment – Extracting limonene form oranges by steam distillation Youtube video – How steam distillation works Education Scotland activity – Preparation of benzoic acid by hydrolysis of ethyl benzoate OCR A Level Chemistry experiment – The preparation of ethyl ethanoate Education Scotland activity – preparation of cyclohexene from cyclohexanol (Unit 3 PPA 1)

	Different videos showing heating under reflux are available on the internet.	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. Possible experiments include: • Preparation of benzoic acid by hydrolysis of ethyl benzoate • Preparation of ethyl ethanoate	Learn Chemistry resources – heating under reflux
	A video on vacuum filtration showing use of a Buchner funnel and a Hirsch funnel is available on the internet.	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	Learn Chemistry resources – vacuum filtration

		medium depends on the quantity and nature of the precipitate. Possible experiments include: • Preparation of potassium trioxolatoferrate(III) • Preparation of aspirin • Preparation of benzoic acid by hydrolysis of ethyl benzoate • Identification by derivative formation	Education Scotland activity – Preparation of potassium trioxolatoferrate(III) Education Scotland activity – Preparation of aspirin Education Scotland activity – Preparation of benzoic acid by hydrolysis of ethyl benzoate Chemistry teaching resources activity – Identification by derivative formation (Unit 3 PPA 2)
	Videos on recrystallisation are available on the internet.	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.	Learn Chemistry video – Recrystallisation

		The more soluble impurities are left behind in the solvent. Possible experiments include: • Preparation of benzoic acid by hydrolysis of ethyl benzoate • Preparation of potassium trioxalatoferrate(III) • Preparation of acetylsalicylic acid	Education Scotland activity – Preparation of benzoic acid by hydrolysis of ethyl benzoate Education Scotland activity – Preparation of potassium trioxolatoferrate(III) Education Scotland activity – Preparation of Aspirin
Solvent Extraction	For example, supercritical CO_2 is used in the preparation of decaffeinated coffee. Videos on solvent extraction are available on the internet.	Use of a separating funnel 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	ChemGuide learner resources – Partition

		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. Possible experiments include: • Preparation of ethyl ethanoate • Extraction of caffeine from tea	OCR A Level Chemistry experiment – The preparation of ethyl ethanoate Nuffield Foundation experiment – extraction of caffeine
Knowledge of the appropriate uses of thin layer chromatograph, melting point and mixed melting point determination in evaluating the purity of an experimental products	Videos of thin-layer chromatography are available on the internet.	Use of thin-layer chromatography to assess product purity Instead of chromatography paper, thin-layer chromatography (TLC) uses a fine film of silica or aluminium oxide spread over glass or plastic. R_f values can be calculated and under similar conditions a compound will always have the same R_f value within experimental error. Since a pure substance will show	Learn Chemistry video – Thin Layer Chromatography (TLC)

		up as only one spot on the developed chromatogram, TLC can be used to assess the purity of a product prepared in the lab.	
Calculation of Rf values from relevant data and its use in following the course of a reaction.		Possible experiments include: • Preparation of aspirin • Hydrolysis of ethyl benzoate	Education Scotland activity – Preparation of benzoic acid by hydrolysis of ethyl benzoate (Unit 3 PPA 3) Education Scotland activity – Preparation of Aspirin NCSEC experiment –Plant pigments activity
	Videos on melting point determination are available on the internet.	Determination of melting point and mixed melting point 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.	Learn Chemistry resources – Melting point determination

		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 Possible experiments include: • Preparation of benzoic acid by hydrolysis of ethyl benzoate • Identification by derivative formation • Preparation of aspirin	Education Scotland activity – Preparation of benzoic acid by hydrolysis of ethyl benzoate Education Scotland activity – Identification by derivative formation Education Scotland activity – Preparation of aspirin
Stoichiometric Calculations Calculations from balanced equations, including multistep reactions, reactant excess, and empirical formulae from given data. Calculations and explanations		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	ChemGuide resources – What does "stoichiometry" mean?

comparing theoretical and actual yield		examinable in the course assessment. Experimental determination of percentage yield and atom economy. 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. Possible experiments include: • Preparation of aspirin • Preparation of potassium trioxolatoferrate(III) • Preparation of benzoic acid by hydrolysis of ethyl benzoate • Preparation of ethyl ethanoate	Education Scotland activity – Preparation of aspirin Education Scotland activity – Preparation of potassium trioxolatoferrate(III) Education Scotland activity – Preparation of benzoic acid by hydrolysis of ethyl benzoate OCR A Level Chemistry experiment – Preparation of ethyl ethanoate