

Scheme of Work

Cambridge International AS & A Level Chemistry 9701

For examination from 2022



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Introduction

This scheme of work has been designed to support you in your teaching and lesson planning. Making full use of this scheme of work will help you to improve both your teaching and your learners' potential. It is important to have a scheme of work in place in order for you to guarantee that the syllabus is covered fully. You can choose what approach to take and you know the nature of your institution and the levels of ability of your learners. What follows is just one possible approach you could take and you should always check the syllabus for the content of your course.

Suggestions for independent study (**I**) and formative assessment (**F**) are also included. Opportunities for differentiation are indicated as **Extension activities**; there is the potential for differentiation by resource, grouping, expected level of outcome, and degree of support by teacher, throughout the scheme of work. Timings for activities and feedback are left to the judgement of the teacher, according to the level of the learners and size of the class. Length of time allocated to a task is another possible area for differentiation.

Key concepts

The key concepts are highlighted as a separate item in the new syllabus. Reference to the Key Concepts is made throughout the scheme of work using the key shown below:

Key Concept 1 (KC1) – Atoms and forces

Matter is built from atoms interacting and bonding through electrostatic forces. The structure of matter affects its physical and chemical properties, and influences how substances react chemically.

Key Concept 2 (KC2) – Experiments and evidence

Chemists use evidence gained from observations and experiments to build models and theories of the structure and reactivity of materials. Theories are tested by further experiments and an appreciation of accuracy and reliability is gained.

Key Concept 3 (KC3) – Patterns in chemical behaviour and reactions

Patterns in chemical behaviour can be identified and used to predict the properties of substances. By applying these patterns, useful new substances can be designed and synthetic routes created.

Key Concept 4 (KC4) – Chemical bonds

The understanding of how chemical bonds are made and broken by the movement of electrons allows us to predict patterns of reactivity. Appreciation of the strength of chemical bonds leads to the understanding of a material's properties and its uses.

Key Concept 5 (KC5) – Energy changes

The energy changes that take place during chemical reactions can be used to predict the extent, feasibility and rate of such reactions. An understanding is gained of why and how chemical reactions happen.

Guided learning hours

Guided learning hours give an indication of the amount of contact time teachers need to have with learners to deliver a particular course. Our syllabuses are designed around 180 hours for Cambridge International AS Level, and 360 hours for Cambridge International A Level. The number of hours may vary depending on local practice and your learners' previous experience of the subject. The table below give some guidance about how many hours are recommended for each topic.

AS Level topics	Teaching time (hours)	Teaching order	A Level topics	Teaching time (hours)	Teaching order
1 Atomic structure	12	1	23 Chemical energetics	22	1
2 Atoms, molecules & stoichiometry	10	2	24 Electrochemistry	18	3
3 Chemical bonding	16	3	25 Equilibria	16	2
4 States of matter	4	4	26 Reaction kinetics	16	13
5 Chemical energetics	10	5	27 Group 2	2	14
6 Electrochemistry	4	10	28 Chemistry of the transition elements	22	15
7 Equilibria	12	11	29 An introduction to organic chemistry	6	4
8 Reaction kinetics	12	12	30 Hydrocarbons	8	5
9 The Periodic Table: chemical periodicity	10	6	31 Halogen compounds	2	6
10 Group 2	5	7	32 Hydroxy compounds	8	7
11 Group 17	10	8	33 Carboxylic acids and derivatives	8	8
12 Nitrogen and sulfur	4	9	34 Nitrogen compounds	12	9
13 An introduction to organic chemistry	included in the teaching of topics 14–21		35 Polymerisation	12	10
14 Hydrocarbons	10	13	36 Organic synthesis	12	11

AS Level topics	Teaching time (hours)	Teaching order	A Level topics	Teaching time (hours)	Teaching order
15 Halogen compounds	8	14	37 Analytical techniques	16	12
16 Hydroxy compounds	10	15			
17 Carbonyl compounds	10	16			
18 Carboxylic acids and derivatives	6	17			
19 Nitrogen compounds	6	18			
20 Polymerisation	3	19			
21 Organic synthesis	10	20			
22 Analytical techniques	8	21			

Resources

You can find the endorsed resources to support Cambridge International AS & A Level Chemistry 9701 on the Published resources tab of the syllabus page on our [public website](#)

Endorsed textbooks have been written to be closely aligned to the syllabus they support, and have been through a detailed quality assurance process. All textbooks endorsed by Cambridge International for this syllabus are the ideal resource to be used alongside this scheme of work as they cover each learning objective. In addition to reading the syllabus, teachers should refer to the specimen assessment materials

School Support Hub

[School Support Hub](#) is a secure online resource bank and community forum for Cambridge teachers, where you can download specimen and past question papers, mark schemes and other teaching and learning resources. We also offer online and face-to-face training; details of forthcoming training opportunities are posted online. This scheme of work is available as PDF and an editable version in Microsoft Word format; both are available on the [School Support Hub](#). If you are unable to use Microsoft Word you can download Open Office free of charge from www.openoffice.org

Websites

This scheme of work includes website links providing direct access to internet resources. Cambridge Assessment International Education is not responsible for the accuracy or content of information contained in these sites. The inclusion of a link to an external website should not be understood to be an endorsement of that website or the site's owners (or their products/services).

The website pages referenced in this scheme of work were selected when the scheme of work was produced. Other aspects of the sites were not checked and only the particular resources are recommended.

How to get the most out of this scheme of work – integrating syllabus content, skills and teaching strategies

We have written this scheme of work for the Cambridge International AS & A Level Chemistry 9701 syllabus and it provides some ideas and suggestions of how to cover the content of the syllabus. We have designed the following features to help guide you through your course.

Learning objectives help your learners by making it clear the knowledge they are trying to build. Pass these on to your learners by expressing them as 'We are learning to / about...'.

Suggested teaching activities give you lots of ideas about how you can present learners with new information without teacher talk or videos. Try more active methods which get your learners motivated and practising new skills.

Extension activities provide your more able learners with further challenge beyond the basic content of the course. Innovation and independent learning are the basis of these activities.

Independent study (I) gives your learners the opportunity to develop their own ideas and understanding with direct input from you.

Past papers, specimen papers and mark schemes are available for you to download at:
www.cambridgeinternational.org/support

Using these resources with your learners allows you to check their progress and give them confidence and understanding.

Resource Plus is available at:
www.cambridgeinternational.org/support

Containing additional teaching and learning materials for challenging topics and skills. Use the videos, lesson plans and worksheets to engage your learners and improve their practical skills.

Syllabus ref. and Key Concepts (KC)	Learning objectives	Suggested teaching activities
	17.1.3 Describe the mechanism of the nucleophilic addition of hydrogen cyanide to aldehydes and ketones (17.1.2(b)).	<p>the product is a primary or a secondary alcohol in each case.</p> <p>Extension activity: More advanced learners can research why one reducing reagent is used over the other, why LiAlH_4 is more powerful than NaBH_4 and how the reactions are carried out.</p> <p>The reactions of aldehydes and ketones with HCN and KCN Learners should first draw out the reaction without considering the mechanism, noting that a hydroxynitrile is produced. (I)</p> <p>Discuss with learners that the attacking species is the electron-rich nucleophile, the cyanide ion. They then draw the mechanism of the reaction.</p> <p>The following site allows learners to view, interact with the mechanism and rotate the resulting structures: www.chemtube3d.com/a-level-additioncyanide/</p> <p>Extension activity: Learners could link this topic with 29.4 Isomerism: optical. They can find out why this reaction produces a racemic mixture of two optical isomers. www.chemguide.co.uk/mechanisms/nucadd/hcn.html#top</p>
17.1 Aldehydes and ketones (KC2)	17.1.4 Describe the use of 2,4-dinitrophenylhydrazine (2,4-DNPH reagent) to detect the presence of carbonyl compounds.	<p>Learners only need to know that DNPH is a reagent used in the qualitative test for the presence of a carbonyl group in aldehydes and ketones. Both produce a yellow-orange precipitate showing that a carbonyl group is present in the molecule.</p> <p>Extension activity: Learners could find out about the historical use of DNPH as a tool to check for carbonyl compounds. They could draw out the structure of DNPH and write an equation showing how it reacts with a carbonyl compound to form the precipitate. www.youtube.com/watch?v=OugcrG8y_lg [historical use of the reagent and a discussion of the test]</p> <p>Discuss with learners that there are several additional tests which can be performed to find out if an unknown compound is an aldehyde or a ketone. www.docbrown.info/page13/ChemicalTests/ChemicalTestsf.htm [describes all of the tests for aldehydes and ketones]</p> <p>Experimental: Resource Plus Carry out the <i>Identifying alkenes, alcohols and halogenoalkanes</i> experiment referring to the Teaching Pack for lesson plans and resources.</p>

Past and specimen papers

Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)

Formative assessment (F) is ongoing assessment which informs you about the progress of your learners. Don't forget to leave time to review what your learners have learnt; you could try question and answer, tests, quizzes, 'mind maps', or 'concept maps'. These kinds of activities can be found in the scheme of work.

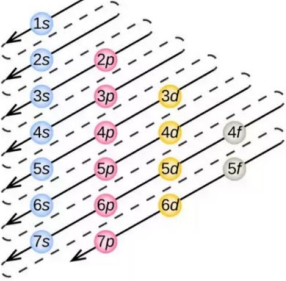
1 Atomic structure

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
1.1 Particles in the atom and atomic radius KC1	1.1.1 Understand that atoms are mostly empty space surrounding a very small, dense nucleus that contains protons and neutrons; electrons are found in shells in the empty space around the nucleus.	<p>Ask learners to sketch an atom, labelling any sub-atomic particles they are able to identify.</p> <p>Mini-project: learners research the history of the atom, producing a timeline of discoveries. A useful reference: www.thoughtco.com [search for A brief history of atomic theory].</p> <p>Rutherford's gold foil experiment: Learners could explore the historical Rutherford scattering experiment using the following simulation: phet.colorado.edu/en/simulation/rutherford-scattering</p> <p>After exploration, ask learners what the experiment demonstrates. Learners should conclude that atoms are mostly empty space.</p> <p>A useful text-based reference for this experiment: //chem.libretexts.org [search for Rutherford's Atomic model]</p> <p>You could also show and discuss a video of a modern-day reconstruction of the historical experiment: www.youtube.com/watch?v=XBqHkraf8iE</p> <p>Extension activity: More advanced learners could imagine that they have: a thin sheet of gold foil; an alpha-particle source; alpha-particle detectors directly behind the gold foil and to the side of it. Tell learners that an atom consists of mostly empty space learners, and ask them to predict the results and conclusion of this experiment.</p>
1.1 Particles in the atom and atomic radius KC1	1.1.2 Identify and describe protons, neutrons and electrons in terms of their relative charges and relative masses. 1.1.3 Understand the terms atomic and proton number; mass and nucleon number.	<p>Learners complete a blank table with the headings: Particle, Relative charge, Relative mass and rows labelled: Proton, Neutron, Electron. Ensure that they understand the term 'relative'. (I)</p> <p>Extension activity: More advanced learners could research the actual masses of these particles and how they were determined. [J. J. Thomson's discovery of the electron, Millikan's experiment determining the charge on an electron, Rutherford's discovery of the proton]</p> <p>Start by defining the terms and invite learners to draw some simple atoms on the board.</p> <p>Alternatively, learn the terms while building various atoms using the following interactive: //interactives.ck12.org/simulations/chemistry.html</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	1.1.4 Describe the distribution of mass and charge within an atom.	[search for atom builder]
1.1 Particles in the atom and atomic radius KC1	1.1.5 Describe the behaviour of beams of protons, neutrons and electrons moving at the same velocity in an electric field.	<p>Give learners a sheet of graph paper showing a beam of particles (electrons, protons and neutrons) of the same velocity, entering an electric field as shown in the following diagram: www.chemguide.co.uk/atoms/properties/gcse.html</p> <p>Learners draw three separate lines for the paths the particles take when an electric field is switched on. (I)</p> <p>If a cathode ray oscilloscope is available, an electric field could be applied to an electron beam to show how it is deflected. Invite learners to prepare this practical with you and perform demonstration. Give learners taking A Level Physics the opportunity to prepare and deliver an explanation.</p> <p>If a cathode ray oscilloscope is not available, show and discuss the following video: www.youtube.com/watch?v=PpOAlj7sOEc</p>
1.1 Particles in the atom and atomic radius KC1	1.1.6 Determine the numbers of protons, neutrons and electrons present in both atoms and ions given atomic or proton number, mass or nucleon number and charge.	<p>The following simulation allows learners to play various games, useful as a starter or as a fun class activity: phet.colorado.edu/sims/html/build-an-atom/latest/build-an-atom_en.html</p> <p>Prepare a worksheet with the headings 'Name of element', 'Chemical symbol', 'Mass number', 'Atomic number', 'Number of protons', 'Number of neutrons' and 'Number of electrons'. For at least 20 elements, provide some of the information above. Learners fill in the blanks in the table, to practise calculating the number of elementary particles and using the necessary terms.</p> <p>Provide a mark scheme for learners to check their answers. (F)</p>
1.1 Particles in the atom and atomic radius KC1	1.1.7 State and explain qualitatively the variations in atomic radius and ionic radius across a period and down a group.	<p>Provide learners with blank Periodic Tables and a data table of atomic and ionic radii. On the blank Periodic Tables, they sketch the relative sizes of the atoms and ions using circles. www.chemedx.org/activity/periodic-trends-guided-inquiry-activity [Blank Periodic Tables and data are downloadable from this site]</p> <p>In the activity below, learners can drag electrons off the outermost shells of electrons and the resulting graph of the atomic radius is displayed and compared to other elements: teachchemistry.org/periodical/issues/march-2016/periodic-trends-ionization-energy-atomic-radius-ionic-radius</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		A general reference to atomic and ionic radius: www.chemguide.co.uk/atoms/properties/atradius.html [there are free downloadable question and answer sheets available].
1.2 Isotopes KC1	1.2.1 Define the term isotope in terms of numbers of protons and neutrons.	Display or draw images of the three isotopes of hydrogen: protium, deuterium and tritium. Ask learners to explain how they are similar and how they are different. Explain that they are three naturally occurring forms of hydrogen, called isotopes. With the knowledge gained about the isotopes of hydrogen ask learners in their own words to write a definition of the term isotope, in terms of the number of protons and neutrons present.
1.2 Isotopes KC1	1.2.2 Understand the notation X_YA for isotopes, where x is the mass or nucleon number and y is the atomic or proton number.	Express the isotopes of hydrogen in this notation labelling x as the mass number and y as the atomic number. (Learners should also be familiar with the terms nucleon number and proton number.) Give the numbers of protons, neutrons and electrons of the three isotopes of carbon and ask learners to express each using this notation. Making models is an effective way to appreciate the way in which isotopes vary. A simple way to do this is to use different-coloured beads arranged on a table to represent just the nucleus of the atom. First create a model of the nucleus of ^{12}C using twelve beads of one colour to represent the protons and twelve beads of another colour to represent the neutrons. Then, add another neutron and then another to show the isotopes of that element, noting that the proton number does not change. Learners can build and test isotopes using this simulation: phet.colorado.edu/en/simulation/isotopes-and-atomic-mass
1.2 Isotopes	1.2.3 State that and explain why isotopes of the same element have the same chemical properties.	Choose and display unlabelled images of isotopes that learners have probably not seen before, for example, the isotopes of potassium, ^{39}K , ^{40}K and ^{41}K . Ask learners why they are isotopes and what it is that makes them the same element. Tell learners that since they are the same element, they have similar chemical properties. Show the following video about D_2 and D_2O to learners. It demonstrates that H_2 and D_2 burn similarly in air. It shows that D_2O and H_2O react similarly with calcium metal: www.youtube.com/watch?v=XiMvUZMI6Og
1.2 Isotopes	1.2.4 State that and explain why isotopes of	Start by showing the following video up to 01:00. www.youtube.com/watch?v=YYInVraBe7s

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities																													
	the same element have different physical properties, limited to mass and density.	Ask learners to explain what appears different about putting cubes of D ₂ O ice in a glass of H ₂ O compared to H ₂ O ice cubes in H ₂ O. Learners can then suggest a reason for the result. [The mass per unit volume (density) of deuterated ice is about 1.11g/cm ³ , thus it sinks in ordinary water.]																													
1.3 Electrons, energy levels and atomic orbitals KC1	1.3.1 Understand the terms: <ul style="list-style-type: none"> shells, sub-shells and orbitals principal quantum number (n) ground state, limited to electronic configuration. 	Ask learners to draw a planetary model of an atom such as sodium using their previous knowledge, showing its electron configuration. Ask them how many shells they have drawn and what the rules are for filling them. Next, give learners a slightly more detailed planetary diagram of the sodium atom: <ul style="list-style-type: none"> Show that the 1st shell contains a maximum of 2 electrons and represents n = 1 For n = 2, replace the single orbital line holding 8 electrons with two orbital lines. In the one closest to the nucleus, place 2 electrons and in the second, place the remaining 6 electrons. Name these the two sub-shells of n = 2. Finally place the last electron in n = 3 explaining that in fact n = 3 has 3 sub-shells. Mention that this is the ground state configuration of the sodium atom, but that electrons may move to higher energy, excited states under certain circumstances. 																													
1.3 Electrons, energy levels and atomic orbitals KC1	1.3.2 Describe the number of orbitals making up s, p and d sub-shells, and the number of electrons that can fill s, p and d sub-shells. 1.3.4 Describe the electronic configurations to include the number of electrons in each shell, sub-shell and orbital.	Expand on the description in 1.3.1 for the sodium atom to include examples with d sub-shells. Learners draw the following table and compare it to the simpler model they used in Cambridge IGCSE Chemistry (or equivalent). <table border="1" data-bbox="779 948 2013 1225"> <thead> <tr> <th>Principal quantum number (n)</th> <th>Sub-shells type</th> <th>Number of orbitals</th> <th>Number of electrons</th> <th>Maximum number of electrons in principal quantum number</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>1s</td> <td>1</td> <td>2</td> <td>2</td> </tr> <tr> <td rowspan="2">2</td> <td>2s</td> <td>1</td> <td>2</td> <td rowspan="2">8</td> </tr> <tr> <td>2p</td> <td>3</td> <td>6</td> </tr> <tr> <td rowspan="3">3</td> <td>3s</td> <td>1</td> <td>2</td> <td rowspan="3">18</td> </tr> <tr> <td>3p</td> <td>3</td> <td>6</td> </tr> <tr> <td>3d</td> <td>5</td> <td>10</td> </tr> </tbody> </table>	Principal quantum number (n)	Sub-shells type	Number of orbitals	Number of electrons	Maximum number of electrons in principal quantum number	1	1s	1	2	2	2	2s	1	2	8	2p	3	6	3	3s	1	2	18	3p	3	6	3d	5	10
Principal quantum number (n)	Sub-shells type	Number of orbitals	Number of electrons	Maximum number of electrons in principal quantum number																											
1	1s	1	2	2																											
2	2s	1	2	8																											
	2p	3	6																												
3	3s	1	2	18																											
	3p	3	6																												
	3d	5	10																												
1.3 Electrons, energy levels and atomic orbitals KC1	1.3.3 Describe the order of increasing energy of the sub-shells within the first three shells and the 4s and 4p sub-shells.	One method to help learners remember the order of increasing energy of the sub-shells is to apply the 'aufbau' principle. The following diagram allows learners to determine the sub-shell energies in an order in which electrons fill these orbitals. Highlight the fact that the 4s level fills before the 3d level. socratic.org/questions/do-electrons-fill-the-lower-energy-levels-first																													

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		 <p>www.youtube.com/watch?v=J-DjEIllynjE</p>
<p>1.3 Electrons, energy levels and atomic orbitals</p> <p>KC1</p>	<p>1.3.6 Determine the electronic configuration of atoms and ions given the atomic or proton number and charge, using either of the following conventions: e.g. for Fe: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$ (full electron configuration) or [Ar] $3d^6 4s^2$ (shorthand electron configuration).</p>	<p>To appreciate this sub-topic, use the 'Electron Hotel' analogy, where each floor of the hotel represents a principal quantum number, n (shell). The hotel has a strict policy of filling the rooms.</p> <p>The ground floor (n = 1) must be filled first. It contains just two guests and each of these guests are in separate beds facing in opposite directions.</p> <p>Link the evidence for electronic configurations as discussed here to successive ionisation energies in section 1.4.</p> <p>The 'Electron hotel' model: pnhs.psd202.org/documents/lcasey/1536685651.pdf</p> <p>Creative learners may like to try to devise their own version of the Electron Hotel and share with the class. Here is one example: www.storyboardthat.com/storyboards/amy-roediger/the-electron-hotel</p>
<p>1.3 Electrons, energy levels and atomic orbitals</p> <p>KC1</p>	<p>1.3.5 Explain the electronic configurations in terms of energy of the electrons and inter-electron repulsion.</p> <p>1.3.7 Understand and use the electrons in boxes</p>	<p>Explain to learners that every electron in an atom is unique and that no two electrons can have identical properties.</p> <p>Show learners how to write H and He first: helium has 2 electrons which fill the lowest energy sub-shell (1s).</p> <p>The orbital with the next lowest energy is Li and then Be filling the 2s sub-shell.</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	notation e.g. for Fe: $[\text{Ar}] \uparrow\downarrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow\downarrow$	<p>When we get to boron, tell learners of the rule that every orbital in a sub-level must be singly occupied before any orbital can be doubly occupied. Also, all of the electrons in singly occupied orbitals must have the same spin (arrows pointing in the same direction in the boxes).</p> <p>Thus carbon becomes $1s^2 2s^2 2p_x^1 2p_y^1$ and Nitrogen $1s^2 2s^2 2p_x^1 2p_y^1 2p_z^1$</p> <p>These can be represented in box notation, for example:</p> <p>Carbon $\begin{array}{ c } \hline \uparrow\downarrow \\ \hline \end{array} \begin{array}{ c } \hline \uparrow\downarrow \\ \hline \end{array} \begin{array}{ c c c } \hline \uparrow & \uparrow & \\ \hline \end{array}$ $1s \quad 2s \quad 2p$</p> <p>Next explain to learners that to save time, chemists use the structures of the noble gases to reduce time in writing electron configurations using this method.</p> <p>Use the example of iron: In long form the electron configuration is: Fe $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$ and since the electron configuration of argon is Ar $1s^2 2s^2 2p^6 3s^2 3p_x^2 3p_y^2 3p_z^2$, the electron configuration of iron can be written in shorthand as simply:</p> <p>Fe $[\text{Ar}] 3d^6 4s^2$</p> <p>In box notation this is Fe $[\text{Ar}] \uparrow\downarrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow\downarrow$</p>
1.3 Electrons, energy levels and atomic orbitals KC1	1.3.8 Describe and sketch the shapes of s and p orbitals.	<p>Explain to learners that up until this point, orbitals have just been considered as boxes but in fact s, p, d orbitals all have unique shapes in space and that they need to know the shape of s and p orbitals.</p> <p>Ask learners to draw the basic shapes of the s and p orbitals and refer to the following reference to learn more about their shapes: www.chemguide.co.uk/atoms/properties/atomorbs.html</p> <p>Now that learners know how to represent orbitals in various ways and understand how to express the electronic configurations of atoms, you could practise all aspects of this section by playing the following game: www.learner.org/series/interactive-the-periodic-table/</p>
	1.3.9 Describe a free radical as a species with one or more unpaired electrons.	<p>Explain to learners that unpaired electrons are called free radicals and they will study these later in the course, for example 'free radical substitution reactions' in organic chemistry (in 14 Hydrocarbons). For now, just explain that a chlorine radical is depicted as $\text{Cl}\cdot$</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		<p>Learners can draw out a chlorine atom and see that it has an outermost shell of 7 electrons. This is a chlorine radical because it has one electron which is unpaired. Explain that this is not the desired stable situation for chlorine and that chlorine 'prefers' to be diatomic bonded by one covalent bond.</p>
1.4 Ionisation energy KC1	1.4.1 Define and use the term first ionisation energy, IE. 1.4.5 Understand that ionisation energies are due to the attraction between the nucleus and the outer electron.	<p>Present learners with the definition: 'The first ionisation energy is the energy required to remove one mole of electrons from one mole of the gaseous species'. Ask them to try to re-state this definition in chemical equation form:</p> $X_{(g)} \longrightarrow X^+_{(g)} + e^-$ <p>Make sure that learners remember to include the state symbol each time. Ask them why this is important. [because it is part of the definition for ionisation energy above]</p> <p>Link to previous knowledge and ask learners if ionisation energy is an exothermic or endothermic process. [It is endothermic because energy is needed to remove electrons.]</p> <p>Next ask learners what the energy input is required for. [Explain that it is needed because the negative outer electron is attracted by the positive nucleus.]</p>
1.4 Ionisation energy KC1	1.4.3 Identify and explain the trends in ionisation energies across a period and down a group of the Periodic Table. 1.4.6 Explain the factors influencing the ionisation energies of elements in terms of nuclear charge, atomic/ionic radius, shielding by inner shells and sub-shells and spin-pair repulsion.	<p>Refer learners to the first ionisation energy data for the elements of Period 3 on page 74 of the syllabus.</p> <p>They should plot a bar chart for the first 20 elements. [x-axis for the elements and the first ionisation energy on the y-axis]. (I)</p> <p>Ask learners what they notice from the chart they have drawn and the way the periodic table is laid out. [They should notice that the first ionisation data shows periodicity, peaking in value at the noble gases, He, Ne and Ar.]</p> <p>Next, learners plot a bar chart for only the elements in Period 2 or 3. They should be able to explain the general trend across a period [which is increasing ionisation from left to right]. (I)</p> <p>Learners then try to explain the fluctuations in ionisation energy values going across a period, considering the factors which influence them including: nuclear charge, atomic/ionic radius, shielding (screening) by inner shells and sub-shells and spin-pair repulsion.</p> <p>Finally, learners plot another bar chart to help them discover the trend in ionisation energy going down a group.</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		<p>Useful reference material: www.chemguide.co.uk/atoms/properties/ies.html#top www.creative-chemistry.org.uk/alevel/core-inorganic/periodicity/trends6 www.youtube.com/watch?v=QaJY3hpDGjw [Periodic Patterns in First Ionisation Energies 1] www.youtube.com/watch?v=rM1CVh5nYLQ [Periodic Patterns in First Ionisation Energies 2] www.youtube.com/watch?v=M5Fb9xtnv-s [OCR A Level Chemistry: Ionisation Energy Essentials] www.youtube.com/watch?v=2AFPfg0Como&t=246s [links to electron configuration and explains Coulomb's law]</p>
<p>1.4 Ionisation energy</p> <p>KC1</p>	<p>1.4.2 Construct equations to represent first, second and subsequent ionisation energies.</p> <p>1.4.4 Identify and explain the variation in successive ionisation energies of an element.</p> <p>1.4.7 Deduce the electronic configurations of elements using successive ionisation energy data.</p> <p>1.4.8 Deduce the position of an element in the Periodic Table using successive ionisation energy data.</p>	<p>Ask learners to choose an element to illustrate the first, second and third ionisation energies, for example, for aluminium:</p> $\text{Al}_{(g)} \longrightarrow \text{Al}^+_{(g)} + e^-$ $\text{Al}^+_{(g)} \longrightarrow \text{Al}^{2+}_{(g)} + e^- \text{ etc}$ <p>Ask learners to explain why successive ionisations display a general increase. [Removing a negative electron from an increasingly positive ion becomes progressively more difficult.]</p> <p>Give learners successive ionisation data in the form of a graph for a chosen element.</p> <ul style="list-style-type: none"> • Encourage learners to consider the energy needed to remove each electron, for each successive ionisation energy from the valence electrons working inwards towards the nucleus of the atom. • Successive electrons in the same main energy level will gradually require more energy to remove them because of the production of an increasingly more positive ion. Highlight that there are more protons compared to electrons for each successive ionisation energy, due to losing electrons from that main shell. • Next show that there will sometimes also be huge jumps in the amount of energy required to remove an electron when it is being removed from an inner full shell of electrons. Thus, successive ionisation energies can be used to identify the main shells in atoms and hence the group number of the element. <p>Useful reference material: www.chemguide.co.uk [search for successive ionisation energies] www.youtube.com/watch?v=RDsCWqckESA [Explaining Successive Ionisation Energies] www.youtube.com/watch?v=wAYzdcMTXWo [Successive ionisation energy / A Level Chemistry]</p>
		<p>The following activity 'Ionisation energy – true or false?' provides 20 questions to help learners focus on some of the common misconceptions on ionisation energies:</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		edu.rsc.org/resources/ionisation-energy/1101.article (F)
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

2 Atoms, molecules and stoichiometry

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
2.1 Relative masses of atoms and molecules KC1	2.1.1 Define the unified atomic mass unit as one twelfth of the mass of a carbon-12 atom. 2.1.2 Define relative atomic mass, A_r , relative isotopic mass, relative molecular mass, M_r , and relative formula mass in terms of the unified atomic mass unit.	<p>Ask learners to find a definition of the modern unified atomic mass unit (amu). (You could cross-reference this topic with 1.2 Isotopes).</p> <p>Learners could research why C-12 was eventually chosen to produce the modern definition. (Historically the unit was based on hydrogen and then on oxygen). (I) chemistry.oregonstate.edu/courses/ch121-3s/ch121/Answers%20to%20interesting%20questions/history_of_the_atomic_mass_unit.htm</p> <p>Next, learners find out the actual masses of atoms to appreciate why using relative atomic masses is much more convenient.</p> <p>Display the definition for relative atomic mass, highlighting the fact that relative atomic masses are compared to 1/12 of the mass of C-12 atom. To aid understanding of this concept, show learners a 10g mass, which could be taken as having a mass = 1 unit. Then display other masses (50g, 100g, 500g) explaining that they have relative masses compared to this.</p> <p>Define relative molecular mass (M_r) and use it to perform calculations on simple molecules. Extend this to incorporate ionic compounds, demonstrating that the procedure is identical, but that the name is called relative formula mass.</p> <p>Link this objective to mass spectra when calculating A_r in objective 22.2.2</p>
2.2 The mole and the Avogadro constant KC1 KC2	2.2.1 Define and use the term mole in terms of the Avogadro constant.	<p>Define the mole in terms of the Avogadro constant. To appreciate its magnitude, the following song provides several helpful analogies: www.youtube.com/watch?v=PvT51M0ek5c [a mole is a unit!]</p> <p>Learners can practise using the Avogadro constant to calculate how many particles of calcium carbonate are left on the ground after writing their name with a stick of chalk. They can then calculate how many individual atoms of oxygen are deposited: www.doe.virginia.gov/testing/sol/standards_docs/science/2010/lesson_plans/chemistry/molar_relationships/ess_CH-4abcd1abcg.pdf [Moles lab activity 3]</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		<p>Another way to help learners appreciate the size of a mole would be to weigh out a mole of several different substances in beakers (for example, carbon, glucose, sodium chloride) and show these to learners. Doing this provides a helpful visual representation of the size of a mole and emphasises that a mole is a unit of the amount of substance and that each of the beakers contains the same number of particles.</p>
<p>2.3 Formulae KC1</p>	<p>2.3.1 Write formulae of ionic compounds from ionic charges and oxidation numbers (shown by a Roman numeral), including:</p> <p>(a) the prediction of ionic charge from the position of an element in the Periodic Table</p> <p>(b) recall of the names and formulae for the following ions: NO_3^-, CO_3^{2-}, SO_4^{2-}, OH^-, NH_4^+, Zn^{2+}, Ag^+, HCO_3^-, PO_4^{3-}</p>	<p>Ask learners which simple monoatomic ions they can remember the correct charges for (for example Na^+, Cl^-, Mg^{2+}, Al^{3+}, O^{2-}). Make a list of these on the board and invite learners to form different ionic compounds from them. You may need to emphasise that the chemical formulae of the compounds must be electrically neutral overall. You might also need to remind learners that they can predict the ionic charge from the position of the element in the Periodic Table.</p> <p>Include examples of transition metals which have multiple oxidation states and explain the meaning of the Roman numeral notation, for example iron (II) = Fe^{2+} and iron (III) = Fe^{3+}</p> <p>Next elicit the names and formulae of any polyatomic ions learners recall (for example SO_4^{2-}, CO_3^{2-}, NO_3^-, NH_4^+). Introduce the rest of the ions associated with this learning objective and then encourage learners to practise forming and naming compounds as above. Stress that the charge on polyatomic ions is spread over the whole ion and that they should not attempt to deconstruct the ion into its constituent atoms.</p> <p>These references explain the steps involved: chem.libretexts.org [search for '5.5: Writing Formulas for Ionic Compounds'] www.thoughtco.com/formulas-of-ionic-compounds-608517</p> <p>This is a game learners can play to practise forming ionic compounds from their constituent ions: www.learner.org/interactives/periodic/bonding/</p>
<p>2.3 Formulae KC1</p>	<p>2.3.2</p> <p>(a) Write and construct equations (which should be balanced), including ionic equations (which should not include spectator ions).</p> <p>(b) Use appropriate state symbols in equations.</p>	<p>Give learners simple word equations for a variety of chemical reactions which they have probably come across before this course: combustion, the Haber process, neutralisation and displacement reactions. Ask them to write balanced equations for these.</p> <p>For all of the above equations encourage learners to use state symbols.</p> <p>This simulation is useful for practising balancing chemical equations: phet.colorado.edu/sims/html/balancing-chemical-equations/latest/balancing-chemical-equations_en.html</p> <p>To write net ionic equations, follow these steps: a) write a balanced chemical equation b) write the soluble ionic compounds (with $_{(aq)}$ state symbols) as dissociated ions c) cancel spectator ions.</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		<p>For an explanation, worked examples and practice sheet with answers: chemistrytutor.me/ionic-equations-half-equations-worksheet/</p> <p>Note that constructing and balancing redox equations using relevant half-equations will be explained in Electrochemistry (24.2.7).</p>
<p>2.3 Formulae</p> <p>KC1</p> <p>KC2</p> <p>KC3</p>	<p>2.3.3 Define and use the terms empirical and molecular formula.</p> <p>2.3.5 Calculate empirical and molecular formulae, using given data.</p> <p>2.3.4 Understand and use the terms anhydrous, hydrated and water of crystallisation.</p>	<p>Provide a definition of empirical formula, and explain its historical use in chemical analysis: www.learner.org/series/chemistry-challenges-and-solutions/quantifying-chemical-reactions-stoichiometry-and-moles/</p> <p>Learners practise empirical formula calculations. There are several worked examples here: www.docbrown.info/page04/4_73calcs05emp.htm</p> <p>Experiment to find the empirical formula of magnesium oxide: edu.rsc.org/resources/the-change-in-mass-when-magnesium-burns/718.article www.youtube.com/watch?v=OuFqtxZJRvM</p> <p>An alternative experiment could be performed as a demonstration: edu.rsc.org/resources/finding-the-formula-of-copper-oxide/727.article</p> <p>Resource Plus</p> <p>Carry out the <i>Finding the empirical formula by displacement</i> experiment referring to the Teaching Pack for lesson plans and resources.</p> <p>edu.rsc.org/resources/finding-the-formula-of-hydrated-copper-ii-sulfate/436.article</p>
<p>2.4 Reacting masses and volumes (of solutions and gases)</p> <p>KC1</p> <p>KC2</p>	<p>2.4.1 Perform calculations including use of the mole concept, involving:</p> <p>(a) reacting masses (from formulae and equations) including percentage yield calculations</p>	<p>Link this objective to the experiment for the determination of the empirical formula of magnesium oxide. Learners could calculate the theoretical maximum mass of magnesium oxide that could be obtained from the mass of magnesium they used in the experiment. They could then compare this to the actual mass of oxide they obtained and find the % yield of product formed.</p> <p>Here are a number of worked examples of reacting masses calculations: www.docbrown.info/page04/4_73calcs06rmc.htm</p> <p>And some practice questions with answers: www.docbrown.info/page04/4_73calcs06rmc.htm</p>

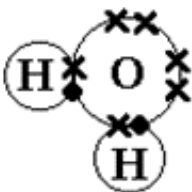
Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>(b) volumes of gases (e.g. In the burning of hydrocarbons)</p> <p>(c) volumes and concentrations of solutions</p> <p>(d) limiting reagent and excess reagent</p> <p>(e) deduce stoichiometric relationships from calculations such as those in 2.4.1 (a)–(d).</p>	<p>Learners should be competent using the formula: $\text{Moles} = \frac{\text{mass of a substance}}{A_r \text{ or } M_r}$.</p> <p>Define the molar gas volume as $1 \text{ mol} = 22.4 \text{ dm}^3$ (at 0°C and 1 atm pressure [standard temperature and pressure, s.t.p.] and as 24.0 dm^3 at 25°C and 1 atm pressure. [room temperature and pressure, r.t.p.] Learners should become familiar with converting a molar quantity to a volume of gas. Highlight the unit commonly used to express molar volume and that $1 \text{ dm}^3 = 1 \text{ l}$</p> <p>Several example calculations, gradually increasing in difficulty: www.docbrown.info/page04/4_73calcs10rgv.htm</p> <p>Note that this objective could be linked to 4.1 The gaseous state: ideal and real gas and $pV = nRT$</p> <p>Experimental work: Finding the molar volume of a gas. React a known mass of magnesium ribbon with excess hydrochloric acid. Collect the volume of hydrogen gas liberated in a gas syringe. Record the temperature of the room. Then, calculate the molar volume comparing it to $1 \text{ mole} = 24 \text{ dm}^3$ at 25°C and 1 atm pressure. Learners compare their result to the known value taking into consideration temperature and pressure differences at their location.</p> <p>Learners should be competent in manipulating the formula: Concentration (in mol dm^{-3}) = number of moles of a substance/volume of a liquid (in dm^3) The concentration of a solution may also be expressed in g dm^{-3}.</p> <p>Worked examples for both types of calculation: www.docbrown.info/page04/4_73calcs11msc.htm</p> <p>Finding the concentration of an unknown solution is one of the objectives of performing analytical titrations. See objectives 7.2.</p> <p>Experimental work:</p> <p>Resource Plus</p> <p>Carry out the <i>To perform an acid-base titration for the determination of the concentration of an unknown ethanoic acid (vinegar) solution using standardised sodium hydroxide solution.</i> experiment referring to the Teaching Pack for lesson plans and resources.</p> <p>To visualise the concept of limiting and excess reagent use the following simulation: phet.colorado.edu/sims/html/reactants-products-and-leftovers/latest/reactants-products-and-leftovers_en.html</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		<p>There are several worked example calculations here: www.docbrown.info/page04/4_73calcs14other5.htm</p> <p>This video explains the basic concepts of limiting and excess reagent: www.youtube.com/watch?v=MuzOmFhiE8o</p> <p>Experimental work: Synthesising chalk In this experiment learners use the concepts of limiting and excess reagent to calculate the theoretical yield and actual yield of their product. www.lacitycollege.edu/Academic-Departments/Chemistry-Earth-Sciences/documents/Chemistry-60-Experiments-Documents/EXPERIMENT13b.pdf</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

3 Chemical bonding

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
3.1 Electronegativity and bonding KC4	3.1.1 Define electronegativity as the power of an atom to attract electrons to itself. 3.1.2 Explain the factors influencing the electronegativities of the elements in terms of nuclear charge, atomic radius and shielding by inner shells and sub-shells.	<p>One approach to understanding this definition is to consider electronegativity as the tendency of an atom to attract a bonding pair of electrons in a covalent bond. www.chemguide.co.uk/atoms/bonding/electroneg.html</p> <p>Discuss the molecule fluorine (F₂). Both atoms are the same and have the same electronegativity and therefore both exert the same influence on the shared pair of electrons.</p> <p>Show part of the video 'Electronegativity demonstration device' starting at: 02:05 – 03:05 which shows equal sharing: www.youtube.com/watch?v=7RxYTFu745I [Electronegativity demonstration device]</p> <p>Explain the factors that affect electronegativity and show this video: www.youtube.com/watch?v=ojgrvPnbPj4 [Electronegativity and Bond Polarity]</p> <p>Next show the previous video again 'Electronegativity demonstration device' from 04:18 to show a model for a polar bond which has an unequal sharing of the bonding electrons.</p> <p>This video explains shielding: www.youtube.com/watch?v=6fGzxmpl1WU</p> <p>This simulation allows learners to explore the effect of having atoms of different electronegativities in molecules with two and three atoms: phet.colorado.edu/sims/html/molecule-polarity/latest/molecule-polarity_en.html</p>
3.1 Electronegativity and bonding KC4	3.1.3 State and explain the trends in electronegativity across a period and down a group of the Periodic Table. 3.1.4 Use the differences in Pauling electronegativity values to predict the formation of ionic and covalent bonds.	<p>Give learners the Periodic Table displaying electronegativity values: www.thoughtco.com/printable-periodic-table-electronegativity-608845 Ask them to explain the trends across a period and down a group.</p> <p>Learners plot graphs to see the trends in electronegativity across Period 3 and down Group 2 from electronegativity values in data tables. They can check these trends here: www.creative-chemistry.org.uk/alevel/core-inorganic/periodicity/trends7 [trend across Period 3] www.creative-chemistry.org.uk/alevel/core-inorganic/periodicity/trends3 [trend down Group 2]</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		<p>Explain to learners, if the difference in electronegativity values between two elements is greater than 1.7, the bond will be essentially ionic in character, and if it is less than this value, covalent in character. Emphasise that apart from diatomic molecules of the same element, there always exists some ionic character in a bond, and that the ionic character increases, as the difference in electronegativity between the two atoms in the bond increases.</p> <p>www.youtube.com/watch?v=PoQjsnQmxok [The Chemical Bond: Covalent vs. Ionic and Polar vs. Nonpolar]</p> <p>Learners can play the electronegativity game 'Gridlocks' : www.rsc.org/learn-chemistry/resources/gridlocks/puzzles/level-3/ElectronegativityValues.html</p> <p>Here is a quiz to practise using electronegativity values: www.softschools.com/quizzes/chemistry/polarity_electronegativity/quiz941.html</p>
3.2 Ionic bonding KC4	3.2.1 Define ionic bonding as the electrostatic attraction between oppositely charged ions (positively charged cations and negatively charged anions). 3.2.2 Describe ionic bonding including the examples of sodium chloride, magnesium oxide and calcium fluoride.	<p>Learners can compare the attraction of the poles of magnets to the electrostatic attraction between ions.</p> <p>Write down the electron configurations of sodium and chlorine atoms, either by drawing orbital diagrams or simply for example as: Na 2,8,1. Show how electron transfer occurs from a metal to a non-metal: www.chemguide.co.uk/atoms/bonding/ionic.html</p> <p>Ionic bonding may be represented using 'dot and cross' diagrams/ Lewis structures. Learners may feel more comfortable drawing full electronic structure diagrams initially, and progress to showing Lewis diagrams which only include the interaction of the valence electrons. www.docbrown.info/page04/4_72bond2.htm#BONDING</p> <p>Learners could practise what they have learned using this resource (answers are included): edu.rsc.org/resources/bonding-starters-16andndash18/4010264.article</p>
3.3 Metallic bonding KC4	3.3.1 Define metallic bonding as the electrostatic attraction between positive metal ions and delocalised electrons.	<p>Learners watch the following video and draw a labelled diagram to explain metallic bonding. www.youtube.com/watch?v=b1y2Q6YX1bQ</p> <p>An explanation of the variation in melting points of metals: www.chemguide.co.uk/atoms/bonding/metallic.html</p>


Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		Learners may wish to investigate some common alloys and explain why their properties are often more useful than the constituent metals alone. (I)
<p>3.4 Covalent bonding and coordinate (dative covalent) bonding</p> <p>KC4</p>	<p>3.4.1 Define covalent bonding as electrostatic attraction between the nuclei of two atoms and a shared pair of electrons.</p> <p>(a) Describe covalent bonding in molecules including:</p> <ul style="list-style-type: none"> • hydrogen, H₂ • oxygen, O₂ • nitrogen, N₂ • chlorine, Cl₂ • hydrogen chloride, HCl • carbon dioxide, CO₂ • ammonia, NH₃ • methane, CH₄ • ethane, C₂H₆ • ethene, C₂H₄. <p>(b) understand that elements in period 3 can expand their octet including in the compounds sulfur dioxide, SO₂, phosphorus pentachloride, PCl₅, and sulfur hexafluoride, SF₆</p> <p>(c) Describe coordinate (dative covalent) bonding, including in the reaction between ammonia and hydrogen chloride gases</p>	<p>Learners try to write their own definitions of covalent bonding based on previous knowledge, and then check for accuracy in the literature.</p> <p>This interactive tutorial explains how covalent bonds are formed: www.pbslearningmedia.org/resource/lsp07.sci.phys.matter.covalentbond/covalent-bonding/#.WyFpHC-ZOH4</p> <p>Learners may be able to demonstrate how covalent bonds are formed in some of the molecules mentioned in this objective. They should be able to write down and explain the reasons why the resulting formulae contain the number of atoms they do, based on the octet rule (and duet rule for n = 1).</p> <p>Stress that only the outermost, valence shell needs to be considered when forming covalent bonds, and that the sharing, (single, double or triple bonds) can be shown by overlapping circles with bonding electrons at the intersections:</p> <div style="text-align: center;">  </div> <p>This video resource explains covalent bonding: www.youtube.com/watch?v=lenvZEcMc60</p> <p>Ask learners to write down the full electronic structures for the elements sulfur and phosphorus. Show them an energy level diagram, and indicate the closeness of the 3d subshell. www.chemguide.co.uk/atoms/properties/3d4sproblem.html [to see the energies of the orbitals]</p> <p>Next, show learners how sulfur can expand its octet in the molecule SF₆ (even though this mode of hybridisation will not be tested): chemistryguru.com.sg [search 'Expansion of octet rule'], and; chem.libretexts.org/ [search for 'Violations of the Octet Rule']</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	to form the ammonium ion, NH_4^+ , and in the Al_2Cl_6 molecule.	This video uses the example of PCl_5 to explain how and why elements in period 3 are able to utilise 3d electrons, thus forming compounds with an expanded octet: www.youtube.com/watch?v=Dkj-SMBLQzM [start at 02:23]
3.4 Covalent bonding and coordinate (dative covalent) bonding KC2 KC4	3.4.2 (a) Describe covalent bonds in terms of orbital overlap giving σ and π bonds: <ul style="list-style-type: none"> • σ bonds are formed by direct overlap of orbitals between the bonding atoms • π bonds are formed by the sideways overlap of adjacent p orbitals above and below the σ bond. (b) Describe how the σ and π bonds form in molecules including H_2 , C_2H_6 , C_2H_4 , HCN and N_2 . (c) Use the concept of hybridisation to describe sp, sp^2 and sp^3 orbitals.	Draw the full structure of ammonia showing all the bonds, including the lone pair of electrons on the nitrogen atom, an H^+ ion on the left hand side of an equation. On the right hand side of the equation draw the product, an ammonium ion showing all the bonds and the positive charge. Ask learners to explain how the new N – H bond must have been formed. Tell them it is a special kind of covalent bond, and ask them to explain how it is different from an ordinary one. www.docbrown.info/page04/4_72bond63.htm [shows the formation of NH_4^+ and gives several other examples of coordinate bonds.] Explain how σ and π bonds are formed using the examples stated. If molecular model kits (such as molymod) are available, allow learners to build models of each molecule. This video explains how hybrid orbitals are formed: www.youtube.com/watch?v=vHXViZTxLXo [Hybrid Orbitals explained - Valence Bond Theory] This page explains how electrons in carbon atoms are promoted to an excited state and hybridised to form hybrid orbitals: www.chemguide.co.uk/atoms/bonding/doublebonds.html Learners may find building balloon models of hybrid orbitals useful to visualise what happens: www.youtube.com/watch?v=Kb0mxAMHnfE
3.4 Covalent bonding and coordinate (dative covalent) bonding KC4	3.4.3 (a) Define the terms: <ul style="list-style-type: none"> • bond energy as the energy required to break one mole of a particular covalent 	Refer learners again to the interactive activity: pbslm-contrib.s3.amazonaws.com/WGBH/arct15/SimBucket/Simulations/chemthink-covalentbonding/content/index.html [go to slide 15 – 21]. This explains that when the two atoms of a diatomic molecule are lowest in potential energy, this is when they are in the most stable state. This defines the bond length between the two atoms.

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>bond in the gaseous state</p> <ul style="list-style-type: none"> • bond length as the intern-nuclear distance of two covalently bonded atoms. <p>(b) Use bond energy values and the concept of bond length to compare the reactivity of covalent molecules.</p>	<p>Define bond energy and ask learners to predict what the pattern in bond energies will be going from C-C, to C=C to $C\equiv C$</p> <p>Refer learners to pages 76–7 of the syllabus to check their predictions.</p> <p>After inspecting the bond energies for C – Hal bonds, ask learners to predict the pattern in reactivity.</p> <p>Ask learners to predict what relationship exists between bond length and bond strength for the compounds HF, HCl, HBr and HI.</p>
<p>3.5 Shapes of molecules</p> <p>KC2</p> <p>KS4</p> <p>3.7 Dot-and-cross diagrams</p> <p>KC4</p>	<p>3.5.1 State and explain the shapes of, and bond angles in, molecules by using VSEPR theory, including as simple examples:</p> <ul style="list-style-type: none"> • BF₃ (trigonal planar, 120°) • CO₂ (linear, 180°) • CH₄ (tetrahedral, 109.5°) • NH₃ (pyramidal, 107°) • H₂O (non-linear, 104.5°) • SF₆ (octahedral, 90°) • PF₅ (trigonal bipyramidal, 120° and 90°). <p>3.5.2 Predict the shapes of, and bond angles in, molecules and ions</p>	<p>Discuss with learners, why understanding the shapes of molecules is important to chemists and biochemists [examples of the importance of this are, solubility predictions, hydrogen bonding, enzyme shape, drug action]. Also mention that drawing dot-and-cross diagrams helps us understand how atoms are connected in a chemical species, but does not define shape.</p> <p>Explain to learners how to apply VSEPR theory to a number of different molecules. Use a range of resources to help them build and visualise the various shapes:</p> <ul style="list-style-type: none"> • Building balloon models: www.youtube.com/watch?v=b0KvfvJi-vk • Building models with sticks and playdough: edu.rsc.org/ideas/the-shapes-of-molecules/3007452.article • Using a simulation in which you can rotate the models on-screen. Bond angles can be displayed and a choice of real and theoretical molecules shown phet.colorado.edu/sims/html/molecule-shapes/latest/molecule-shapes_en.html <p>A tutorial comparing Lewis dot-and-cross diagrams of a range of molecules to the VSEPR shapes. The molecules may also be rotated and bond angles inspected. They could also use molecular models: www.schoolspecialty.com/molymod-molecular-geometry-vsepr-model-kit-528384</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>analogous to those specified in 3.5.1.</p> <p>3.7.1 Use dot-and-cross diagrams to illustrate ionic, covalent and coordinate bonding including the representation of any compounds stated in 3.4 and 3.5.</p>	
<p>3.6 Intermolecular forces, electronegativity and bond properties</p> <p>KC4</p>	<p>3.6.3 a) Describe van der Waals' forces as the intermolecular forces between molecular entities other than those due to bond formation, and use the term van der Waals' forces as a generic term to describe all intermolecular forces.</p> <p>(b) describe the types of van der Waals' force:</p> <ul style="list-style-type: none"> • instantaneous dipole – induced dipole (id-id) force, also called London dispersion forces • permanent dipole – permanent dipole (pd-pd) force, including hydrogen bonding. 	<p>Start this section by making sure that learners appreciate that 'inter' means between and that intermolecular forces are weak forces that exist between neighbouring molecules of all substances.</p> <p>Learners could do some project-based research to find out the names of the different types of intermolecular forces, their differences and find examples of each. (Interesting examples include: hydrogen bonding in DNA and proteins, transport of water in plants, detergents and their action on cohesive forces, how Geckos stick to walls using van der Waals forces). (I)</p> <p>These videos cover different types of intermolecular forces with examples from everyday life: www.youtube.com/watch?v=-QqTwJzi7Wo www.youtube.com/watch?v=08kGgrqaZXA www.youtube.com/watch?v=PyC5r2mB4d4</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	(c) Describe hydrogen bonding and understand that hydrogen bonding is a special case of permanent dipole – permanent dipole force between molecules where hydrogen is bonded to a highly electronegative atom.	
3.6 Intermolecular forces, electronegativity and bond properties KC4 KC2	3.6.1 (a) Describe hydrogen bonding, limited to molecules containing N–H and O–H groups, including ammonia and water as simple examples. (b) Use the concept of hydrogen bonding to explain the anomalous properties of H ₂ O (ice and water): <ul style="list-style-type: none"> • its relatively high melting and boiling points • its relatively high surface tension • the density of the solid ice compared with the liquid water. 	<p>If learners plot boiling point data [y-axis] against the members of groups 15, 16 and 17 going from right to left on the x-axis, they will discover the pattern that those compounds with H-F, H-O and H-N bonds have much higher boiling points than would be expected. The explanation for these trends is the existence of hydrogen bonding in those molecules. Learners could take the data from data tables or from this page where there are example graphs: www.chemguide.co.uk/atoms/bonding/hbond.html</p> <p>Define hydrogen bonding, and explain the criteria necessary for this type of bonding to occur. Learners can then draw a diagram for how these bonds are represented in water.</p> <p>The anomalous properties of ice and water can be explained by hydrogen bonding. This link has images and clips showing the partially ordered structure in liquid water and the ridged lattice structure in ice. The ice structure clearly shows the empty spaces within the ice structure, explaining why ice is less dense than water and thus floats on it: www.nyu.edu/pages/mathmol/textbook/info_water.html</p> <p>Experimental work: There are several experiments that can be performed to illustrate various hydrogen-bonding-related effects:</p> <ol style="list-style-type: none"> 1. Surface tension effects. Place a paper clip on the surface of water and ask learners why it is able to float. Ask them what could be added to break this tension (cohesive effect). [adding detergent] www.usgs.gov/special-topic/water-science-school/science/surface-tension-and-water?qt-science_center_objects=0#qt-science_center_objects <p>Another experiment challenges learners to see how many drops of water (and other liquids) they can place on a coin: www.rookieparenting.com/how-many-drops-of-water-can-you-put-on-a-penny/</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		<p>2. Density. Before you cover the theory on this topic, float a cube of ice on water in a beaker and ask learners to explain this. Elicit that there must be a different arrangement of water molecules in the structure of water and ice.</p> <p>3. Viscosity due to hydrogen bonding. Swirl flasks of ethanol and glycerin. Decide which is the more viscous and justify after calculating the number of hydrogen bonds the molecules can form.</p> <p>4. Comparing molecules that have only instantaneous dipole – induced dipole (London dispersion) forces. Give samples of propane, hexane and paraffin to learners to observe. Draw structural formulae of each and explain their physical states in terms of the amount of these forces they possess.</p> <p>5. Using evaporation to compare attraction between molecules. Simultaneously place one drop each of the following liquids on the workbench: propan-2-ol, acetone and water. Draw the structural formulae for the three liquids and identify the molecular forces present in each liquid. Explain the order of evaporation according to their structures and intermolecular forces.</p> <p>6. Boiling points of liquids. Test a range of liquids to see the order in which they boil. Learners explain the order with respect to the main intermolecular forces present in their molecules.</p> <p>Extension activities: An interesting article which shows how hydrogen bonds have been detected for the first time: www.sciencealert.com/hydrogen-bonds-have-been-directly-detected-for-the-first-time (I)</p> <p>This article explains how there is evidence of hydrogen bonding in sulfur: www.chemistryworld.com/news/hydrogen-sulfide-surprises-as-its-discovered-to-have-hydrogen-bonds/3009753.article (I)</p>
<p>3.6 Intermolecular forces, electronegativity and bond properties</p> <p>KC4</p> <p>KC2</p>	<p>3.6.2 Use the concept of electronegativity to explain bond polarity and dipole moments of molecules.</p>	<p>Learners can apply their knowledge of electronegativity to identify polar bonds in a range of molecules. Explain the meaning of dipole moment to learners qualitatively, and use simple molecules such as water to show how dipole moments are represented.</p> 

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		<p>Give learners the formulae and/or names of a range of molecules. They first draw the structures and shapes of the molecules using VSEPR theory. Next they indicate any dipole moments present. Finally, taking into consideration the symmetrical or non-symmetrical nature of the molecules, they predict whether the molecules will be polar or not. chem.libretexts.org [search '13.3: Bond Polarity and Dipole Moments']</p> <p>Learners could do the 'deflecting jets' experiment explained in this video. www.youtube.com/watch?v=D2R4ccyvclM www.youtube.com/watch?v=k4AdJ2PSlco A jet of a polar liquid will be deflected when a statically charged rod is brought close to it. A non-polar liquid will not be deflected.</p>
3.6 Intermolecular forces, electronegativity and bond properties KC4	3.6.4 State that, in general, ionic, covalent and metallic bonding are stronger than intermolecular forces.	Learners can research the relative strengths of intermolecular forces compared to ionic, metallic and covalent bonds. (I)
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

4. States of matter

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
4.1 The gaseous state: ideal and real gases and $pV = nRT$ KC1	4.1.1 Explain the origin of pressure in a gas in terms of collisions between gas molecules and the wall of the container.	Very briefly, revise/draw ideas of 'particles in a box' discussing distances between gas particles, movement and collisions against the wall of the containing vessel.
4.1 The gaseous state: ideal and real gases and $pV = nRT$ KC1 KC2	4.1.2 Understand that ideal gases have zero particle volume and no intermolecular forces of attraction. 4.1.3 State and use the ideal gas equation $pV = nRT$ in calculations, including in the determination of M_r .	<p>Discuss that although no gas is entirely ideal in behaviour, considering a theoretical ideal gas is a useful tool for chemists and physicists. Learners research, list and describe the assumptions made in considering an ideal gas. In particular, they should be able to recall that even though the ideal gas is considered to be made up of particles, they occupy zero volume in their container. Additionally, they exert zero forces of attraction on each other.</p> <p>Learners do not need to know how to derive the equation for an ideal gas, but you could ask learners to list what factors affect the pressure of a gas.</p> <p>Learners explore the effects of changing the temperature, volume and gas particle added to a vessel in this simulation: ch301.cm.utexas.edu/simulations/js/idealgaslaw/</p> <p>This reference discusses real and ideal gases. There are video links and a graphical treatment of real and ideal gases: www.siyavula.com/read/science/grade-11/ideal-gases/07-ideal-gases-01#targetText=An%20ideal%20gas%20has%20identical,how%20real%20gases%20will%20behave.</p> <p>Learners should perform calculations using the ideal gas equation, paying particular attention to the manipulation of units. The molar mass, M_r can be found using the ideal gas equation: study.com/academy/lesson/using-the-ideal-gas-law-to-find-the-molar-mass-of-a-gas.html</p> <p>Worked examples of gas law calculations: www.docbrown.info/page03/3_52gaslaws2.htm</p> <p>Experimental work: Finding M_r for butane gas: www.youtube.com/watch?v=loCWUYMagEg [experiment] www.youtube.com/watch?v=loCWUYMagEg [calculations for the experiment]</p> <p>An alternative experiment for finding M_r of hydrogen gas:</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
<p>4.2 Bonding and structure</p> <p>KC4</p> <p>4.2 Bonding and structure</p> <p>KC4</p> <p>KC2</p>	<p>4.2.1 Describe, in simple terms, the lattice structure of a crystalline solid which is:</p> <p>(a) giant ionic, including sodium chloride and magnesium oxide</p> <p>(b) simple molecular, including iodine, buckminsterfullerene C₆₀ and ice</p> <p>(c) giant molecular, including silicon(IV) oxide, graphite and diamond</p> <p>(d) giant metallic, including copper.</p> <p>4.2.2 Describe, interpret and predict the effect of different types of structure and bonding on the physical properties of substances, including melting point, boiling point, electrical conductivity and solubility.</p> <p>4.2.3 Deduce the type of structure and bonding</p>	<p>edu.rsc.org/resources/the-determination-of-relative-atomic-mass/401.article</p> <p>Giant ionic From the charges on their ions, learners write down the formulae of the suggested ionic substances. Ask them why 'molecules' of sodium chloride is the wrong term to use, and ask them to propose a way in which a crystal lattice is formed. Also elicit what the simplest ratio of ions is within the structure.</p> <p>Build ball-and-stick or space-filling models of sodium chloride to visualise the structure. View models of the structure: www.siyavula.com/read/science/grade-10/chemical-bonding/06-chemical-bonding-04</p> <p>Extension activity: Why sodium chloride is 6:6 coordinated: www.chemguide.co.uk/atoms/structures/ionicstruct.html (1)</p> <p>Structures of magnesium oxide and sodium oxide for comparison with sodium chloride: www.docbrown.info/page07/ASA2ptable5b.htm</p> <p>This video explains how giant ionic structures are formed: www.youtube.com/watch?v=leVxy7cjZMU</p> <p>Simple molecular Learners suggest why iodine is a molecular substance consisting of discrete I₂ molecules. They may also be able to suggest a molecular lattice structure, where iodine molecules are attracted to each other by London dispersion forces.</p> <p>A rotatable structure of the lattice: wwwchem.uwimona.edu.jm/courses/CHEM1902/IC10K_MG_struct_elementsPS.html</p> <p>The structure of ice was considered in section 3.6.1</p> <p>Buckminsterfullerene (C₆₀), also has a simple molecular structure though it is important to point out to learners why it is a simple structure, not a giant structure like the other allotropes of carbon, diamond and graphite. The molecules are quite large, but the bonding between them is still London dispersion forces.</p> <p>Giant molecular Learners build models of graphite and diamond to compare their structures. Alternatively, they can draw the two structures side-by-side for comparison. Instructions for drawing the diamond structure:</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	present in a substance from given information.	<p>www.chemguide.co.uk/atoms/structures/giantcov.html</p> <p>A video comparing the structure and properties of graphite and diamond: www.youtube.com/watch?v=FeZlIR50XoY</p> <p>The structure of silicon (IV) oxide can confuse learners. In the structure, each silicon atom is bonded to four oxygen atoms and each oxygen atom is bonded to two silicon atoms. Diagram and explanation of structure: www.chemguide.co.uk/atoms/structures/giantcov.html</p> <p>Metallic bonding Learners should be able to draw a simplistic model of metallic bonding and explain the 'sea of electrons'. Metallic bonding is often confused with ionic bonding because the diagrammatic models represent positive metal species in them. Point out to learners that a metal is composed of atoms, and that the positive centre in the diagrams represent all the rest of the atoms, apart from the outer electron(s). These electrons are not lost but are part of the sea of electrons as explained here: www.chemguide.co.uk/atoms/bonding/metallic.html</p> <p>Metallic bonding examples and properties: www.youtube.com/watch?v=eVv3TpaQ2-A&t=218s Metallic bonding in potassium animation: www.youtube.com/watch?v=V5tj-xADB1c</p> <p>Experimental work: Learners test a range of unlabelled white covalent and ionic substances for: solubility in water, hardness, relative melting point, and conductivity if they dissolve in water. They decide, on the basis of the majority of results if the bonding in the substances is covalent or ionic in nature. [A variation of this experiment is to use just sugar and salt (sodium chloride) for the test].</p> <p>A video of a similar experiment (two of the compounds, nickel chloride and cobalt sulfate, are very toxic): www.youtube.com/watch?v=CpVfEs1TnXM</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

5 Chemical energetics

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
5.1 Enthalpy change, ΔH KC5	5.1.1 Understand that chemical reactions are accompanied by enthalpy changes and these changes can be exothermic (ΔH is negative) or endothermic (ΔH is positive). 5.1.2 Construct and interpret a reaction pathway diagram, in terms of the enthalpy change of the reaction and of the activation energy. 5.1.4 Understand that energy transfers occur during chemical reactions because of the breaking and making of chemical bonds.	Ask learners to produce a list of exothermic and endothermic reactions from their previous studies in chemistry. Discuss learners' ideas as a class, it will be apparent that there are many more exothermic reactions than endothermic ones. Mention at this stage that changes in enthalpy can occur in processes without chemical change to the structure of the species. [Explained in the A Level syllabus in 23.2]. Learners draw energy diagrams to show the difference between exothermic and endothermic reactions: www.chemguide.co.uk/physical/energetics/basic.html#top Make sure that learners are aware that breaking a chemical bond involves an input of energy (endothermic). For learners who find this idea challenging, break an old pencil. Ask if energy was put in to do this or given out. Energy is therefore released when bonds are formed (exothermic process).
5.1 Enthalpy change, ΔH KC5	5.1.5 Use bond energies (ΔH positive, i.e. bond breaking) to calculate enthalpy change of reaction, ΔH_r . 5.1.6 Understand that some bond energies are exact and some bond energies are averages.	Learners look at the tables of bond energies in the syllabus (pages 76–77). Ask them if there are any general trends between related bond energies. [for example, between carbon – carbon, single, double and triple bonds]. Establish that all bond energies are always endothermic. Learners build on previous knowledge of calculating the enthalpy change of reaction from individual bond energies. Give learners practice calculations to determine the overall enthalpy change of a reaction for a range of different chemical reactions. Worked examples: www.docbrown.info/page03/3_51energyC.htm

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		<p>Except for the simplest of examples, encourage learners to draw out the full structural formula of compounds so that they consider the correct number of bonds in the bond breaking and making process. Also make sure that learners insert the 'negative' sign if the outcome of the summation process is exothermic overall, as it is with most reactions.</p> <p>Video learning resources: www.youtube.com/watch?v=eExCBkp4jB4 www.youtube.com/watch?v=PdValXAVUOc</p> <p>Learners now consider the bond energy data they have used in various calculations. Except for very simple molecules, bond energies are often quoted as average values: www.chemguide.co.uk/physical/energetics/bondenthalpies.html#top [This page examines the literature value for the C-H bond. C-H bond enthalpies vary slightly depending on their environment.]</p>
5.1 Enthalpy change, ΔH KC5	5.1.3 Define and use the terms: (a) standard conditions (this syllabus assumes that these are 298k and 101 kPa) shown by \ominus . (b) enthalpy change with particular reference to: reaction, ΔH_r , formation, ΔH_f , combustion, ΔH_c , neutralisation, ΔH_{neut}	Learners research, write down and compare the various definitions for enthalpy changes. (I)
5.1 Enthalpy change, ΔH KC5 KC2	5.1.7 Calculate enthalpy changes from appropriate experimental results, including the use of the relationships $q = mc\Delta T$ and $\Delta H = -mc\Delta T$	<p>Discuss the significance of specific heat capacity (c) and quote some example values for it, including units.</p> <p>Introduce the formula for calculating enthalpy changes and perform sample calculations, explaining the assumptions used in the calculations.</p> <p>Experimental work: There are many experiments which can be performed on this topic. Some suggestions include:</p> <ol style="list-style-type: none"> Resource Plus experiment: <p>Resource Plus</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		<p>Carry out the <i>Determining the enthalpy change for the thermal decomposition of $KHCO_3$</i> experiment referring to the Teaching Pack for lesson plans and resources.</p> <ol style="list-style-type: none"> Determining the enthalpy of reaction for a zinc/ copper sulfate displacement reaction www.youtube.com/watch?v=705mr95c_QA&lc=Ugxt-6hyT3vvryOSWhN4AaABAg.8oAKDRqNVjl8q0Cz94qpob Determining the enthalpy of neutralisation www.youtube.com/watch?v=705mr95c_QA&lc=Ugxt-6hyT3vvryOSWhN4AaABAg.8oAKDRqNVjl8q0Cz94qpob Enthalpy of combustion of ethanol (using a copper can): www.youtube.com/watch?v=99-qeNNozU <p>Simulated experiments: media.pearsoncmg.com/bc/bc_0media_chem/chem_sim/calorimetry/Calor.php</p> <p>Practical work teaching tips for your classroom: edu.rsc.org/resources/measure-enthalpy-changes/2395.article</p>
<p>5.2 Hess's Law</p> <p>KC5</p> <p>KC2</p>	<p>5.2.1 Apply Hess's Law to construct simple energy cycles.</p> <p>5.2.2 Carry out calculations using cycles and relevant energy terms, including:</p> <p>(a) determining enthalpy changes that cannot be found by direct experiment</p> <p>(b) use of bond energy data.</p>	<p>Study the definition of Hess's law: 'The enthalpy change accompanying a chemical change is independent of the route by which the chemical change occurs.'</p> <p>Explain that there are two different approaches to perform Hess's law calculations:</p> <ul style="list-style-type: none"> Cycles are drawn and an unknown value calculated: chemistryguru.com.sg/energy-cycle-for-enthalpy-change-of-formation www.docbrown.info/page07/delta1Ha.htm <p>Video explanations: www.youtube.com/watch?v=4lxORLTdk-c www.youtube.com/watch?v=fyfW8YvYHy0 www.youtube.com/watch?v=Fq9mqz1TbSw</p> <ul style="list-style-type: none"> Calculations are performed - this involves equations, which are treated in a summative fashion, without drawing cycles: www.learner.org/series/chemistry-challenges-and-solutions/the-energy-in-chemical-reactions-thermodynamics-and-enthalpy/

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		<p>Activity using summation method: www.sciencegeek.net/Activities/Hesslaw.html</p> <p>Experimental work:</p> <ul style="list-style-type: none"> Resource Plus experiment: <p>Resource Plus</p> <p>Carry out the <i>Determining the enthalpy change for the thermal decomposition of KHCO_3</i> experiment referring to the Teaching Pack for lesson plans and resources.</p> <p>Virtual lab: chemcollective.org/vlab/138 [Heats of reaction – Hess' Law]</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

6 Electrochemistry

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
6.1 Redox processes: electron transfer and changes in oxidation number (oxidation state) KC5	6.1.1 Calculate oxidation numbers of elements in compounds and ions. . 6.1.5 Use a Roman numeral to indicate the magnitude of the oxidation number of an element.	<p>Recall previous knowledge on the loss and gain of electrons in half-reactions using OIL RIG. Learners should be comfortable writing electron half-equations of the type:</p> $\text{Cu}^{2+}_{(\text{aq})} + 2\text{e}^{-} \rightarrow \text{Cu}_{(\text{s})}$ <p>They should be familiar with the idea that Cu^{2+} is Cu(II) and that this conversion is a reduction. Learners should also be able to recognise the oxidation state of a species from its chemical name, for example, copper (I) oxide = Cu_2O, where copper ions are Cu^{+}. Give learners practice exercises to make sure they are confident in this area.</p> <p>Give learners a list of the rules for calculating oxidation numbers and discuss notable exceptions to the rules. Learners should be able to use these rules to work out the oxidation states of compounds and ions. www.chemguide.co.uk/inorganic/redox/oxidnstates.html [with downloadable practice question and answer sheets]</p> <p>Play gridlocks for learning oxidation states: rsc.org/learn-chemistry/resources/gridlocks/puzzles/level-3/OxidationNumberRules.html</p> <p>Extension activity: For more able learners: oxidation numbers in terms of electron accounting and polar bonds: edu.rsc.org/download?ac=12042 [with questions and answers]</p>
6.1 Redox processes: electron transfer and changes in oxidation number (oxidation state) KC5	6.1.2 Use changes in oxidation numbers to help balance chemical equations. 6.1.3 Explain and use the terms redox, oxidation, reduction and disproportionation in terms of electron transfer and changes in oxidation number.	<p>Give learners a range of balanced chemical reactions, asking them if they are redox reactions or not.</p> <p>In disproportionation reactions, learners may need extra guidance to help them identify that a single species has been both oxidised and reduced.</p> <p>Identify oxidation and reduction in a range of equations – a useful way to do this is to draw bars above and below to show the species which have changed oxidation state, as in this link: www.chemguide.co.uk/inorganic/redox/definitions.html</p> <p>Video learning: www.youtube.com/watch?v=gmbuTl2ariI [review] www.youtube.com/watch?v=Kzt4LdM8A1w [What is a Disproportionation Reaction?]</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	6.1.4 Explain and use the terms oxidising agent and reducing agent.	
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

7 Equilibria

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
7.1 Chemical equilibria: reversible reactions, dynamic equilibrium KC2	7.1.1 (a) Understand what is meant by a reversible reaction. (b) Understand what is meant by dynamic equilibrium in terms of the rate of forward and reverse reactions being equal and the concentration of reactants and products remaining constant. (c) Understand the need for a closed system in order to establish dynamic equilibrium.	<p>Reversible reactions Take bottles of concentrated hydrochloric acid and concentrated ammonia solution. Remove the stoppers and ask learners to explain why white clouds form when ammonia and hydrogen chloride gases meet. [ammonium chloride formed]</p> <p>Next, take some ammonium chloride from a bottle and heat it to decompose it in a test tube. The gases ammonia and hydrogen chloride are produced and may be tested. www.docbrown.info/page04/4_74revNH3a.htm</p> <p>Ask learners to explain how this is a reversible reaction and how they are represented in chemical equations.</p> <p>Next, formally define a reversible reaction. [When a reactant or reactants produce products which themselves can react to give the reactants back again.] Stress that reversible reactions may occur in an open system as above.</p> <p>Simulation: phet.colorado.edu/en/simulation/legacy/reversible-reactions</p> <p>Experimental work:</p> <ul style="list-style-type: none"> • A reversible reaction using hydrated copper(II) sulfate: edu.rsc.org/ [search reversible reactions] • Synthesis and decomposition of ammonium chloride: www.dimanregional.org <p>Videos of experiments: www.youtube.com/watch?v=KDJV19GTwrI [heating copper sulphate; a reversible reaction] www.youtube.com/watch?v=br8IKynV1Hc [ammonium chloride thermal decomposition]</p> <p>Dynamic equilibrium Define the term dynamic equilibrium emphasising that it must occur in a closed system. Illustrate dynamic equilibrium using the above examples with ammonium chloride and copper (II) sulfate. Those reactions could become reversible reactions in dynamic equilibrium if the system were closed and they were allowed to reach a constant state of dynamic equilibrium.</p> <p>Videos to explain dynamic equilibrium: www.youtube.com/watch?v=JsoawKguU6A</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		<p>Explaining dynamic equilibrium graphically can be helpful: faculty.chem.queensu.ca/people/faculty/mombourquette/FirstYrChem/equilibrium/index.htm</p> <p>Practical activity: Simulating/modelling dynamic equilibrium with paper clips: studylib.net/doc/7571540/dynamic-equilibrium-with-coins</p>
<p>7.1 Chemical equilibria: reversible reactions, dynamic equilibrium</p> <p>KC2</p>	<p>7.1.2 Define Le Chatelier's principle as: if a change is made to a system at dynamic equilibrium, the position of equilibrium moves to minimise this change.</p> <p>7.1.3 Use Le Chatelier's principle to deduce qualitatively (from appropriate information) the effects of changes in temperature, concentration, pressure or presence of a catalyst on a system at equilibrium.</p>	<p>Define Le Chatelier's principle and ask learners to suggest what external stresses could be applied to a closed system in dynamic equilibrium. [pressure, temperature, concentration]</p> <p>Choose a familiar, reversible chemical reaction and illustrate the effects of changing the pressure, temperature and concentration on the system, for example: $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g})$</p> <p>Theory of Le Chatelier's principle www.chemguide.co.uk/physical/equilibria/lechatelier.html</p> <p>Experimental work: chem.libretexts.org [search for: 'Equilibrium and Le Chatelier's principle experiments']</p> <p>There are several other experiments to try, illustrated in the following videos:</p> <ul style="list-style-type: none"> • Cobalt chloride equilibrium: www.youtube.com/watch?v=R0z8Ya-kl4 • Iron thiocyanate equilibrium: www.youtube.com/watch?v=ZOYyCTvLa9E • Chromate – dichromate equilibrium: www.youtube.com/watch?v=jypU3FvS_o • Demonstration of acid-base equilibrium shift with simple chemicals: www.youtube.com/watch?v=OSWISc0RQ-8 • The blue bottle equilibrium: www.youtube.com/watch?v=OSWISc0RQ-8 • Changing volume/ pressure: www.youtube.com/watch?v=pnU7ogsgUW8
<p>7.1 Chemical equilibria: reversible reactions, dynamic equilibrium</p> <p>KC2</p>	<p>7.1.4 Deduce expressions for equilibrium constants in terms of concentrations, K_c</p>	<p>Start by deriving an expression for K_c for a generic reaction in which all reactants and products are in the same phase (homogenous equilibria). Point out to learners that equilibrium expressions are really just a mathematical expression of Le Chatelier's principle.</p> <p>Common examples and a derivation are explained here: www.chemguide.co.uk/physical/equilibria/kc.html#top</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>7.1.5 Use the terms mole fraction and partial pressure.</p> <p>7.1.6 Deduce expressions for equilibrium constants in terms of partial pressures, K_p.</p> <p>7.1.7 Use the K_c and K_p expressions to carry out calculations</p> <p>7.1.8 Calculate the quantities present at equilibrium, given appropriate data.</p>	<p>Note that although K_c expressions can be derived for gases, it is more common to use K_p in these circumstances.</p> <p>Next look at K_c for heterogeneous reactions, stressing that solid reactants are not included in the equilibrium expression. Ensure that learners give units when performing calculations and realise that units vary from case to case.</p> <p>Explain the basic theory of partial pressures to learners and derive an expression for K_p using a generic, algebraic reaction. www.chemguide.co.uk/physical/equilibria/kp.html#top</p> <p>One approach to solving K_c and K_p calculations is to draw up Initial, Change, Equilibrium (I.C.E.) tables. Learners will need plenty of practice. Some worked examples are detailed here: chemistryguru.com.sg/determine-equilibrium-constant-ice-table and; www.chemteam.info/Equilibrium/Calc-equib-from-init-cond.html</p> <p>Worked examples: www.docbrown.info/page07/equilibria2b.htm www.chemhume.co.uk/AS%20AQA%20CHEM/Physical/1.10%20Equilibria%20and%20Kp.pdf</p> <p>Experimental work: If a spectrophotometer is available you could perform this experiment to determine the equilibrium constant for the system: $\text{Fe}^{3+}(\text{aq}) + \text{SCN}^{-}(\text{aq}) \rightleftharpoons \text{FeSCN}^{2+}(\text{aq})$ www.youtube.com/watch?v=xAcfl7tNnS0 An explanation of this experiment: chem.libretexts.org/ [search 'Determination of K_c for a complex ion formation experiment']</p> <p>If a spectrophotometer is not available, the equilibrium constant for an esterification reaction may be determined by titration. www.sserc.org.uk/subject-areas/chemistry/chemistry-resources/equilibrium-constant/ [contains teacher, learner and technician instruction sheets]</p>
	<p>7.1.9 State whether changes in temperature, concentration or pressure or the presence of a catalyst affect the value</p>	<p>Learners predict and explain what effect changing the conditions of temperature, pressure and adding a catalyst will have on the Haber and Contact processes.</p> <p>The Haber process is detailed here: www.chemguide.co.uk/physical/equilibria/haber.html</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>of the equilibrium constant for a reaction.</p> <p>7.1.10 Describe and explain the conditions used in the Haber process and the Contact process, as examples of the importance of an understanding of dynamic equilibrium in the chemical industry and the application of Le Chatelier's principle.</p>	<p>ed.ted.com/lessons/the-chemical-reaction-that-feeds-the-world-daniel-d-dulek [The chemical reaction that feeds the world] www.youtube.com/watch?v=BPDkI92NCUs [Which way will the equilibrium shift?]</p> <p>Learners can explore the effect of changing conditions in a Haber-Bosch ammonia plant in this simulation: www.learner.org/series/chemistry-challenges-and-solutions/control-a-haber-bosch-ammonia-plant/</p>
<p>7.2 Brønsted–Lowry theory of acids and bases</p> <p>KC2</p> <p>KC3</p>	<p>7.2.1 State the names and formulae of the common acids, limited to hydrochloric acid, HCl, sulfuric acid, H₂SO₄, nitric acid, HNO₃, ethanoic acid, CH₃COOH.</p> <p>7.2.2 State the names and formulae of the common alkalis, limited to sodium hydroxide, NaOH, potassium hydroxide, KOH, ammonia, NH₃.</p>	<p>Learners carry out independent study to complete this section. (I)</p> <p>Give learners a short test to check that they know the names and formulae of these acids and bases.</p>
	<p>7.2.3 Describe the Brønsted–Lowry theory of acids and bases.</p> <p>7.2.4 Describe strong acids and strong bases as fully dissociated in</p>	<p>Learners expand on the list of acids and bases in 7.2.1 and 7.2.2 and find out how and why they are categorised as strong and weak acids and bases. Confirm that learners have understood the concept of complete and partial dissociation (ionisation) in water, giving examples.</p> <p>Ensure that learners use a reversible arrow for species which only partially ionise.</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>aqueous solution and weak acids and weak bases as partially dissociated in aqueous solution.</p> <p>7.2.5 Explain qualitatively the differences in behaviour between strong and weak acids including the reaction with a reactive metal and difference in pH values by use of a pH meter, universal indicator or conductivity.</p> <p>7.2.6 Appreciate that water has pH of 7, acid solutions pH of below 7 and alkaline solutions pH of above 7.</p>	<p>Experimental work: Ask learners to draw a table including various strong and weak acids with column headings of relative reaction rate with magnesium, pH value, effect on universal indicator and conductivity. Include a sample of pure water for reference.</p> <p>Simulation: phet.colorado.edu/sims/html/acid-base-solutions/latest/acid-base-solutions_en.html [conductivity, Universal indicator paper, degree of dissociation]</p>
<p>7.2 Brønsted–Lowry theory of acids and bases</p> <p>KC2</p> <p>KC3</p>	<p>7.2.7 Understand that neutralisation reactions occur when $\text{H}^+(\text{aq})$ and $\text{OH}^-(\text{aq})$ form $\text{H}_2\text{O}(\text{l})$.</p> <p>7.2.8 Understand that salts are formed in neutralisation reactions.</p>	<p>Learners write balanced chemical equations for a range of acid base reactions. Next, they write the general ionic equations for these reactions and finally the net ionic equations noticing that the only species that react are the H^+ and the OH^- ions. Reference this back to Enthalpy change 5.1.3, asking learners which enthalpy change this reaction defines. [enthalpy of neutralisation]</p> <p>Inspect the general ionic equations once again, focusing on the spectator ions on the right side of the equations. These are the salts. Learners should also be able to name these salts. Reference this work back to Formulae 2.3.2. www.usetute.com.au/neutralise.html</p>
	<p>7.2.9 Sketch the pH titration curves of titrations using</p>	<p>It would be best to start with a practical activity (suggestions below) in which learners plot a pH graph of a strong acid–strong base system. You could then ask them to predict and sketch the shape of the graph if the liquids in the burette and titration flask were reversed.</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>combinations of strong and weak acids with strong and weak alkalis.</p> <p>7.2.10 Select suitable indicators for acid-alkali titrations, given appropriate data (pK_a values will not be used).</p>	<p>Learners label the equivalence point on the graph, noting that its pH value occurs at pH 7.0. Ask them to sketch the graphs involving either a weak acid or a weak base (or both).</p> <p>Tell learners they will gain a more complete understanding of the reasons for these shapes when they have studied section 25.1, Acids and bases. Reference material: www.chemguide.co.uk/physical/acidbaseeqia/phcurves.html</p> <p>Give learners a list of indicators (p.61 of the syllabus) and which pH range they function in effectively, such as in this page: www.docbrown.info/page07/equilibria6a.htm Then allow learners to write the names of suitable indicators on their sketch graphs above (you will need to add thymolphthalein from another source).</p> <p>Experimental work:</p> <ul style="list-style-type: none"> • Generating curve manually using graph paper: www.youtube.com/watch?v=FPkl3f4lpJ0 www.youtube.com/watch?v=FTjeBG94t-8 [drawing a pH curve using Excel manually] • Generating a pH curve automatically using a data logger/PC: www.youtube.com/watch?v=ApRYZQnuVoU • Resource plus experiment: <p>Resource Plus</p> <p>Carry out the <i>Determining the % of ethanoic acid in a commercial vinegar product by titration using thymolphthalein indicator</i>.experiment referring to the Teaching Pack for lesson plans and resources.</p> <p>Simulations: employees.oneonta.edu/viningwj/sims/titration_curves_s.html</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

8 Reaction kinetics

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
8.1.1 Rate of reaction KC3	8.1.1 Explain and use the term rate of reaction, frequency of collisions, effective collisions and non-effective collisions. 8.1.2 Explain qualitatively, in terms of frequency of effective collisions, the effect of concentration and pressure changes on the rate of a reaction.	Present learners with a balanced chemical reaction and ask them what criteria are important for the particles to react. Elicit that for effective collisions [a reaction] to occur the particles must collide with sufficient energy, collide in the correct orientation and to increase the rate of a reaction, collide frequently enough. Video: www.youtube.com/watch?v=SbapBWjDA74 [Collision theory and reactions - part 1] www.youtube.com/watch?v=Eikf0VwtoxQ [part 2] www.youtube.com/watch?v=sVNdyT7paZE [collision theory]
8.1.1 Rate of reaction KC2 KC3	8.1.3 Use experimental data to calculate the rate of a reaction.	At this level, learners should be able to interpret graphs derived from experimental data, for example, a graph of 'quantity of product formed' [y-axis] against 'time' [x-axis]. From this, they should be able to calculate the mean rate of reaction. Mean rate of reaction = change in mass or volume of product/ change in time Experimental work: <ul style="list-style-type: none"> Resource Plus experiment: <div style="border: 1px solid black; padding: 5px; margin: 5px 0;"> <p>Resource Plus Carry out <i>The effect of changing the concentration of hydrochloric acid on the rate of reaction with calcium carbonate</i> experiment in Cambridge IGCSE Chemistry 0620 Resource Plus, referring to the Teaching Pack for lesson plans and resources.</p> </div> Effect of changing the surface area on the rate of reaction. Use different sizes of marble chips and hydrochloric acid. Plot graphs of loss in mass (y-axis) against time (x-axis). For basic set-up: www.youtube.com/watch?v=Ui_74hXRugI Sodium thiosulfate–hydrochloric acid experiment. Change the concentration of hydrochloric acid and observe a disappearing cross. www.youtube.com/watch?v=r4IZDPpN-bk

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
8.2 Effect of temperature on reaction rates and the concept of activation energy KC2 KC3	8.2.1 Define activation energy, E_A , as the minimum energy required for a collision to be effective. 8.2.2 Sketch and use the Boltzmann distribution to explain the significance of activation energy. 8.2.3 Explain qualitatively, in terms both of the Boltzmann distribution and of frequency of effective collisions, the effect of temperature change on the rate of a reaction.	Examples of activation energy in practice: ask learners to research exemplar reactions where energy is needed to initiate a reaction, for example, lighting a match or combustion of a fuel in car engine or lighter. Using textbooks or online sources, learners define activation energy and sketch a Boltzmann distribution graph. Video explanation: www.youtube.com/watch?v=YacslU97OFc Experimental work: Experiments investigating the effect of temperature on the rate of reaction: <ul style="list-style-type: none"> • Investigate the rate of decomposition of hydrogen peroxide at various temperatures [oxygen collected in gas syringe] • The rate of reaction between hydrochloric acid and marble chips at various temperatures [carbon dioxide gas collected in a gas syringe]. • Investigate the rate of reaction between sodium thiosulfate and hydrochloric acid at various temperatures [disappearing cross experiment]: • www.youtube.com/watch?v=hjh7chIAEOW
8.3 Homogeneous and heterogeneous catalysts KC2 KC3 KC4	8.3.1 Explain and use the terms catalyst and catalysis. (a) Explain that, in the presence of a catalyst, a reaction has a different mechanism, i.e. one of lower activation energy. (b) Explain this catalytic effect in terms of the Boltzmann distribution. (c) Construct and interpret a reaction pathway diagram, for a	Ask learners to define what a catalyst is and give a couple of examples where catalysts are used in industry. Ask why they are needed and also why all reactions do not require catalysts to proceed. Make sure that learners, within their definition of a catalyst, include that it is not used up in the reaction and is therefore not a reactant. Ask learners to design an experiment to show that a catalyst can be recovered and re-used after a chemical reaction. [Suggest the classic manganese (IV) oxide-catalysed decomposition of hydrogen peroxide.] Demonstrate one or more catalysed and uncatalysed reactions to learners and draw energy pathway diagrams for the reaction and also a Boltzmann distribution diagram. www.chemguide.co.uk/physical/basicrates/catalyst.html Experimental work: 'Genie in a bottle' demonstrating the catalytic decomposition of hydrogen peroxide. [safety information and link to the preparation in the video]: www.youtube.com/watch?v=S3o-tQ7MME

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	reaction in the presence and absence of an effective catalyst.	<p>Homogeneous and heterogeneous catalysts: Discuss with learners that probably most of the examples of catalysts they have come across involve heterogeneous catalysts but that homogeneous catalysts are also widely known and used. Ask learners to research some examples of homogeneous catalysts.</p> <p>Acid catalysts: for example in esterification (syllabus 18.1), hydrolysis of esters (syllabus 18.2) and the nitration of arenes (syllabus 30.1).</p> <p>Ask learners if they know the name for 'biological catalysts' and link to catalysis using the example of enzymes in the body. These are also an example of homogeneous catalysts. The enzyme catalase, present in high amounts in the liver, also catalyses the decomposition of hydrogen peroxide. This can easily be demonstrated in the lab: www.youtube.com/watch?v=Ya3k0Qd5N1Q</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

9 The Periodic Table: chemical periodicity

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
9.1.1 Periodicity of physical properties of the elements in Period 3 KC3	9.1.1 Describe qualitatively (and indicate the periodicity in) the variations in atomic radius, ionic radius, melting point and electrical conductivity of the elements. 9.1.2 Explain the variation in melting point and electrical conductivity in terms of the structure and bonding of the elements.	Look at images and/or samples of each of the Period 3 elements in order from left to right as they are presented in the Periodic Table. Ask learners to comment on their physical appearance and any general trends they already know. www.thoughtco.com/chemical-element-pictures-photo-gallery-4052466 [scroll through images of each of the elements] www.youtube.com/watch?v=pKGZG6W51Os [images of each element] Give learners four empty graphs of element (x -axis) and either atomic radius, ionic radius, melting point and electrical conductivity (y -axis). Learners plot these graphs from available data on the internet. Identify patterns in periodicity and discuss those elements that have the highest and lowest melting points and electrical conductivity and elicit from learners how this relates to their bonding and structures. [link to Chemical Bonding 3]
9.2 Periodicity of chemical properties of the elements in Period 3 KC2 KC3	9.2.1 Describe, and write equations for, the reactions of the elements with oxygen (to give Na_2O , MgO , Al_2O_3 , P_4O_{10} , SO_2), chlorine (to give NaCl , MgCl_2 , AlCl_3 , SiCl_4 , PCl_5) and water (Na and Mg only). 9.2.2 State and explain the variation in the oxidation number of the oxides (Na_2O , MgO , Al_2O_3 , P_4O_{10} , SO_2 and SO_3 only) and chlorides (NaCl , MgCl_2 , AlCl_3 , SiCl_4 , PCl_5 only) in terms	As a review, ask learners to list the elements in this period and write out their full electronic configurations. To bring this section to life, learners need to observe as many of the reactions by experiment / using videos as possible in this section. For each compound, discuss which type of bonding it possesses and relate this to the compound's appearance and physical state. Web references: rod.beavon.org.uk/incat4.htm [reactions of Period 3 elements] <u>Reactions of the elements with oxygen</u> Experimental work: Reacting elements with oxygen: edu.rsc.org/ [search 'reacting elements with oxygen' [free membership and resources]] <u>Reactions of the elements with water</u> Learners can perform test tube reactions with these compounds and test the pH's of the resulting solution/mixture.

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>of their outer shell (valence shell) electrons.</p> <p>9.2.3 Describe, and write equations for, the reactions, if any, of the oxides Na_2O, MgO, Al_2O_3, SiO_2, P_4O_{10}, SO_2 and SO_3 with water including the likely pHs of the solutions obtained.</p> <p>9.2.4 Describe, explain, and write equations for, the acid / base behaviour of the oxides Na_2O, MgO, Al_2O_3, P_4O_{10}, SO_2 and SO_3 and the hydroxides NaOH, $\text{Mg}(\text{OH})_2$, $\text{Al}(\text{OH})_3$ including, where relevant, amphoteric behaviour in reactions with acids and bases (sodium hydroxide only)</p> <p>9.2.5 Describe, explain, and write equations for, the reactions of the chlorides NaCl, MgCl_2, AlCl_3, SiCl_4, PCl_5 with water including the likely pHs of the solutions obtained.</p> <p>9.2.6 Explain the variations and trends in 9.2.2, 9.2.3, 9.2.4 and</p>	<p>Video:</p> <ul style="list-style-type: none"> • Reaction of chlorine and Period 3 elements: www.youtube.com/playlist?list=PLFR8mGXN8I5jGOBFCZF3i8o1WzF1BfWde • Reactions of metal oxides with water: www.youtube.com/watch?v=ZEOF5k5TU1M • Reaction of $\text{P}_2\text{O}_5/\text{P}_4\text{O}_{10}$ with water: www.youtube.com/watch?v=v_xoZUuor3Y • Reaction of MgO with water: www.youtube.com/watch?v=qaBUHS5dJhQ • Shows Na_2O reacting with water and the resulting solution being tested with phenolphthalein which turns pink showing that it is an alkaline solution: www.youtube.com/watch?v=PH9eis-89OE <p><u>Reactions of the chlorides with water</u> Before performing these test tube reactions and/or showing these videos, encourage learners to predict the pH of the solutions formed after adding water to the chlorides.</p> <p>www.youtube.com/watch?v=9VCSDuwoA8U [reactions of the chlorides with water, theory] www.youtube.com/watch?v=8bKzoFLVedY [reaction of NaCl and MgCl_2 with water] www.youtube.com/watch?v=oZITsa_fqzs [reaction of SiCl_4 with water] www.youtube.com/watch?v=z1Bic5wRil4 [reaction of AlCl_3 with water] www.youtube.com/watch?v=hWNAtg9sMQI [reaction of PCl_5 with water]</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>9.2.5 in terms of bonding and electronegativity.</p> <p>9.2.7 Suggest the types of chemical bonding present in the chlorides and oxides from observations of their chemical and physical properties.</p>	
<p>9.3 Chemical periodicity of other elements</p> <p>KC3</p>	<p>9.3.1 Predict the characteristic properties of an element in a given group by using knowledge of chemical periodicity.</p> <p>9.3.2 Deduce the nature, possible position in the Periodic Table and identity of unknown elements from given information about physical and chemical properties.</p>	<p>Based on the characteristic properties and reactions of the Period 3 elements, you could ask learners to predict the reactions and properties of the Period 2 elements.</p> <p>Point to elements in the Periodic Table and learners predict the properties and reactions based on previous knowledge.</p> <p>Describe unknown compounds or elements and give clues to help learners decide on the position in the Periodic Table.</p>
<p>Past and specimen papers</p>		
<p>Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)</p>		

10 Group 2

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
10.1 Similarities and trends in the properties of the Group 2 metals, magnesium to barium, and their compounds KC2 KC3	10.1.1 Describe, and write equations for, the reactions of the elements with oxygen, water and dilute hydrochloric and sulfuric acids.	<p>For all of the reactions mentioned in this objective, learners could research and produce a summary poster/presentation including balanced equations and trends in reactivity. (I)</p> <p>Experimental work: Reactions of the metals with acids Only two of the metals, magnesium and calcium, are readily available on which to conduct test tube experiments, but you can use these to demonstrate that calcium is much more reactive than magnesium. edu.rsc.org/resources/the-reactivity-of-the-group-2-metals/409.article [reaction of Mg and Ca with dilute hydrochloric acid]</p> <p>Reactions of the metals with water If the metals are not available for test tube experiments, the reactivities can be compared in this video: www.youtube.com/watch?v=O6DaCYKh77E [reactions of Mg, Ca and Sr with water] www.youtube.com/watch?v=9srJdQU3NOo [Ba reacting with water at 07:25] alevelchem.com/aqa_a_level_chemistry/unit3.2/sub3206/02.htm [summary of reactions with water]</p> <p>Reactions of the metals with oxygen Available metals can be burned in air, or oxygen gas produced first and then combusted. www.youtube.com/watch?v=ny0FG2FMSXQ [Mg burning in air] www.youtube.com/watch?v=1bJBueGSC9M&feature=g-crec-u [Ca burning in air] www.youtube.com/watch?v=kDuE3CVWjUk [Sr metal burning in air] www.youtube.com/watch?v=xupVPQpDuwo [Ba metal burning in air]</p> <p>Extension activity: Learners can find out much more information of interest about each element from this website: www.periodicvideos.com/</p>
10.1 Similarities and trends in the properties of the Group 2 metals	10.1.2 Describe, and write equations for, the reactions of the oxides, hydroxides and carbonates with water	<p>Learners research and write balanced chemical equations for the reactions.</p> <p>Experimental work: Learners design, and then perform an experiment to test the reactivity of the oxides or hydroxides or carbonates with either hydrochloric or sulfuric acids. [For example, by measuring the temperature of the reaction, or the evolution of gas for the carbonates.]</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
KC2 KC3	and dilute hydrochloric and sulfuric acids.	
10.1 Similarities and trends in the properties of the Group 2 metals KC2	10.1.3 Describe, and write equations for, the thermal decomposition of the nitrates and carbonates, to include the trend in thermal stabilities.	<u>Group 2 metal carbonates and nitrates</u> The temperature at which most of the carbonates decompose is so high that the pattern in decomposition cannot easily be explored in a school laboratory. Learners write balanced equations for the reactions and research the trend in stabilities.
10.1 Similarities and trends in the properties of the Group 2 metals KC2 KC3	10.1.5 State the variation in the solubilities of the hydroxides and sulfates.	Learners discover the trends in solubility by performing test tube experiments if possible. Highlight the fact that the pattern of solubility of the hydroxides and sulfates are opposite to each other going down Group 2. The explanations for these trends is part of the A Level syllabus, discussed later (27.1.2).
10.1 Similarities and trends in the properties of the Group 2 metals KC2 KC3	10.1.4 Describe, and make predictions from, the trends in physical and chemical properties of the elements involved in the reactions in 10.1.1 and the compounds involved in 10.1.2, 10.1.3 and 10.1.5.	These aspects have been covered above.
Past and specimen papers		

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
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11 Group 17

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
11.1 Physical properties of the Group 17 elements KC2 KC3	11.1.1 Describe the colours and the trend in volatility of chlorine, bromine and iodine.	Learners observe samples or compare images of the halogens, noting that their colour gets darker as you go down the group. www.youtube.com/watch?v=u2ogMUDBaf4 [shows samples of Cl ₂ , Br ₂ and I ₂] Volatility is related to the melting and boiling points of the elements. Learners interpret this data, arriving at the conclusion that the volatility decreases going down the group.
11.1 Physical properties of the Group 17 elements KC3	11.1.2 Describe and explain the trend in the bond strength of the halogen molecules.	Ask learners to define the term bond strength, recalling the work they did in Topic 5 Chemical energetics. Bond energies can be found in the syllabus (page 76-77). Elicit from learners the pattern that bond strength decreases as the size of the halogen atom increases. www.chemguide.co.uk/inorganic/group7/properties.html
11.1 Physical properties of the Group 17 elements KC2 KC3	11.1.3 Interpret the volatility of the elements in terms of instantaneous dipole–induced dipole forces.	Refer learners to Topic 3.6 Intermolecular forces, electronegativity and bond properties. Ask them to explain why iodine has the largest instantaneous dipole–induced dipole forces compared to bromine and iodine. This video compares the halogens: www.youtube.com/watch?v=bio1C-7gOUI [Dispersion forces in halogens]
11.2 The chemical properties of the halogen elements and the hydrogen halides KC2	11.2.1 Describe the relative reactivity of the elements as oxidising agents.	Discuss ideas about redox that learners can recall from Cambridge IGCSE Chemistry (or equivalent). Briefly discuss the meaning of OILRIG (Oxidation is Loss, Reduction is Gain) and how it can be applied to halogen reactions. The relative reactivity of the halogens as aqueous solutions can be established by experiment: edu.rsc.org/resources/reactions-of-halogens-as-aqueous-solutions/733.article

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
KC3		<p>Video (two slightly different ways of performing the experiment):</p> <ul style="list-style-type: none"> • www.youtube.com/watch?v=HW2jRyQ3dzo [in this video the halogens are added directly to the aqueous halide ions and colour changes observed] • www.youtube.com/watch?v=QYuOobnP2sI [watch until 06:40] [in this procedure hexane is added to see the reactions more clearly.] <p>Theory in terms of OILRIG; explains the facts, observations, and order of oxidising ability: www.chemguide.co.uk/inorganic/group7/halogensasoas.html</p> <p>Extension activity: For more advanced learners, they continue watching the video above for more in-depth theory.</p>
11.2 The chemical properties of the halogen elements and the hydrogen halides KC3	11.2.2 Describe the reactions of the elements with hydrogen and explain their relative reactivity in these reactions.	<p>Learners predict the order of reactivity between the halogens and hydrogen, and write equations for their reactions.</p> <p>Videos: www.youtube.com/watch?v=NN82GoBG98s [reaction of chlorine and hydrogen] www.youtube.com/watch?v=SloaknYYsGI [reaction of bromine and hydrogen] www.youtube.com/watch?v=KsDqJiWvNq [reaction of iodine and hydrogen]</p>
11.2 The chemical properties of the halogen elements and the hydrogen halides KC2 KC3	11.2.3 Describe the relative thermal stabilities of the hydrogen halides and explain these in terms of bond strengths.	<p>Ask learners to study the bond energies of the hydrogen-halogen bonds in the syllabus (p76–77) and predict the order for the thermal stabilities of the halides.</p> <p>www.chemguideforcie.co.uk/section94/learningde.html</p>
11.3 Some reactions of the halide ions KC2	11.3.1 Describe the relative reactivity of halide ions as reducing agents.	<p>Ask learners to predict and write down the order of relative reactivity of the halide ions, based on their knowledge of the order of oxidising ability of the halogens (above). They write balanced equations for these transformations.</p> <p>Video of reactions of the halides with concentrated sulfuric acid:</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
<p>KC3</p>	<p>11.3.2 Describe and explain the reactions of halide ions with:</p> <p>(a) aqueous silver ions followed by aqueous ammonia</p> <p>(b) concentrated sulfuric acid, to include balanced chemical equations.</p>	<p>www.youtube.com/watch?v=_I5O5dYEdO4</p> <p>Theory and equations: www.chemguide.co.uk/inorganic/group7/halideions.html</p> <p>Experimental work: Ask learners how they tested for halide ions in qualitative analysis in Cambridge IGCSE Chemistry (or equivalent). Elicit which colours of precipitates were initially formed and what happened when aqueous ammonia was added in excess.</p> <p>www.youtube.com/watch?v=_96chpEILg [show the tests using acidified silver nitrate solution and ammonia]</p>
<p>11.4 The reactions of chlorine</p> <p>KC2</p> <p>KC3</p>	<p>11.4.1 Describe and interpret, in terms of changes in oxidation number, the reaction of chlorine with cold and with hot aqueous sodium hydroxide and recognise these as disproportionation reactions.</p>	<p>Display the balanced equation for chlorine reacting with cold aqueous sodium hydroxide. Ask learners to re-write this as an ionic equation and then to assign oxidation numbers to the chlorine on the left hand side of the equation and both oxidation states of chlorine on the right hand side. If learners have already covered disproportionation in Electrochemistry 6.1.3, ask them if they can remember the name of this special class of redox reaction.</p> <p>Next, display the equation for chlorine reacting with hot aqueous sodium hydroxide. Learners can once again assign oxidation numbers and define the reaction as a disproportionation reaction.</p> <p>Both equations are explained here: www.chemguide.co.uk/inorganic/group7/otherreactions.html [there are links to downloadable question and answer sheets on this topic]</p>
<p>11.4 The reactions of chlorine</p> <p>KC2</p> <p>KC3</p>	<p>11.4.2 Explain, including by use of an equation, the use of chlorine in water purification to include the production of the active species HOCl and ClO which kill bacteria.</p>	<p>Show the equation to learners and ask them to show that this is also an example of a disproportionation reaction (if they have already covered 6.1.3).</p> <p>www.youtube.com/watch?v=rrdnnF1wQ5U</p>

Past and specimen papers

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
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12 Nitrogen and sulfur

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
12.1 Nitrogen and sulfur KC3	12.1.1 Explain the lack of reactivity of nitrogen, with reference to triple bond strength and lack of polarity.	Learners find out and explain why nitrogen is so unreactive in terms of bonding and lack of polarity. Discuss what conditions are needed for reactions to occur with nitrogen (for example, high temperatures during an electrical storm causing nitrogen and oxygen to react together to form nitrogen oxides; or magnesium nitride formation during the combustion of magnesium in air.)
12.1 Nitrogen and sulfur KC2 KC3	12.1.2 Describe and explain: (a) the basicity of ammonia, using the Brønsted–Lowry theory (b) the structure of the ammonium ion and its formation by an acid–base reaction (c) the displacement of ammonia from ammonium salts by an acid–base reaction.	Define the Brønsted–Lowry theory. Learners use it to illustrate how ammonia reacts with a hydrogen ion to form an ammonium ion. www.chemguide.co.uk/organicprops/amines/base.html Relate (c) to the qualitative analysis test for ammonium salts in Cambridge IGCSE Chemistry (or equivalent). You could demonstrate it as a reminder. www.youtube.com/watch?v=LUEakMDNRsM
12.1 Nitrogen and sulfur KC3 14.1 Alkanes KC3	12.1.3 State and explain the natural and man-made occurrences of oxides of nitrogen and their catalytic removal from the exhaust gases of internal combustion engines. 14.1.6 Recognise the environmental	Learners could research the most commonly formed oxides of nitrogen and their occurrence. (I) cnx.org/contents/9G6Gee4A@25.9:Oe0F39vv@1/Oxides-of-Nitrogen Allow learners to research which main pollutants modern catalytic converters treat (CO, NO _x , hydrocarbons). Of these, find out, with equations, how CO and NO _x are converted to less harmful substances. Learners could indicate which elements are oxidised and which are reduced, linking to redox ideas. (I) Catalytic converters: letstalkscience.ca/educational-resources/stem-in-context/catalytic-converters

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>consequences of carbon monoxide, oxides of nitrogen and unburnt hydrocarbons arising from the combustion of alkanes in the internal combustion engine and of their catalytic removal.</p> <p>12.1.4 Understand that atmospheric oxides of nitrogen (NO and NO₂) can react with unburned hydrocarbons to form peroxyacetyl nitrate, PAN, which is a component of photochemical smog.</p> <p>12.1.5 Describe the role of NO and NO₂ in the formation of acid rain both directly and in their catalytic role in the oxidation of atmospheric sulfur dioxide.</p>	<p>Mention also that unburnt hydrocarbons from fuel contribute to the greenhouse effect, in a similar way to methane.</p> <p>Video of catalytic converters: www.youtube.com/watch?v=t85O0KJ1W-Y [The catalytic converter] http://www.youtube.com/watch?v=nM9mdY10ZTU [looking at the parts inside a catalytic converter]</p> <p>Learners research what photochemical smog is and what chemicals it contains. (I)</p> <p>Video resources: www.youtube.com/watch?v=CdbBwlqg4rs [photochemical smog] www.youtube.com/watch?v=fuQT3wnn1KY [formation of photochemical smog] www.youtube.com/watch?v=R4Leb9YDhxU [oxides of nitrogen: a general discussion]</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

13 An introduction to AS Level organic chemistry

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
13.1 Formulae, functional groups and the naming of organic compounds	These Learning outcomes are in Topic 14 Hydrocarbons.	
13.2 Characteristic organic reactions	<p>13.2.1 Interpret and use the following terminology associated with types of organic compounds and reactions:</p> <p>(a) homologous series (b) saturated and unsaturated (c) homolytic and heterolytic fission (d) free radical, initiation, propagation, termination (e) nucleophile, electrophile, nucleophilic, electrophilic (f) addition, substitution, elimination, hydrolysis, condensation (g) oxidation and reduction.</p> <p>13.2.2 Understand and use the following terminology associated with types of organic mechanisms:</p>	<p>The terms are all used in context. References within this document where they are discussed are as follows:</p> <p>(a) homologous series: in 13.1 (with Hydrocarbons, but where all the other functional groups are mentioned) (b) saturated and unsaturated: in Alkenes (14.2) (c) homolytic and heterolytic fission: in Alkanes (14.1.3) (d) free radical, initiation, propagation, termination: in Alkanes (14.1.3) (e) nucleophile/nucleophilic: in Halogen compounds (15.1 and 15.3) electrophile/electrophile: in Alkenes (14.2) (f) addition, substitution: 14.1, 14.2, 15.1, 16.1, 17.1 and 20.1 elimination: 14.2 and 15.1 hydrolysis: 16.1, 18.1, 18.2 and 19.2 condensation: 18.2 (g) oxidation and reduction in organic reactions. oxidation: 14.2, 16.1, 17.1, 18.1 reduction: 16.1, 17.1, 18.1</p> <p>13.2.2 (a), (b), (c) and (d) have all been mentioned above</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	(a) free-radical substitution (b) electrophilic addition (c) nucleophilic substitution (d) nucleophilic addition (in organic reaction mechanisms, the use of curly arrows to represent movement of electron pairs is expected; the arrow should begin at a bond or a lone pair of electrons).	
13.3 Shapes of organic molecules; σ and π bonds	13.3.1 Describe organic molecules as either straight-chained, branched or cyclic. 13.3.2 Describe and explain the shape of, and bond angles in, molecules containing sp , sp^2 and sp^3 hybridised atoms. 13.3.3 Describe the arrangement of σ and π bonds in molecules containing sp , sp^2 and sp^3 hybridised atoms. 13.3.4 Understand and use the term planar when describing the arrangement of atoms in	The shapes of organic molecules are discussed in 13.1 Formulae, functional groups and the naming of organic compounds (in 14 Hydrocarbons). Revise with learners the shapes of orbitals with sp , sp^2 and sp^3 hybridised atoms, that they covered in Covalent bonding 3.4.2. The arrangement of σ and π bonds is covered in 3.4.2 Covalent bonding. The term planar is used in 3.5.1 Shapes of molecules, for example BF_3 is trigonal planar. In organic chemistry it is used in Alkenes (14.2.2).

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	organic molecules, for example ethane.	
13.4 Isomerism: structural and stereoisomerism	<p>13.4.1 Describe structural isomerism and its division into chain, positional and functional group isomerism.</p> <p>13.4.2 Describe stereoisomerism and its division into geometrical (cis/trans) and optical isomerism.</p> <p>13.4.3 Describe geometrical (cis/trans) isomerism in alkenes, and explain its origin in terms of restricted rotation due to the presence of π bonds.</p> <p>13.4.4 Explain what is meant by a chiral centre and that such a centre gives rise to two optical isomers (enantiomers).</p> <p>13.4.5 Identify chiral centres and geometrical (cis-trans) isomerism in a molecule of given structural formula Including cyclic compounds.</p>	<p>Carbon chain isomerism is discussed in 13.1 Formulae, functional groups and the naming of organic compounds in 14 Hydrocarbons.</p> <p>13.4.1 Positional and functional group isomerism: see introduction to 16 Hydroxy compounds</p> <p>13.4.2 and 13.4.3 Cis/trans isomerism is discussed in 14.2 Alkenes in 14 Hydrocarbons.</p> <p>13.4.4 and 13.4.5 Chiral centres are covered in 29.4 Isomerism: optical.</p> <p>13.4.6 Deducing optical isomers is implicitly covered in the above notes.</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	13.4.6 Deduce the possible isomers for an organic molecule of known molecular formula.	
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

14 Hydrocarbons

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
13.1 Formulae, functional groups and the naming of organic compounds	<p>13.1.1 Define the term hydrocarbon as a compound made up of C and H atoms only.</p> <p>13.1.2 Understand that alkanes are simple hydrocarbons with no functional group.</p> <p>13.1.3 Understand that the compounds in the table on page 26 and 27 contain a functional group which dictates their physical and chemical properties.</p> <p>13.1.4 Interpret and use the general, structural, displayed and skeletal formulae of the classes of compound stated in the table on page 26 and 27.</p> <p>13.1.5 Understand and use systematic nomenclature of simple aliphatic organic molecules with functional groups detailed in the</p>	<p>Open the topic by discussing the element carbon. Tell learners there are a huge number of organic compounds based on carbon, and ask learners to find out why this element is so special. [The answer: It catenates, which means it bonds to itself to form chains. Carbon is the element with the highest degree of catenation of any element in the Periodic Table. Other important points are that carbon has a valency of four and forms four strong bonds]. (I)</p> <p>Learners should be able to predict the definition of hydrocarbon from its name. Provide a couple of examples of representative compounds.</p> <p>Alkanes are simple hydrocarbons with general formula C_nH_{2n+2}. Explain that they are a homologous series of hydrocarbons, meaning that they have similar chemical properties and trends in physical properties. Learners practise drawing out the displayed formula for straight-chain alkanes containing 1–6 carbon atoms. Next they name them and learn the necessary prefixes.</p> <p>Learners have only drawn straight-chain examples so far. However, tell learners that two or more compounds with the same molecular formula may exist. Ask learners what the name is for how they are related. [isomers]. Learners practise drawing these structural isomers, (called carbon-chain isomers) with a particular molecular formula, appreciating that their physical properties, for example, boiling points are different from each other.</p> <p>Mention that cyclic hydrocarbons also exist, but these are a different homologous series to the alkanes. (These will not be formally studied but learners should be aware of their existence.) Draw structures such as cyclohexane to demonstrate this.</p> <p>Many other compounds in organic chemistry contain functional groups which determine their physical and chemical properties. (See table on pages 26–7 of the syllabus). Familiarise learners with each one (alkene, halogenoalkanes, alcohols, aldehyde, ketone, carboxylic acid, ester, primary amine and nitrile). Mention that each of these forms a homologous series.</p> <p><u>Molecular model building</u> If available, introduce learners to molecular models (example: Molymod kits). Build example molecules containing the functional groups. Concentrate on learners recognising and naming the functional groups only</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>table on page 26 and 27, up to six carbon atoms (six plus six for esters, straight chains only for esters and nitriles).</p> <p>13.1.6 Deduce the molecular and/or empirical formula of a compound, given its structural, displayed or skeletal formula.</p>	<p>at first, and later introduce nomenclature. Learners also compare the model to the way the structural formula (and skeletal formula) of the functional group is represented in the syllabus.</p> <p>Another key focus of model building is being able to visualise the molecules in 3-D and write them in 2-D (and go from 2-D to 3-D).</p> <p>Mention that all of the molecules learners have built are termed aliphatic compounds. You could display an aromatic compound for reference, explaining that they will study aromatic chemistry in the A Level part of the course.</p> <p><u>Virtual models</u> Sites allowing learners to build molecular models and explore their shape: molview.org/ chemagic.org/molecules/amini.html</p> <p>Learners could test each other's knowledge of functional groups and naming organic molecules using flashcards or creating a quizlet, for example: quizlet.com/7468964/organic-chemistry-functional-groups-flash-cards/</p> <p><u>Empirical formula</u> Ask learners to explain what an empirical formula is and give examples (it was covered in 2.3 Formulae).</p> <p>To explain the difference between structural, displayed and skeletal formulae, start with the molecular formula of, for example, hexane C_6H_{12} and ask learners what the simplest formula could be (CH_2). Discuss, in terms of bonding, why this structure could not exist as a molecular formula. After this give molecules with displayed, and structural and skeletal formulae and ask learners to find the empirical formulae. As learners study more functional groups, ask them about empirical formulae again.</p>
<p>14.1 Alkanes</p> <p>KC2</p> <p>KC3</p>	<p>14.1.1 Recall the reactions (reagents and conditions) by which alkanes can be produced:</p> <p>(a) addition of hydrogen to an alkene in a</p>	<p><u>Hydrogenation</u> Learners research the conditions and catalyst needed to produce margarine from animal and vegetable oils, determine what the basic transformation is, and then write a simpler reaction example for ethene to ethane to illustrate the reaction. Ask them to explain why it is called an addition reaction. (I)</p> <p><u>Cracking</u></p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>hydrogenation reaction, $\text{H}_2(\text{g})$ and Pt/Ni catalyst and heat (b) cracking of a longer chain alkane, heat with Al_2O_3</p> <p>14.1.4 Suggest how cracking can be used to obtain more useful alkanes and alkenes of lower M_r from heavier crude oil fractions</p>	<p>Learners find out why long-chain hydrocarbons in the petrochemicals industry are commonly broken down into simpler molecules. Ask them to write one example reaction such as in the reference below, noting that an alkene is always produced alongside one or more alkanes. (I)</p> <p>www.chemguide.co.uk/organicprops/alkanes/cracking.html</p> <p>www.youtube.com/watch?v=ZYyKUePdC2Y [cracking of liquid paraffin to produce alkane + alkene]</p>
<p>14.1 Alkanes</p> <p>KC2</p> <p>KC3</p> <p>KC5</p>	<p>14.1.2 Describe:</p> <p>(a) the complete and incomplete combustion of alkanes</p> <p>(b) the free-radical substitution of alkanes by Cl_2 or Br_2 in the presence of ultraviolet light, as exemplified by the reactions of ethane.</p> <p>14.1.3 Describe the mechanism of free-radical substitution with reference to the initiation, propagation and termination steps.</p>	<p><u>Complete combustion</u></p> <p>Give learners a variety of alkanes, and they write and balance complete combustion reactions. Learners should also note details about the colour of the flames produced. (They tend to change as the length of the carbon chain changes; as does the ease of ignition of the hydrocarbon.)</p> <p>Experimental work: Ask learners to design (and test) a combustion reaction to show that carbon dioxide and water are produced.</p> <p>www.youtube.com/watch?v=wzJQFI1k9I</p> <p>www.youtube.com/watch?v=PR46y8DSJdc [comparing the flames produced by hexane, heptane, octane, decane]</p> <p>www.youtube.com/watch?v=qPPWo1UG1b8 [apparatus to prove the products of combustion. Also this video discusses the difference in products of complete and incomplete combustion]</p> <p><u>Incomplete combustion</u></p> <p>Discuss that depending on the amount of oxygen present, carbon or carbon monoxide may be produced in incomplete combustion reactions.</p> <p><u>Free radical substitution reactions</u></p> <p>Explain to learners that the covalent bond between bromine (or chlorine) molecules, in the presence of UV light, splits to form reactive species called radicals. Introduce the term homolytic fission when a bond splits</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		<p>evenly in this way. Contrast this with heterolytic fission, where the shared pair of electrons is taken by one of the atoms.</p> <p>In a series of steps, one of the hydrogen atoms in ethane is substituted with bromine. Learners write an overall chemical equation for this reaction. www.youtube.com/watch?v=aR9zMLiOmyk [video showing the reaction between hexane and bromine. The product, HBr is tested with damp litmus paper]</p> <p>Draw the stepwise reaction sequence for learners making it clear why the reaction is a substitution and asking learners to identify the initiation, propagation and termination steps. www.scienceskool.co.uk/free-radical-substitution-and-cfcs.html [for methane]</p>
<p>KC2</p> <p>KC3</p> <p>KC4</p>	<p>14.1.5 Understand the general unreactivity of alkanes, including towards polar reagents in terms of the strength of the C–H bonds and their relative lack of polarity.</p>	<p>Ask learners to look at the bond energies of C–C and C–H bonds on page 77 of the syllabus, and comment on their strength relative to other single bonds. [They should discover that these bonds are strong]. Ask learners what this means in terms of their reactivity.</p> <p>Next ask learners to comment on the polarity of these bonds, if necessary referring to the table of electronegativity values in the syllabus on page 80. The overall conclusion should be that the alkanes are very unreactive and that polar reagents are therefore not easily able to react with them. www.youtube.com/watch?v=60fYqvUaWrA [explains the low reactivity of the alkanes]</p>
<p>14.2 Alkenes</p>	<p>Introduction</p>	<p>As an introduction to alkenes, see if learners can work out what the general formula for this homologous series is.</p> <p>Next explain that they are unsaturated molecules, containing a C=C double bond. This contrast with alkanes which contain only C–C single bonds and are described as saturated molecules.</p> <p>Learners compare models of ethene to ethane, observing that there is restricted rotation about the C=C double bond (compared with free rotation of the C–C single bond). This restricted rotation makes possible a type of stereoisomerism, called geometrical isomerism (cis/trans isomerism). Explain restricted rotation in terms of the π bond.</p> <p>Refer learners to Topic 3 Chemical bonding – they should be able to build up a structure for ethene and explain the shape (planar) and that the carbon atoms are sp^2 hybridised. www.chemguide.co.uk/basicorg/bonding/ethene.html</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
14.2 Alkenes KC2 KC3	14.2.1 Recall the reactions (including reagents and conditions) by which alkenes can be produced: (a) elimination of HX from a halogenoalkane by ethanolic NaOH and heat (b) dehydration of an alcohol, by using a heated catalyst (e.g. Al_2O_3) or a concentrated acid (c) cracking of a longer chain alkane.	Learners research and write down the equations and conditions necessary to prepare alkenes from halogenoalkanes, by dehydration of an alcohol and by cracking of a long -chain alkane. (I) Check they understand the theory, then they perform or examine some of the experiments detailed below. Experimental work: www.youtube.com/watch?v=FROh61wuwbI [shows the reaction of an alkyl halide with KOH, the resulting alkene is tested with bromine water] edu.rsc.org/resources/dehydration-of-ethanol-to-form-ethene/1718.article [dehydration of ethanol to form ethane] www.youtube.com/watch?v=zggTsWpab_g [dehydration of cyclohexanol to prepare cyclohexene] www.rsc.org/suppdata/books/184973/9781849739634/bk9781849739634-chapter%209.1.pdf [this experiment comes with supplementary preparation and identification notes] edu.rsc.org/resources/cracking-hydrocarbons/681.article [cracking – preparation also includes video instruction]
14.2 Alkenes KC2 KC3 KC4	14.2.2 Describe the following reactions of alkenes: (a) The electrophilic addition of: (i) hydrogen in a hydrogenation reaction, $\text{H}_2(\text{g})$ and Pt/Ni catalyst and heat (ii) steam, $\text{H}_2\text{O}(\text{g})$ and H_3PO_4 catalyst (iii) a hydrogen halide, $\text{HX}(\text{g})$ at room temperature (iv) a halogen, X_2	<u>Electrophilic addition</u> Ask learners which bond in alkenes is the most vulnerable to attack by electrophiles, and why. If possible show a molecular model of ethene showing the σ and π bond (remind learners of 13.3 Shapes of molecules). Ask learners to predict the hybridisation and shape of the molecule. [sp^2 hybridised atoms resulting in a planar molecule). Next, define what qualities an electrophile has, explaining that powerful electrophiles have polar bonds as in H-X where there is a permanent δ^+/δ^- polar bond. Learners write equations and conditions for the addition of hydrogen, water, bromine and hydrogen halides to ethene. (Highlight that the addition of bromine to a double bond is a particularly useful reaction for testing for unsaturation). Next look at the mechanism for electrophilic addition, defining the term carbocation and using curly arrows to show the formation of the product. Learners should pay attention to the correct use of 'curly arrows' – see page 72 of the syllabus.

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>(b) The oxidation by cold dilute acidified KMnO_4 to form the diol</p> <p>(c) The oxidation by hot concentrated acidified KMnO_4 leading to the rupture of the carbon-carbon double bond and the identities of the subsequent products to determine the position of alkene linkages in larger molecules</p> <p>(d) Addition polymerisation exemplified by the reactions of ethene and propene.</p> <p>14.2.3 Describe the use of aqueous bromine to show the presence of a C=C bond.</p> <p>14.2.4 Describe the mechanism of electrophilic addition in alkenes, using bromine / ethene and hydrogen bromide / propene as examples.</p>	<p>www.chemguide.co.uk/mechanisms/eladd/whatis.html#top www.docbrown.info/page06/OrgMechs1e.htm [hydrogenation mechanism which is still an electrophilic addition but assisted by catalysts] www.youtube.com/watch?v=eoBCsE_PCas [Video explanation of the mechanism]</p> <p><u>The oxidation of alkenes</u> Demonstrate as a test tube reaction, how cold dilute acidified KMnO_4 solution can sometimes be used as an alternative to bromine water to test for the presence of a C=C bond. Mention that it is not as reliable as using bromine water as further oxidation can easily occur because of the powerful oxidising nature of the oxidant. www.youtube.com/watch?v=nRlybwU1GVU [comparing the addition of KMnO_4 to hexane and cyclohexene]</p> <p>Point out to learners that Mn(II) is colourless as is the resulting diol.</p> <p>Learners complete a worksheet on deducing the position of the double bond after oxidation: www.chemguide.co.uk/organicprops/alkenes/kmno4.html</p> <p>If hot, concentrated acidified KMnO_4 solution is used, the diol produced (as explained above) is further oxidised, and ketones may be produced.</p> <p><u>Addition polymerisation</u> Covered in detail in Polymerisation 20.1.1</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
14.2 Alkenes KC4	14.2.5 Describe and explain the inductive effects of alkyl groups on the stability of primary, secondary and tertiary cations formed during electrophilic addition (this should be used to explain Markovnikov addition).	It would be helpful to learners to write out the mechanism for this reaction and consider the inductive effect of the alkyl groups and stability of the intermediate carbocations. www.chemguide.co.uk/mechanisms/eladd/unsymprob.html chim.lu/ech1800.php [compares inductive effects and carbocation stability] www.youtube.com/watch?v=QCJVYXSkPsY [video: electrophilic addition of propene and HBr: Markovnikov's rule]
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

15 Halogen compounds

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
15.1 Halogenoalkanes KC3 KC4	15.1.1 Recall the reactions (reagents and conditions) by which halogenoalkanes can be produced: (a) the free-radical substitution of alkanes by Cl_2 or Br_2 in the presence of ultraviolet light, as exemplified by the reactions of ethane (b) electrophilic addition of an alkene with a halogen, X_2 , or hydrogen halide, $\text{HX}(\text{g})$, at room temperature (c) substitution of an alcohol, e.g. by reaction with HX or KBr with H_2SO_4 or H_3PO_4 ; or with PCl_3 and heat; or with PCl_5 ; or with SOCl_2 .	As revision, ask learners to recall these reactions from Alkanes 14.1, Alkenes 14.2 and Hydroxy compounds 16.1 of the syllabus. You could do this as a quick quiz or learners could produce a title page for this topic including the basic transformations.
15.1 Halogenoalkanes KC4	15.1.2 Classify halogenoalkanes into primary, secondary and tertiary.	Learners make models and draw 2-D and 3-D representations of primary, secondary and tertiary halogenoalkanes. They could also build virtual models and rotate them using the following virtual lab program: molview.org/ [learners first construct 2-D structures and the program transforms these into 3-D rotational images]

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		Building models physically or virtually allows learners to appreciate the relative positions of atoms in the molecules. For this section, this understanding is vital, as it affects the direction of approach of the incoming nucleophile in nucleophilic substitution described below.
15.1 Halogenoalkanes	15.1.4 Describe the elimination reaction with NaOH in ethanol and heat to produce an alkene as exemplified by bromoethane.	Covered in Alkenes 14.2.1 (a)
15.1 Halogenoalkanes KC2 KC3 KC4	15.1.3 Describe the following nucleophilic substitution reactions: (a) the reaction with NaOH(aq) and heat to produce an alcohol (b) the reaction with KCN in ethanol and heat to produce a nitrile (c) the reaction with NH ₃ in ethanol heated under pressure to produce an amine (d) the reaction with aqueous silver nitrate in ethanol as a method of identifying the halogen present as exemplified by bromoethane.	Define a nucleophile, stressing that it may be a neutral or negatively charged species. In both cases, it must possess a pair of electrons which will form a new bond. Elicit a range of potential nucleophiles from learners. <u>Nucleophilic substitution with the hydroxide ion</u> Using the nucleophile OH ⁻ , explain both S _N 1 and S _N 2 mechanisms to learners. Choose one of the simplest tertiary halogenoalkanes to illustrate the S _N 1 mechanism using for example, 2-methyl 2-chloropropane as the substrate. Ask learners why and where the nucleophile, OH ⁻ will attack the molecule. Use models to help learners visualise the two-step process: 1) the carbon-chlorine bond breaks and a chloride ion leaves; 2) attack of the nucleophile. Using models will help learners appreciate in which direction the nucleophile will attack the resulting tertiary carbocation. (from the front) Make sure that learners understand the meaning of S _N 1 and S _N 2 using the terms substitution, nucleophilic and uni and bi-molecular. This will in turn help them understand the mechanisms. Link this topic to rate of reaction: Reaction kinetics 26.1. The term 'inductive effect' can be used to explain the difference in stability/reactivity of the intermediate carbocations: www.docbrown.info/page06/OrgMechs2.htm www.youtube.com/watch?v=Bg3c5c9b1BQ&t=117s [mechanisms compared in detail] www.rsc.org/education/teachers/resources/afchem/resources/55/index.htm [contains printable cards to aid understanding of the mechanisms involved]

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>15.1.5 Describe the S_N 1 and S_N 2 mechanisms of nucleophilic substitution in halogenoalkanes including the inductive effects of alkyl groups.</p> <p>15.1.6 Recall that primary halogenoalkanes tend to react via the S_N 2 mechanism; tertiary halogenoalkanes via the S_N 1 mechanism; and secondary halogenoalkanes by a mixture of the two, depending on structure.</p>	<p>Videos: www.youtube.com/watch?v=Bg3c5c9b1BQ [S_N1 and S_N2 nucleophilic substitution]</p> <p>Extension activity: Learners could find out more about these reactions by investigating the conditions used in the preparation of alcohols from halogenoalkanes under reflux conditions. They may be interested to learn more about the effect solvent has on the reactions, the inversion of stereochemistry which occurs and what a transition state is. www.youtube.com/watch?v=bl38lSn3UPg [effect of using polar aprotic and protic solvents]</p> <p><u>Nucleophilic substitution using the cyanide ion and ammonia</u> Learners need to know the conditions and example reaction, such as:</p> $\text{CH}_3\text{CH}_2\text{Br} + \text{NH}_3 \longrightarrow \text{CH}_3\text{CH}_2\text{NH}_2$ <p>and $\text{CH}_3\text{CH}_2\text{Br} + \text{CN}^- \longrightarrow \text{CH}_3\text{CH}_2\text{CN}$</p> <p>For both reactions ask learners to name the reactants and products and in the case of the reaction with cyanide ions, point out that it is extremely useful to chemists to be able to extend the carbon chain by one carbon atom using this method.</p>
<p>15.1 Halogenoalkanes</p> <p>KC2</p> <p>KC3</p> <p>KC4</p>	<p>15.1.7 Describe and explain the different reactivities of halogenoalkanes (with particular reference to the relative strengths of the C–X bonds as exemplified by the reactions of halogenoalkanes with aqueous silver nitrate).</p>	<p>Experimental work: Choose three primary halogenoalkanes with the same chain length (for example, 1-chlorobutane, 1-bromobutane and 1-iodobutane). Before starting the experiment, ask learners what the nucleophile is. Ask them to predict the products and what they think the relative rates of hydrolysis will be and why. Also ask them to find out the role of the ethanol used in the experiment (solvent).</p> <p>www.ocr.org.uk/Images/163774-explaining-observations-activity-teacher-instructions.pdf [procedure for the experiment] www.youtube.com/watch?v=Nr_1HSQ2LIc [video]</p> <p>In the conclusion to the experiment, suggest that learners justify their results according to the bond energies of the carbon-halogen bonds (page 77 of the syllabus).</p> <p>Helpful reference with downloadable question and answer sheets on this topic: www.chemguide.co.uk/organicprops/haloalkanes/agno3.html</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		Extension activity: More advanced learners could draw out the mechanism for the reaction involving water as the nucleophile. Also ask them to justify why the reaction is quite slow compared to using the hydroxide ion for example. www.chemguide.co.uk/mechanisms/nucsub/water.html
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

16 Hydroxy compounds

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	Introduction	<p>Before you start to discuss specific reactions of the alcohols, discuss that they are an homologous series of organic compounds with a defining general formula. Learners can try to work this out [$C_nH_{2n+1}OH$]. Learners could build models, real or virtual to explore the range possible structures. Highlight that a type of structural isomer called positional isomers exist. Encourage learners to build molecules such as butan-1-ol and butan-2-ol to show this. Learners should also build isomeric compounds such as ethanol and dimethyl ether noting that they belong to different homologous series. These isomers are called functional group isomers.</p>
16.1 Alcohols KC3	16.1.1 Recall the reactions (reagents and conditions) by which alcohols can be produced: (a) electrophilic addition of steam to an alkene, $H_2O(g)$ and H_3PO_4 catalyst (b) reaction of alkenes with cold dilute acidified potassium manganate(VII) to form a diol (c) substitution of a halogenoalkane using $NaOH(aq)$ and heat (d) reduction of an	You could set this as an independent study research project presented in poster form or as a computer infographic. Learners should present both the word and symbol equations for the transformations along with the conditions and reagents required. (I)

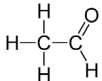
Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	aldehyde or ketone using NaBH_4 or LiAlH_4 (e) reduction of a carboxylic acid using NaBH_4 or LiAlH_4 or $\text{H}_2(\text{g})/\text{Ni}$ and heat (f) hydrolysis of an ester using dilute acid or dilute alkali and heat.	
16.1 Alcohols KC2 KC3 KC5	16.1.2 Describe: (a) the reaction with oxygen (combustion) (b) substitution to halogenoalkanes, e.g. by reaction with HX or KBr with H_2SO_4 or H_3PO_4 ; or with PCl_3 and heat; or with PCl_5 ; or with SOCl_2 (c) the reaction with $\text{Na}(\text{s})$ (d) oxidation with acidified $\text{K}_2\text{Cr}_2\text{O}_7$ or acidified KMnO_4 to: (i) carbonyl compounds by distillation (ii) carboxylic acids by refluxing (primary alcohols give aldehydes)	<p><u>Combustion reactions</u> Learners predict the products and write balanced equations for the complete and incomplete combustion of some primary alcohols. They should also be able to predict the possible products of incomplete combustion.</p> <p>Extension activity: Give more advanced learners challenge of comparing the enthalpy of combustion of a homologous alkane and alcohol, for example, methane and methanol as in the following activity: chem.umn.edu/heat-combustion-alkane-vs-alcohol</p> <p><u>Nucleophilic substitution by a halogen</u> This objective explores the various methods which may be used to substitute an $-\text{OH}$ group by a halogen ion. This reference considers all conversion methods required: www.chemguide.co.uk/organicprops/alcohols/halogen.html [with downloadable question and answer sheets]</p> <p>Experimental work: The conversion of alcohols to halogenoalkanes: ethanol + phosphorous (III) bromide. (The alternative method of heating the alcohol under reflux with sodium bromide and conc. sulfuric acid, generating HBr in situ is also mentioned but the yields are normally low.): edu.rsc.org/resources/the-conversion-of-alcohols-to-halogenoalkanes/558.article</p> <p><u>The reaction of an alcohol with sodium</u> Demonstrate the reaction of sodium and water with small pieces of sodium or show the video of the reaction: www.youtube.com/watch?v=aGaWwnMyKVE</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>which can be further oxidised to carboxylic acids, secondary alcohols give ketones, tertiary alcohols cannot be oxidised)</p> <p>(e) dehydration to an alkene, by using a heated catalyst, e.g. Al_2O_3 or a concentrated acid</p> <p>(f) formation of esters by reaction with carboxylic acids and concentrated H_2SO_4 or H_3PO_4 as catalyst as exemplified by ethanol</p> <p>16.1.5 Explain the acidity of alcohols compared with water.</p>	<p>Learners should observe that this reaction is much slower than with water. Then write and discuss the equation for the reaction. The slower rate of reaction shows that ethanol is a weaker acid than water. Return to this point after learners have studied conjugate acids and bases in Topic 25.1 Acids and bases. They will then appreciate that the weaker the acid the stronger its conjugate base – for now, depending on the group you teach, you may wish to just mention that the ethoxide ion is a very powerful base.</p> <p><u>The oxidation of alcohols</u> In this section, it is most important that learners understand the difference between the processes of refluxing and distillation.</p> <p>If possible, set up reflux apparatus and a distillation starting with the same reactant, ethanol. Run these experiments one after the other and test the resulting products formed. These videos compare the difference between the necessary set-ups and the products formed: www.youtube.com/watch?v=i7Ai5JdPYaY [the mild oxidation of ethanol to ethanol and its testing] www.youtube.com/watch?v=VwEiuNPkm3g [reflux of ethanol to ethanoic acid] www.youtube.com/watch?v=r8g1ysWemp4</p> <p>If the equipment is not available, then the oxidation of ethanol by acidified sodium dichromate can be performed in a test tube and the products tested by a difference in odour. In this case, learners should carefully research diagrams of the differences between reflux and distillation set-ups afterwards. edu.rsc.org/resources/oxidation-of-ethanol/1757.article edu.rsc.org/resources/a-microscale-oxidation-of-alcohols/553.article</p> <p><u>The dehydration of an alcohol to an alkene</u> This is not an easy reaction to set up in the lab. Instead, show and discuss the following video: www.youtube.com/watch?v=I-10WJ_t4NQ</p> <p><u>Esterification</u> State the reaction and conditions briefly here, but the preparation of an ester from a carboxylic acid is covered in detail in topic 18.2 Esters.</p> <p>Acidity of alcohols compared to water is covered above in (c)</p>
16.1 Alcohols	16.1.3	Build models to illustrate the difference between primary, secondary and tertiary alcohols. Additionally/ alternatively, learners can build models virtually and rotate them using the following virtual lab:

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
KC4	<p>(a) classify alcohols as primary, secondary and tertiary alcohols, to include examples with more than one alcohol group</p> <p>(b) state characteristic distinguishing reactions, e.g. mild oxidation with acidified $K_2Cr_2O_7$, colour change from orange to green.</p>	<p>molview.org [learners first construct 2-D structures and the program transforms these into 3-D rotational images]</p> <p>If learners are unable to use models or access the virtual environment above, draw the full structural formula of each alcohol. It is important to see clearly, for example, that a tertiary alcohol has oxidisable hydrogen atoms attached to the carbon atom which carries the $-OH$ group.</p> <p>This reference illustrates the idea clearly: www.chemguide.co.uk/organicprops/alcohols/oxidation.html [this link also contains downloadable questions and answers on this topic]</p>
<p>16.1 Alcohols</p> <p>KC2</p> <p>KC4</p>	<p>16.1.4 Deduce the presence of a $CH_3CH(OH)-$ group in an alcohol, $CH_3CH(OH)-R$, from its reaction with alkaline $I_2(aq)$ to form a yellow precipitate of tri-iodomethane and an ion, RCO_2^-</p>	<p>This reaction is commonly called the Iodoform test or the Tri-iodomethane test. This resource explains the reagents needed and the results obtained for the reaction: www.chemguide.co.uk/organicprops/alcohols/iodoform.html [there are questions and answers downloadable from this page]</p> <p>Experimental work: Learners could carry out the reaction as explained in the following video: www.youtube.com/watch?v=iOeDDme-Tl0</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

17 Carbonyl compounds

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
17.1 Aldehydes and ketones KC2 KC3	17.1.1 Recall the reactions (reagents and conditions) by which aldehydes and ketones can be produced: (a) the oxidation of primary alcohols using acidified $K_2Cr_2O_7$ or acidified $KMnO_4$ and distillation to produce aldehydes (b) the oxidation of secondary alcohols using acidified $K_2Cr_2O_7$ or acidified $KMnO_4$ and distillation to produce ketones.	This topic is covered in section 16.1.2 Alcohols. Learners revise the topic by summarising the methods of preparation of aldehydes and ketones as a one-page poster.
17.1 Aldehydes and ketones KC4	17.1.2 Describe: (a) the reduction of aldehydes and ketones, using $NaBH_4$ or $LiAlH_4$ to produce alcohols (b) the reaction of aldehydes and ketones with HCN , KCN as catalyst, and heat to produce hydroxynitriles	Before you give any specific reactions ask learners to draw out any aldehyde and ketone in their notebooks and indicate which part of the molecules is vulnerable to attack. If they find this challenging, ask them to consider electronegativity differences in the molecules and why that might be important. <u>The reduction of aldehydes and ketones</u> The important thing when using either of these reagents is to know that they are both a good source of hydrogen for reduction in the form of the hydride ion (H^-). It is perfectly acceptable to write the reductions using $[H]$ in simplified chemical equations: $+ 2[H] \quad \longrightarrow \quad \begin{array}{c} H & H \\ & \\ H-C & -C-O-H \\ & \\ H & H \end{array}$

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>exemplified by ethanal and propanone.</p> <p>17.1.3 Describe the mechanism of the nucleophilic addition reactions of hydrogen cyanide with aldehydes and ketones in 17.1.2(b).</p>	<p>The conditions for and the mechanism of this reaction are not required. Learners should be able to justify why the product is a primary or a secondary alcohol in each case.</p> <p>Extension activity: More advanced learners can research why one reducing reagent is used over the other, why LiAlH_4 is more powerful than NaBH_4 and how the reactions are carried out.</p> <p><u>The reactions of aldehydes and ketones with HCN and KCN</u> Learners should first draw out the reaction without considering the mechanism, noting that a hydroxynitrile is produced.</p> <div style="text-align: center;">  </div> <p>Discuss with learners that the attacking species is the electron-rich nucleophile, the cyanide ion. They then draw the mechanism of the reaction.</p> <p>The following site allows learners to view, interact with the mechanism and rotate the resulting structures: www.chemtube3d.com/a-level-additioncyanide/</p> <p>Extension activity: Learners could link this topic with 29.4 Isomerism: optical. They can find out why this reaction produces a racemic mixture of two optical isomers. www.chemguide.co.uk/mechanisms/nucadd/hcn.html#top</p>
<p>17.1 Aldehydes and ketones</p> <p>KC2</p> <p>KC3</p>	<p>17.1.4 Describe the use of 2,4-dinitrophenylhydrazine (2,4-DNPH reagent) to detect the presence of carbonyl compounds.</p> <p>17.1.5 Deduce the nature (aldehyde or ketone) of an unknown carbonyl compound from the results of simple tests (Fehling's and Tollens' reagents; ease of oxidation).</p>	<p>Learners only need to know that DNPH is a reagent used in the qualitative test for the presence of a carbonyl group in aldehydes and ketones. Both produce a yellow-orange precipitate showing that a carbonyl group is present in the molecule.</p> <p>Extension activity: Learners could find out about the historical use of DNPH as a tool to characterise compounds. They could draw out the structure of DNPH and write an equation showing how the hydrazone is formed. www.youtube.com/watch?v=OugcrG8y_Ig [historical use of the reagent and a discussion of its safety]</p> <p>Discuss with learners that there are several additional tests which can be performed to find out whether an unknown compound is an aldehyde or a ketone. www.docbrown.info/page13/ChemicalTests/ChemicalTestsf.htm [describes all of the tests for aldehydes and ketones]</p> <p>Experimental work: Resource Plus</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		Carry out the <i>Identifying alkenes, alcohols and halogenoalkanes</i> experiment referring to the Teaching Pack for lesson plans and resources.
17.1 Aldehydes and ketones KC2 KC3	17.1.6 Deduce the presence of a CH_3CO -group in an aldehyde or ketone, $\text{CH}_3\text{CO-R}$, from its reaction with alkaline $\text{I}_2(\text{aq})$ to form a yellow precipitate of tri-iodomethane and an ion, RCO_2^- .	This test is described in 16.1.4 Alcohols.
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

18 Carboxylic acids and derivatives

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
18.1 Carboxylic acids KC2 KC3	18.1.1 Recall the reactions by which carboxylic acids can be produced: (a) oxidation of primary alcohols and aldehydes with acidified $K_2Cr_2O_7$ or acidified $KMnO_4$ and refluxing (b) hydrolysis of nitriles with dilute acid or dilute alkali followed by acidification (c) hydrolysis of esters with dilute acid or dilute alkali and heat followed by acidification.	<u>The oxidation of primary alcohols and aldehydes</u> Covered in topic 17 Carbonyl compounds. <u>The hydrolysis of nitriles</u> Explain to learners that usually hydrolysis is a chemical process in which molecule(s) of water are added to a substance. The hydrolysis is very slow using just water, so a dilute alkali or acid are used to speed it up. www.chemguide.co.uk/organicprops/nitriles/hydrolysis.html Experimental work: www.prepchem.com/synthesis-of-benzoic-acid/ [the base hydrolysis of benzonitrile] www.youtube.com/watch?v=pYSPeiDkb0g [the base hydrolysis of benzonitrile] <u>The hydrolysis of an ester</u> Normally this reaction is carried out under alkaline reflux conditions with dilute sodium hydroxide solution and the resulting sodium salt acidified to yield the resulting carboxylic acid. The alcohol produced is easily removed by distillation. Extension activity: Ask learners to find out why the hydrolysis of esters is not usually carried out under acid conditions. www.chemguide.co.uk/organicprops/esters/hydrolysis.html
18.1 Carboxylic acids KC2 KC3	18.1.2 Describe: (a) the redox reaction with reactive metals to produce a salt and $H_2(g)$ (b) the neutralisation reaction with alkalis to produce a salt and $H_2O(l)$	(a) Experimental work: Add a small length of magnesium metal to ethanoic acid. Fizzing is observed and the liberated hydrogen gas can be tested with a lighted splint. Learners should be careful writing the correct formula of the salt produced, magnesium ethanoate, $(CH_3COO)_2Mg$ (b) and (c) are described in section 7 Equilibria. (d) is covered below in Esters (18.2.1)

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>(c) the acid–base reaction with carbonates to produce a salt and H₂O(l) and CO₂(g)</p> <p>(d) esterification with alcohols with concentrated H₂SO₄ as catalyst</p> <p>(e) reduction by LiAlH₄ to form a primary alcohol.</p>	<p>(e) The reduction of carboxylic acids to primary alcohols requires severe conditions provided by the strong reducing agent LiAlH₄. Learners may already have seen this reagent in section 17.1.2 Aldehydes and ketones, and should note that NaBH₄ is not strong enough to produce this transformation.</p> <p>Experimental work: The acid reactions of ethanoic acid may be explored in this practical edu.rsc.org/resources/the-acidic-reactions-of-ethanoic-acid/462.article</p>
<p>18.2 Esters</p> <p>KC2</p> <p>KC3</p>	<p>18.2.1 Recall the reaction (reagents and conditions) by which esters can be produced:</p> <p>(a) the condensation reaction between an alcohol and a carboxylic acid with concentrated H₂SO₄ as catalyst.</p>	<p>Learners only need to know the reagents and conditions necessary to produce an ester, but drawing the structure of esters and naming them can cause difficulty. Use these activities/games to help learners recognise and name esters:</p> <p>rsc.org/learn-chemistry/resources/gridlocks/puzzles/level-3/NamingEsters.html legacy.chemgym.net/as_a2/topics/carboxylic_acids_and_esters/quiz_1.html</p> <p>Learners could build models of the reactants, combining these to form the ester, noticing that one molecule of water is condensed out.</p> <p>Experimental work: edu.rsc.org/resources/making-esters-from-alcohols-and-acids/1743.article [test-tube reactions to transform a range of acids and alcohols into esters]</p> <p>A more ambitious project would be to prepare and isolate an ester by distillation: www.youtube.com/watch?v=LRayglG3ZUY [an ester is made from propanoic acid and methanol] www2.ucdsb.on.ca/tiss/stretton/chem3/Lab_13_Ester_Formation%20and%20Purification.html [preparation details], also: www.dhouts.com/Ester_Synthesis_Lab.pdf</p> <p>Resource Plus</p> <p>Carry out the <i>Making esters</i> experiment in Cambridge IGCSE Chemistry 0620 Resource Plus, referring to the Teaching Pack for lesson plans and resources.</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
18.2 Esters KC2 KC3	18.2.2 Describe the hydrolysis of esters by dilute acid and by dilute alkali and heat	Covered above.
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

19 Nitrogen compounds

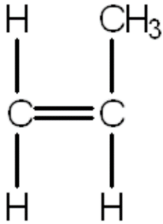
Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
19.1 Primary amines KC2 KC3	19.1.1 Recall the reactions by which amines can be produced: (a) reaction of a halogenoalkane with NH_3 in ethanol heated under pressure	This reaction is covered in section 15.1.3 Halogenoalkanes.
19.2 Nitriles and hydroxynitriles KC2 KC3	19.2.1 Recall the reactions by which nitriles can be produced: (a) reaction of a halogenoalkane with KCN in ethanol and heat. 19.2.2 Recall the reactions by which hydroxynitriles can be produced: (a) the reaction of aldehydes and ketones with HCN, KCN as catalyst, and heat.	This reaction is covered in section 15.1.3 Halogenoalkanes. This reaction is discussed in section 17.1.2 Aldehydes and ketones.
19.2 Nitriles and hydroxynitriles KC2 KC3	19.2.3 Describe the hydrolysis of nitriles with dilute acid or dilute alkali followed by acidification to produce a carboxylic acid.	This reaction is discussed in section 18.1.2 Carboxylic acids.

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
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Past and specimen papers

Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)

20 Polymerisation

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
20.1 Addition polymerisation KC3 KC4	20.1.1 Describe addition polymerisation as exemplified by poly(ethene) and poly(chloroethene), PVC. 20.1.2 Deduce the repeat unit of an addition polymer obtained from a given monomer. 20.1.3 Identify the monomer(s) present in a given section of an addition polymer molecule.	<p>Display a range of products made from polyethene, polypropene and PVC. Briefly discuss their differences and where the raw materials come from.</p> <p>Ask learners to write the structure of several molecules of ethene across the top of a page in their notebooks and show how polythene is formed. Next ask them to identify a repeating unit and represent the polymer in this way.</p> <p>Following this, repeat the process, this time using propene. Learners may need help in drawing the monomer so that the addition reaction can be easily visualised:</p> <div style="text-align: center;">  </div> <p>www.youtube.com/watch?v=rz4eLiXKbo4 [shows the polymerisation of ethene and propene]</p> <p>Extension activities:</p> <ul style="list-style-type: none"> • More able learners may realise that several forms of the polymer may be formed, depending on reaction conditions, and can read this article: www.essentialchemicalindustry.org/polymers/polypropene.html [discusses the structures of the different polypropenes] • Learners investigate how changing the substituents on ethene affects the properties and uses of the polymer: • www.youtube.com/watch?v=tTfCx9nCDz4 [the chemistry and uses of polyethene, polypropene, PVC]

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
20.1 Addition polymerisation KC3	20.1.4 Recognise the difficulty of the disposal of poly(alkene)s, i.e. non-biodegradability and harmful combustion products.	Learners research this topic to prepare a presentation (for example in a school assembly) to heighten awareness of this global problem. They could include: <ul style="list-style-type: none"> • the discovery of plastics and the environmental solutions chemists hoped they would provide www.youtube.com/watch?v=DQW5w9yAWgE#action=share • the use of single-use plastics and how we are currently trying to reducing their use • why plastics can't simply be disposed of by burning • current research in biodegradable plastics • recycling.
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

21 Organic synthesis (1)

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
21.1 Organic synthesis KC3	21.1.1 For an organic molecule containing several functional groups: (a) identify organic functional groups using the reactions in the syllabus (b) predict properties and reactions.	Make sure that learners are familiar with the functional groups, reagents and conditions to effect all of the transformations covered in the AS Chemistry syllabus, before starting this topic. Learners summarise their previous work using mind maps or tables or reactions. Learners could also create their own quiz to test their friends, or use this example: quizlet.com/7468964/organic-chemistry-functional-groups-flash-cards/ [free but you have to become a member of quizlet]
21.1 Organic synthesis KC3	21.1.2 Devise multi-step synthetic routes for preparing organic molecules using the reactions in the syllabus. 21.1.3 Analyse a given synthetic route in terms of type of reaction and reagents used for each step of it, and possible by-products.	Introduce this topic by discussing the reasons why chemists need to plan synthetic routes in organic chemistry. www.dur.ac.uk/chemistry/outreach/dusting/learners/synthesis/ alevelchemistry.co.uk/notes/organic-synthesis/ Using all of the transformations necessary to make products via two-step organic syntheses in 21.1.1, learners try to produce a reaction pathways map, drawing arrows between functional groups, including reagents and conditions above the arrows. Learners could try 'Synthesis explorer' to help them organise and plan syntheses: edu.rsc.org/resources/synthesis-explorer/3.article www.ocr.org.uk [search 'organic synthesis reaction pathways' and 'organic synthesis activity 2' and several other helpful articles helpful for teachers and learners]
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

22 Analytical techniques

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
22.1 Infra-red spectroscopy KC1 KC2	22.1.1 Analyse an infra-red spectrum of a simple molecule to identify functional groups (see the Data section for the functional groups required).	<p>Elicit from learners that infra-red is electromagnetic radiation just beyond the visible red part of the spectrum. Discuss with them that this energy interacts with the bonds in organic molecules, causing them to vibrate and that this vibration can be displayed as an infra-red chart.</p> <p>Mention to learners that different frequencies of electromagnetic radiation are used in different ways, in different instruments, to observe and characterise compounds (for example NMR spectroscopy utilises radio waves). Also mention that microwave and ultraviolet spectroscopy instruments are used to identify structures. If possible, make links and organise trips to local universities or companies who have these spectroscopic instruments.</p> <p>Refer learners to page 82 of the syllabus where characteristic infra-red absorption frequencies for some bonds are shown. Explain that the infra-red spectrum of an unknown sample can be compared to vast libraries of known compounds, whose functional groups interact with infra-red at these specific frequencies, in order to identify the sample.</p> <p>Show learners the following video which shows an infra-red instrument in operation and gives some background on how a spectrum is obtained: www.youtube.com/watch?v=DDTIJgIh86E</p> <p>A large, displayable reference chart for infra-red spectroscopy: www.compoundchem.com/2015/02/05/irspectroscopy/</p> <p>The spectra and their interpretation for a range of simple compounds: www.chemguide.co.uk/analysis/ir/interpret.html#top [there is also a downloadable question and answer sheet]</p> <p>Extension activity (if an infra-red spectrophotometer is available): edu.rsc.org/resources/spectroscopy-in-a-suitcase-ir-teacher-resources/940.article</p>
22.2 Mass spectroscopy KC1 KC2	22.2.1 Analyse mass spectra in terms of m/e values and isotopic abundances.	<p>Although learners don't need to know how a mass spectrometer works, an appreciation of it will help learners understand how the instrument helps us identify the structures of substances. This reference clearly explains what happens: www.chemguide.co.uk/analysis/masspec/howitworks.html#top and this reference provides a simple simulation: nationalmaglab.org/education/magnet-academy/watch-play/interactive/mass-spectrometer-single-sector</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	22.2.2 Calculate the relative atomic mass of an element given the relative abundances of its isotopes, or its mass spectrum.	<p>Ask learners to recall and write down a definition of relative atomic mass (The relative atomic mass of an element is the weighted average of the masses of the isotopes on a scale on which a carbon-12 atom has a mass of exactly 12 units).</p> <p>Explain how relative atomic mass is calculated for chlorine, emphasising that the % abundances are found from mass spectrum data: www.bbc.co.uk/bitesize/guides/zy2h9qt/revision/3 www.docbrown.info/page04/4_71atomMSintro.htm [several worked examples with spectra]</p>
22.2 Mass spectroscopy KC1 KC2	<p>22.2.3 Deduce the molecular mass of an organic molecule from the molecular ion peak in a mass spectrum.</p> <p>22.2.4 Suggest the identity of molecules formed by simple fragmentation in a given mass spectrum.</p> <p>22.2.5 Deduce the number of carbon atoms, n, in a compound using the $M + 1$ peak and the formula</p> $n = \frac{100 \times \text{abundance of } M + 1 \text{ ion}}{1.1 \times \text{abundance of } M + \text{ion}}$ <p>22.2.6 Deduce the presence of bromine and chlorine atoms in a compound using the $M + 2$ peak.</p>	<p>Explain that the major use of mass spectrometry is in the identification of chemical structures and that one of the most important peaks to look for in a spectrum is the molecular ion peak (or base peak). www2.chemistry.msu.edu/faculty/reusch/VirtTxtJml/Spectrpy/MassSpec/masspec1.htm www.chemguide.co.uk/analysis/masspec/mplus.html [contains questions and answers on this topic]</p> <p>Ask learners to suggest why molecules become fragmented in a mass spectrometer. Explain to them that the reasons for the pattern observed for a particular molecule depends on its structure. Make sure that learners understand that when one electron is removed from a molecule after bombardment, a positive ion, called the molecular ion is seen in the spectrum (noting that a radical is also produced in the process). Then this species may break up into smaller, more stable species forming the fragmentation pattern for that specific molecule.</p> <p>Examples of patterns produced: www.chemguide.co.uk/analysis/masspec/fragment.html#top [with question and answer sheets]</p> <p>Video with examples: www.youtube.com/watch?v=Y4BRFobuLro www.youtube.com/watch?v=xx8CaHVYm8</p> <p>Extension activity: to help learners understand fragmentation patterns: edu.rsc.org/resources/a-model-of-mass-spectrometry/2390.article</p> <p>Ask learners to state which the most common element in organic compounds is and why it deserves special attention in this sub-topic. Show learners the region of a mass spectrum where the molecular ion is situated and ask them to suggest why an $M + 1$ peak exists to the right of the main peak about 1% the height of the main peak.</p> <p>Learners practise calculating the number of carbon atoms in a compound using the formula given.</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		<p>www.chemguide.co.uk/analysis/masspec/mplus1.html#top www.chemguideforcie.co.uk/2016section22/learning22p3all.html</p> <p>Similar to the above, if a chlorine atom is present an M+2 peak is found in a ratio of 3:1, and if a bromine atom exists in a molecule an M+2 peak with a ratio of approx. 1:1 is present. This means the presence of chlorine or bromine can be detected.</p> <p>www.chemguide.co.uk/analysis/masspec/mplus2.html [with questions and answers]</p> <p>Practical extension activity: for learners who have access to a mass spectrometer: edu.rsc.org/resources/spectroscopy-in-a-suitcase-mass-spectrometry-resources/943.article [contains an introduction to practical mass spectrometry, and a learner and teacher sheet]</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

23 Chemical energetics

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
23.1 Lattice energy and Born-Haber cycles KC5	23.1.1 Define and use the terms: (a) enthalpy change of atomisation, ΔH_{at} (b) lattice energy, ΔH_{latt} (the change from gas phase ions to solid lattice)	<p>Explain that lattice energy is a measure of the forces between the ions in an ionic crystal and that Born-Haber cycles are used to calculate their magnitude. Also tell learners that for calculations on Born-Haber cycles to be made, they need to know several terms. Elicit from learners the definitions of the terms ionisation enthalpy and enthalpy of formation, which they met in AS Chemistry.</p> <p>Learners write out definitions for the enthalpy change of atomisation and the lattice energy. Check that they understand them.</p> <p>It is important for learners to note that in this syllabus the change defined by ΔH_{latt} is gas to solid. For example,</p> $\text{Na}^+(\text{g}) + \text{Cl}^-(\text{g}) \longrightarrow \text{Na}^+ \text{Cl}^-(\text{s})$ <p>This is sometimes termed the lattice formation enthalpy.</p> <p>Define the enthalpy of sublimation which is also needed in the construction of Born-Haber cycles.</p>
23.1 Lattice energy and Born-Haber cycles KC5	23.1.2 (a) define and use the term first electron affinity, EA (b) explain the factors affecting the electron affinities of elements (c) describe and explain the trends in the electron affinities of the Group 16 and Group 17 elements	<p>(a) Learners find a definition for electron affinity, EA. This is most easily understood by writing a symbol equation.</p> <p>(c) Encourage learners to list the electron affinities of Group 16 and Group 17 elements and discuss patterns they notice. Emphasise that there is a general trend of decreasing electron affinity even though the topmost elements at the top of the group are exceptions to this (and these exceptions do not need to be studied). They could use this data: periodictable.com/Properties/A/ElectronAffinity.v.log.html</p> <p>(b) After noticing the general trends in electron affinities descending the groups, learners try to explain why less energy is released when an electron is acquired by a gaseous atom lower down each group. Discuss nuclear charge, distance and screening effects just as for ionisation energies.</p> <p>Extension activity: More advanced learners can investigate why fluorine and oxygen break the trend in electron affinity.</p>
23.1 Lattice energy and Born-Haber cycles	23.1.3 Construct and use Born-Haber cycles for ionic solids (limited to +1	<u>The Born-Haber cycle for sodium chloride</u>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
KC5	<p>and +2 cations, –1 and –2 anions).</p> <p>23.1.4 Carry out calculations involving Born–Haber cycles.</p> <p>23.1.5 Explain, in qualitative terms, the effect of ionic charge and of ionic radius on the numerical magnitude of a lattice energy.</p>	<p>Learners often find it difficult to appreciate how Born-Haber cycles are useful to chemists. Explain that a good starting point in the cycle is to write down the elements you want to combine in their standard states. The goal is to calculate the lattice energy for the compound – a value which cannot be measured directly by experiment.</p> <p>Learners draw out the Born-Haber cycle step-by-step as in the link provided: www.knockhardy.org.uk/sci_htm_files/15le.pdf [see page 5] Once they have completed the cycle they can calculate any of the missing steps.</p> <p>This activity is useful in helping learners match the names of the enthalpy changes to their definitions and equations: rsc.org/learn-chemistry/resources/gridlocks/puzzles/level-3/BornHaberNaCl.html</p> <p><u>Born-Haber cycles for other compounds</u> Give learners the necessary data, and they construct similar cycles to the above with only slight variations. For MgCl₂: rsc.org/learn-chemistry/resources/gridlocks/puzzles/level-3/BornHaberMgCl2.html</p> <p>Video instruction for CaCl₂: www.youtube.com/watch?v=KnnOCYA1a18</p> <p>Extension activities: Learners could draw the Born-Haber cycle and calculate a value for aluminium oxide: www.stem.org.uk/resources/elibrary/resource/29389/born-haber-cycles [free log-in required for download]</p> <p>Learners could use Born-Haber cycles to find out why/ why not a particular ionic formula exists. The cycles for MgCl, MgCl₂ and MgCl₃ are explored here: www.chemguide.co.uk/physical/energetics/lattice.html</p> <p><u>The effect of ionic charge and ionic radius on the value of lattice energy</u> Learners consider the lattice energies they have calculated for various compounds and inspect the following table: calculla.com/lattice_energy_table</p> <p>With guidance, if necessary, learners observe that lattice enthalpy increases with:</p> <ul style="list-style-type: none"> • increasing charge on the ions • decreasing distance between the centres of oppositely charged ions. www.chemguide.co.uk/physical/energetics/lattice.html

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
23.2 Enthalpies of solution and hydration KC5	23.2.1 Define and use the term enthalpy change with reference to hydration, Δh_{hyd} , and solution, Δh_{sol} . 23.2.2 Construct and use an energy cycle involving enthalpy change of solution, lattice energy and enthalpy change of hydration. 23.2.3 Carry out calculations involving the energy cycles in 23.2.2 23.2.4 Explain, in qualitative terms, the effect of ionic charge and of ionic radius on the numerical magnitude of an enthalpy change of hydration.	<p>Learners research and write down definitions for the enthalpy change terms. In this topic, it is vital for learners to see the interconnection between these terms. It is also important to realise that for the enthalpy of solution, the value obtained may be endothermic or exothermic, but for the hydration enthalpy the value is always exothermic.</p> <p>www.docbrown.info/page07/delta2Ha.htm</p> <p>Experimental work: Measuring the enthalpies of solution for a range of salts sites.middlebury.edu/chem103lab/2017/01/24/heats-of-reaction/ [results table for download available]</p> <p>Reference videos: www.youtube.com/watch?v=xRwVOKJkXZI [explanation in terms of energy cycles] www.youtube.com/watch?v=Qyhe8hOfhu8 [for calculation examples]</p> <p>Explain to learners that the size of the hydration enthalpy depends on:</p> <ol style="list-style-type: none"> the size of the ion (smaller the ion, the larger the attraction and the larger the hydration enthalpy) the greater the charge on the ion, the larger the hydration enthalpy <p>Give learners the following data table on hydration enthalpies, and ask them to work out the effect of changing the ionic radius and ionic charge: www.wiredchemist.com/chemistry/data/enthalpies-hydration</p> <p>www.chemguide.co.uk/physical/energetics/solution.html [contains questions and answers on solution enthalpies]</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
23.3 Entropy change, ΔS KC5	23.3.1 Define the term entropy, S , as the number of possible arrangements of the particles and their energy in a given system. 23.3.2 Predict and explain the sign of the entropy changes that occur: (a) during a change in state, e.g. melting, boiling and dissolving (and their reverse) (b) during a temperature change (c) during a reaction in which there is a change in the number of gaseous molecules.	Introduce this topic by discussing the tendency of the universe towards disorder. If possible show this video of Prof. Brian Cox using the example of a sandcastle to explain entropy: www.youtube.com/watch?v=uQSoaiubuA0 He explains that a sandcastle is a highly ordered structure in terms of the particles that compose it. There are very few ways of reordering it, and changing its structure, so it has low entropy. In contrast, a pile of sand has a much higher entropy. Examples of entropy values for solids, liquids and gases: www.chemguide.co.uk/physical/entropy/introduction.html Extension activity: More able learners could watch the following video which explains entropy, not only as a measurement of disorder, but, more accurately, in terms of probability: www.youtube.com/watch?v=YM-uykVfq_E [Ted-Ed, What is Entropy?] Learners need to appreciate that if $\Delta S = +$, the entropy increases and if it is negative entropy decreases. (a) For each example of a state change, learners should decide whether the entropy is increasing or decreasing each time. For example, if a solid changes to a liquid during melting, then $\Delta S = +$ Dissolving a substance in a solvent is also an increase in entropy. (b) Ask learners to consider the sign of the entropy change of a liquid which is being heated (to below its boiling point). The particles will move more quickly and more randomly so again entropy of the system increases. (c) Give learners chemical reactions which have gaseous reactants and products and explain why the entropy decreases when there are fewer gas molecules on the products side of the equation. www.chemguide.co.uk/physical/entropy/introduction.html
23.3 Entropy change, ΔS KC5	23.3.3 Calculate the entropy change for a reaction, ΔS , given the standard entropies, S^\ominus , of the reactants and products, $\Delta S^\ominus = \sum S^\ominus$	Learners just need to realise that the total entropy change is simply: the sum of the entropies in the products – the sum of the entropies of the reactants www.chemguide.co.uk/physical/entropy/entropychange.html [a simple worked answer] www.chem.wisc.edu/deptfiles/genchem/netorial/modules/thermodynamics/table.htm [entropy values table] Video explanation:

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	(products) – $\sum S^\ominus$ (reactants)	www.youtube.com/watch?v=lwRy4iYVQLI
23.4 Gibbs free energy change, ΔG KC5	23.4.1 State and use the Gibbs equation $\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus$ 23.4.2 Perform calculations using the equation $\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus$ 23.4.3 State whether a reaction or process will be feasible by using the sign of ΔG . 23.4.4 Predict the effect of temperature change on the feasibility of a reaction, given standard enthalpy and entropy changes.	Introduce learners to the equation and tell them that ΔG represents the change in free energy. This can be thought of as the maximum useful energy taken in or given out when a reaction system goes from reactants to products. Check that learners know the units for the other terms in the equation, and elicit that temperature must be in Kelvin. Also remind learners that the units of entropy are measured in Joules not KJ, and therefore they may need to convert units in calculations. Learners should practise predicting whether a particular process or reaction will be feasible as a result of the sign of free energy change. The important thing to note is that when $\Delta G = 0$, the point of feasibility of the process is reached. Learners can use the same equation in this form to calculate T: $T = \Delta H / \Delta S$ www.docbrown.info/page07/delta3SGc.htm [conditions for feasibility detailed and worked calculation examples] Free energy analogy activity: www.chemedx.org/blog/gibbs-free-energy-analogy [activity with supporting downloads] Spontaneous assembly of straws: www.flinnsci.com/spontaneous-assembly-of-straws/dc91846/ [download available] Video: www.youtube.com/watch?v=Gu6-zc9Ye2o [The Pluses and Minuses of Enthalpy, Entropy and Free Energy]
		General revision problems on all of the Energetics topics for AS and A Level: edu.rsc.org/resources/ [search 'starters for 10 thermodynamics']
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

24 Electrochemistry

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
24.1 Electrolysis KC2 KC3 KC4	24.1.1 Predict the identities of substances liberated during electrolysis from the state of electrolyte (molten or aqueous), position in the redox series (electrode potential) and concentration	<p>Molten electrolysis Learners should already be familiar with the (reactivity (redox) series of metals arranged from highest to lowest reactivity with hydrogen and carbon placed in-between. As an initial exercise, ask learners to try to place common metals they recall into a reactivity series, and then reveal the correct list to them.</p> <p>Next, discuss the electrolysis of molten compounds. Ask learners to describe and explain, using half-equations, the electrolysis of lead bromide including the conditions needed (heating strongly).</p> <p>Learners practise solving problems about molten electrolysis. Relate this to topic 6.1 Redox processes.</p> <p>After this, show learners the electrochemical series, explaining that it is similar to the reactivity (redox) series and that it will be explained fully later. Explain to them that for the purposes of this initial topic, it lists the metals in order of reactivity, highest to lowest.</p> <p>Experimental work: Experiment including video: edu.rsc.org/resources/electrolysis-of-molten-zinc-chloride/826.article</p> <p>Resource Plus Carry out the <i>Electrolysis of molten zinc chloride</i> experiment in Cambridge IGCSE Chemistry 0620 Resource Plus, referring to the Teaching Pack for lesson plans and resources.</p> <p>A creative microscale method: www.youtube.com/watch?v=LwwmRP8Zpaw</p> <p>The electrolysis of aqueous solutions First discuss with learners how they think water affects the outcome of electrolysis of aqueous salts. Next discuss the electrolysis of water.</p> <p>Resource Plus Carry out <i>The electrolysis of acidified water</i> experiment referring to the Teaching Pack for lesson plans and resources.</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		<p>Simulation: www.edumedia-sciences.com/en/media/713-electrolysis-of-water</p> <p>Discuss the importance of the nature of the electrodes and how the outcome of electrolysis is changed when using inert electrodes (for example, carbon or platinum) or active electrodes (for example, copper).</p> <p>Experimental work: Carry out the electrolysis of dilute copper (II) chloride solution or copper (II) sulfate using inert carbon electrodes. Learners should try to justify with half-equations, the products at each electrode:</p> <ul style="list-style-type: none"> • The electrolysis of copper (II) sulfate using carbon electrodes (also using copper electrodes as an extension) edu.rsc.org/resources/electrolysis-of-copperii-sulfate-solution/476.article • The microscale electrolysis of copper (II) chloride (CLEAPSS) science.cleapss.org.uk/Resource-Info/Microscale-Electrolysis-of-Copper-Chloride.aspx [how to make the microscale apparatus and video of it in action] • The series of experiments included in this practical could be used as a basis for investigating the preferential discharge of ions during electrolysis. Each group of learners could investigate a different aqueous electrolysis experiment and the results are collated in a plenary session edu.rsc.org/resources/preferential-discharge-of-cations-during-electrolysis/1759.article <p>Video – the electrolysis of copper (II) chloride using carbon electrodes: www.youtube.com/watch?v=tCHE_7QeRUc&t=79s</p> <p>The electrolysis of copper (II) sulfate using carbon electrodes: www.youtube.com/watch?v=L_BjGkM2Bk</p> <p>For an overall summary of the topic of electrolysis and downloadable question and answer sheets: www.chemguide.co.uk/inorganic/electrolysis/solutions.html</p>
24.1 Electrolysis KC3 KC4	24.1.2 State and apply the relationship $F = Le$ between the Faraday constant, F , the Avogadro constant, L , and the charge on the electron, e 24.1.3 Calculate:	Ask learners to research a definition of the Faraday as being equal to 96,500 coulombs. State the equation $F = Le$ It is a simple relationship and means that when 1 mole of electrons flow this is equivalent to 1 faraday. (a) $Q = It$ is a formula which can be used in electrolysis to calculate the current passed, quantity of charge or the time it takes to pass a quantity of charge during electrolysis. Learners can work through the examples here: www.docbrown.info/ephysics/electricity3.htm

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	(a) the quantity of charge passed during electrolysis, using $Q = It$ (b) the mass and/or volume of substance liberated during electrolysis.	(b) Ask learners to consider the electrolysis they have performed so far. Then ask them what factors might affect the amount of substance formed during an electrolysis experiment. They should realise that the charge on the ion, the current flow and the time current is passed are all important. Learners should also be able to equate the mass to a volume. Several worked examples here: www.docbrown.info/page04/4_73calcs13pec.htm www.chem.purdue.edu/gchelp/howtosolveit/Electrochem/Electrolysis.htm www.chemguide.co.uk/inorganic/electrolysis/basiccalcs.html
24.1 Electrolysis KC2 KC3 KC4	24.1.4 Describe the determination of a value of the Avogadro constant by an electrolytic method.	Experimental work: Determination of Avogadro's number using an electrochemical cell: mse.engineering.ucdavis.edu/graduate/GAANN Video: www.youtube.com/watch?v=vp9QYJqFq5s [determination of Avogadro's number by electrolysis]
24.2 Standard electrode potentials E^\ominus ; standard cell potentials E^\ominus_{cell} and the Nernst equation KC3 KC4	24.2.7 Construct redox equations using the relevant half-equations.	There are simple rules which help learners build and balance redox equations from half-equations as explained in this page: www.chemguide.co.uk/inorganic/redox/equations.html [includes a downloadable question and answer sheet] Video instruction: www.youtube.com/watch?v=IZ1tKxsqV74
24.2 Standard electrode potentials E^\ominus ; standard cell	24.2.1 Define the terms: (a) standard electrode (reduction) potential	Learners turn to the list of standard electrode (reduction) potentials in the syllabus, noting that this is also known as the electrochemical series (pages 78–9). Notice that this list is in alphabetical order. Ask them to place ten reactive and non-reactive metals they know from the list, in order from most reactive to least reactive and explain what they notice. (Hopefully they will agree that the list is approximately the same as the

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
<p>potentials $E^{\ominus}_{\text{cell}}$ and the Nernst equation</p> <p>KC2</p> <p>KC3</p> <p>KC4</p> <p>KC5</p>	<p>(b) standard cell potential.</p> <p>24.2.6 Deduce from e^{\ominus} values the relative reactivity of elements, compounds and ions as oxidising agents or as reducing agents.</p> <p>24.2.2 Describe the standard hydrogen electrode.</p> <p>24.2.3 Describe methods used to measure the standard electrode potentials of:</p> <p>(a) metals or non-metals in contact with their ions in aqueous solution</p> <p>(b) ions of the same element in different oxidation states.</p>	<p>reactivity series they used in previous courses.) Point out that although the half-reactions are written as reductions, they are reversible reactions.</p> <p>Learners need to know that the more negative the E^{\ominus} value, the more easily the metal loses electrons and therefore the stronger reducing agent it is. It follows that a reactive metal like lithium functions very poorly as an oxidising agent. A non-metal such as fluorine is a very powerful oxidising agent, as exemplified by its highly positive electrode potential.</p> <p>In the list of reduction potentials in the syllabus, there are also compounds and ions, which follow the same logic in terms of their oxidising and reducing ability.</p> <p>Explain that electrode potentials cannot be measured in isolation and are measured relative to a standard hydrogen electrode (S.H.E.).</p> <p>Diagram and working of the hydrogen electrode: alevelchemistry.co.uk/notes/redox-and-electrode-potential/</p> <p>This reference explains how standard electrode potentials are measured for metals: www.chemguide.co.uk/physical/redoxeqia/introduction.html#top</p> <p>and for non-metals and ions of the same element in different oxidation states: www.chemguide.co.uk/physical/redoxeqia/nonmetal.html</p> <p>Video explaining the operation of an S.H.E. while measuring the standard electrode potential of copper: www.youtube.com/watch?v=V46rDZaZhmK</p>
<p>24.2 Standard electrode potentials E^{\ominus}; standard cell potentials $E^{\ominus}_{\text{cell}}$ and the Nernst equation</p> <p>KC5</p>	<p>24.2.4 Calculate a standard cell potential by combining two standard electrode potentials.</p>	<p>There are several methods of combining standard electrode potentials to calculate the overall $E^{\ominus}_{\text{cell}}$ value. Detailed here is one method, based on the IUPAC system of cell notation: www.docbrown.info/page07/equilibria7c.htm</p> <p>An alternative method is, in electrochemical cells which are spontaneous/feasible, on combination of two half-cells, a positive E_{cell} value is produced.</p> <p><u>One method of finding the overall E_{cell} value.</u> Consider the combination of the two half-cells: $\text{Zn}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Zn} = -0.76\text{V}$ with $\text{Fe}^{2+} + 2\text{e}^{-} \rightleftharpoons \text{Fe} = -0.44\text{V}$</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		<p>1. The half reaction with the most negative E_{cell} value is reversed and its sign changed: $\text{Zn} \rightleftharpoons \text{Zn}^{2+} + 2\text{e}^- = +0.76\text{V}$</p> <p>2. The E_{cell} value is calculated for the overall reaction: $\text{Zn} + \text{Fe}^{2+} \longrightarrow \text{Zn}^{2+} + \text{Fe}$ $E_{\text{cell}} = +0.76\text{V} + (-0.44\text{V}) = +0.32\text{V}$</p>
<p>24.2 Standard electrode potentials E^\ominus; standard cell potentials E^\ominus_{cell} and the Nernst equation</p> <p>KC5</p>	<p>24.2.5 Use standard cell potentials to:</p> <p>(a) deduce the polarity of each electrode and hence explain/deduce the direction of electron flow in the external circuit of a simple cell</p> <p>(b) predict the feasibility of a reaction.</p> <p>24.2.8 Predict qualitatively how the value of an electrode potential, E, varies with the concentrations of the aqueous ions.</p> <p>24.2.9 Use the Nernst equation, e.g. $E = E^\ominus + (0.059/z) \log$ [oxidised species]/[reduced species] to predict quantitatively how the value of an electrode potential varies</p>	<p>(a) This page explains the direction of electron flow in a simple cell: www.siyavula.com/read/science/grade-12/electrochemical-reactions/13-electrochemical-reactions-04</p> <p>(b) A method for predicting the feasibility of a reaction: www.chemguide.co.uk/physical/redoxeqia/predict.html</p> <p>Simulations/videos: In this series of experiment videos and animations learners will build an electrochemical cell (also called a Galvanic cell). Cell potentials are measured under standard conditions and then under non-standard conditions using the Nernst equation. chemcollective.org/chem/electrochem/</p> <p>Experimental work:</p> <ul style="list-style-type: none"> Ice cube tray redox experiment: www.siyavula.com/read/science/grade-12/electrochemical-reactions/13-electrochemical-reactions-06 To see how changes in concentration and pH affect the potential in an electrochemical cell, and confirm the Nernst equation: webassign.net/question_assets/ncsugenchem202labv1/lab_10/manual.html [contains equipment and reagent lists and a downloadable procedure]. An experiment to investigate the concentration dependence of voltage in concentration cells: www.webassign.net/labsgraceperiod/ucscgenchem11/lab_13/manual.html <p>If learners have studied topic 23.4 Gibbs free energy change, ΔG, they will already know that for a spontaneous reaction to occur in a reaction, its value must be negative.</p> <p>Video explanations of the equation $\Delta G^\ominus = -nFE^\ominus$: www.youtube.com/watch?v=Xrzhby7bsJw</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	with the concentrations of the aqueous ions; examples include $\text{Cu}^{2+}(\text{aq}) + 2\text{e}^{-} \rightleftharpoons \text{Cu}(\text{s})$, $\text{Fe}^{3+}(\text{aq}) + \text{e}^{-} \rightleftharpoons \text{Fe}^{2+}(\text{aq})$. 24.2.10 Understand and use the equation $\Delta g^{\ominus} = -ne^{\ominus}_{\text{cell}} F$	www.youtube.com/watch?v=2efANhyBrDs
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

25 Equilibria

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
25.1 Acids and bases KC4	25.1.1 Understand and use the terms conjugate acid and conjugate base. 25.1.2 Define conjugate acid–base pairs, identifying such pairs in reactions.	<p>Learners write a chemical equation for hydrochloric acid reacting with water. Remind them that it is reversible with the equilibrium lying far to the right since the acid is almost fully dissociated.</p> $\text{HCl} + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^+ + \text{Cl}^-$ <p>Elicit that a proton has been donated from the acid which has been accepted by the water molecule. (Refer to topic 7.2 Brønsted–Lowry theory of acids and bases.)</p> <p>Draw bars as follows on the equation, asking learners how the indicated pairs are related to each other.</p> $\begin{array}{ccccccc} \text{HCl} & + & \text{H}_2\text{O} & \rightleftharpoons & \text{H}_3\text{O}^+ & + & \text{Cl}^- \\ & & & & \uparrow & & \uparrow \\ & & & & \text{H}^+ & & \text{H}^+ \end{array}$ <p>Finally mark in the conjugate acid–base pairs, making sure that learners appreciate that each pair differs only by one proton. They could indicate this by adding $-\text{H}^+$ and $+\text{H}^+$ to the above diagram.</p> <p>Video instruction: www.youtube.com/watch?v=fUhPLe0NAvA</p>
25.1 Acids and bases	25.1.3 Define mathematically the terms pH, K_a , pK_a and K_w and use them in calculations. 25.1.4 Calculate $[\text{H}^+(\text{aq})]$ and pH values for: (a) strong acids (b) strong alkalis	<p>Learners should recall the following equations:</p> $\text{pH} = -\log_{10}[\text{H}^+] \qquad K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]}$ $\text{p}K_a = -\log K_a \qquad K_w = [\text{H}^+][\text{OH}^-]$ <p>Make sure that learners realise that in some sites $[\text{H}_3\text{O}^+]$ is used instead of $[\text{H}^+]$</p> <p><u>The calculation of pH for a strong acid or strong alkali</u> Ask learners to define what the following words mean: strong, weak, concentrated, dilute in connection with common acids and alkalis they can name to make sure that there is no initial misunderstanding.</p> <p>Next work through examples for calculating the pH of strong monobasic acids of various concentrations.</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	(c) weak acids.	<p>To calculate the pH values of strong alkalis, learners should first calculate the concentration of hydroxide ions $[\text{OH}^-]$ and then use the ionic product of water, $K_w = [\text{H}^+][\text{OH}^-]$ to obtain the $[\text{H}^+]$.</p> <p>www.chemguide.co.uk/physical/acidbaseeqia/acids.html [with downloadable question and answer sheets]</p> <p><u>The calculation of pH for weak acids</u> To calculate the pH of these, the concentration of the acid is required as well as the amount to which the species dissociates in solution which is K_a. Note that, in order to prevent learners needing to solve quadratic equation in these problems two assumptions are made: i) that $[\text{H}^+] = [\text{A}^-]$ (which means that the tiny concentration of H^+ ions due to the dissociation of water is neglected.) ii) at equilibrium the concentration of the acid equals the original concentration of the acid solution (this can be assumed because the acid is a weak acid).</p> <p>Worked example for ethanoic acid: alevelchem.com/aqa_a_level_chemistry/unit3.4/s3403/04.htm</p> <p>Extension activity: Learners who are competent in the use of quadratic equations could try calculating the pH of a weak acid without making the assumptions mentioned above and comparing the answer to that made when making assumptions.</p> <p>Example calculations can be found here: www.thoughtco.com/calculating-ph-of-a-weak-acid-problem-609589</p> <p>Useful reference material for converting to pK_a and calculating logarithms on a calculator: sciencing.com/calculate-pka-values-2765.html</p> <p>Experimental work: edu.rsc.org/resources/the-ph-scale/395.article In this experiment learners prepare a series of solutions by dilution. Each solution approximates to a pH number</p> <p>Simulations exploring pH changes with various substances: phet.colorado.edu/sims/html/ph-scale/latest/ph-scale_en.html</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
25.1 Acids and bases KC2 KC3	<p>25.1.5</p> <p>(a) Define a buffer solution.</p> <p>(b) Explain how a buffer solution can be made.</p> <p>(c) Explain how buffer solutions control pH; use chemical equations in these explanations.</p> <p>(d) Describe and explain the uses of buffer solutions, including the role of HCO_3^- in controlling pH in blood.</p> <p>25.1.6 Calculate the pH of buffer solutions, given appropriate data.</p>	<p>Define a buffer solution and allow learners time to research the use of buffer solutions in everyday life. They can also research what composes a buffer solution.</p> <p>For both acidic and basic buffers, learners should be able to explain, using chemical equations, how buffer solutions maintain a particular pH, when small amounts of acids and alkalis are added to them. They should remember that these reactions are reversible.</p> <p>www.chemguide.co.uk/physical/acidbaseeqia/buffers.html [with question and answer sheets]</p> <p><u>Calculating the pH of buffer solutions</u> Lead into this topic by taking learners through a step-by-step calculation: www.chemguide.co.uk/physical/acidbaseeqia/buffers.html www.docbrown.info/page07/equilibria6c.htm [further worked examples]</p> <p>The pH of a buffer solution can also be calculated using the Henderson-Hasselbalch equation: chem.libretexts.org/Bookshelves/Physical and Theoretical Chemistry Textbook Maps/Supplemental Modules (Physical and Theoretical Chemistry)/Acids and Bases/Buffers/Henderson-Hasselbalch Approximation</p> <p>Web references: dept.harpercollege.edu/chemistry/chm/100/dgodambe/thedisk/bloodbuf/zback.htm [how the blood pH is controlled by hydrogen carbonate buffer]</p> <p>Experimental work:</p> <ul style="list-style-type: none"> • The carbonic acid/carbonate buffer: dept.harpercollege.edu/chemistry/chm/100/dgodambe/thedisk/bloodbuf/bloodbuf.htm • Based on the carbonic acid/carbonate buffer system: • www.sserc.org.uk/subject-areas/chemistry/chemistry-resources/bad-breath-indicator/ • Preparation of acetate and phosphate buffers: • www.webassign.net/question_assets/ncsugenchem202labv1/lab_7/manual.html <p>Videos: The ability of a phosphate buffer and Alka-Seltzer® to resist pH changes highlights the physiological role of buffers within cells and in consumer products: www.youtube.com/watch?v=7ciO9eO3OQg Buffering the pH in blood:</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		www.youtube.com/watch?v=rIvEwViJGk
25.1 Acids and bases KC2	25.1.7 Understand and use the term solubility product, K_{sp} . 25.1.8 Write an expression for K_{sp} . 25.1.9 Calculate K_{sp} from concentrations and vice versa.	<u>Theory of K_{sp}</u> Downloadable question and answer sheets: www.chemguide.co.uk/physical/ksp/introduction.html Video tutorial, theory of K_{sp} and calculation examples : www.youtube.com/watch?v=WjiXbemBXkE Virtual lab: chemcollective.org/vlab/88
25.1 Acids and bases KC2	25.1.10 (a) Understand and use the common ion effect to explain the different solubility of a compound in a solution containing a common ion. (b) Perform calculations using K_{sp} values and concentration of a common ion.	The salting-out process used in the manufacture of soaps relies on the common-ion effect to precipitate out the soap. This is one application of the common-ion effect which you could tell to learners to contextualise this process. Demonstrate and discuss the common-ion effect as in this video: www.youtube.com/watch?v=c9_Ab0BzIC4 Calculations: www.youtube.com/watch?v=VVyseROOw7E www.youtube.com/watch?v=qawipem0LwA Experimental work: <ul style="list-style-type: none"> • Simple experiment investigating precipitation: www.chalkbored.com/lessons/chemistry-12/common-ion-lab.pdf • Determine the value of a K_{sp} equilibrium constant in the presence and absence of a common ion: www.usna.edu/ChemDept/ [search 'tartrate']
25.2 Partition coefficients	25.2.1 State what is meant by the term partition coefficient, K_{pc} .	Note that partition coefficient = distribution coefficient Start by asking learners the meaning of 'immiscible' and elicit example pairs e.g. water and petrol. Use the following example to help learners understand what partition coefficient means:

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>25.2.2 Calculate and use a partition coefficient for a system in which the solute is in the same physical state in the two solvents.</p> <p>25.2.3 Understand the factors affecting the numerical value of a partition coefficient in terms of the polarities of the solute and the solvents used</p>	<p>www.chemguideforcie.co.uk/section112/learningf.html</p> <p>A use of partition coefficient in cosmetics: www.cosmeticsandtoiletries.com/research/chemistry/8282222.html</p> <p>Partitioning between liquid phases including an explanation of the polarity effect of solvents: www.youtube.com/watch?v=udDDQuO4Mh8</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

26 Reaction kinetics

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
<p>26.1 Simple rate equations, orders of reaction and rate constants</p> <p>KC2</p> <p>KC3</p>	<p>26.1.1 Explain and use the terms rate equation, order of reaction, overall order of reaction, rate constant, half-life, rate-determining step and intermediate.</p> <p>26.1.2</p> <p>(a) Understand and use rate equations of the form $\text{rate} = k [\text{a}]^m [\text{b}]^n$ (for which m and n are 0, 1 or 2).</p> <p>(b) Deduce the order of a reaction from concentration-time graphs or from experimental data relating to the initial rates method and half-life method.</p> <p>(c) Interpret experimental data in graphical form, including concentration-time and rate-concentration graphs.</p>	<p>Check that learners recall that the rate of a chemical reaction often increases by increasing the concentration of a reactant and that experiments can be performed to find the average rate of reaction from a graph for example, concentration vs. time.</p> <p>Explain that when reaction systems are investigated in greater depth, chemists study rate equations.</p> <p>Choose a simple reaction system and use it to show what a rate equation looks like. Explain what the individual orders, overall order and the rate constant are. Also emphasise the importance of using square brackets for concentration. Another important thing to highlight is that the rate constant is not a true constant, as it varies with temperature and with the use of catalysts.</p> <p>Emphasise that rate equations cannot be determined from the stoichiometry of a reaction and are always found by experiment.</p> <ul style="list-style-type: none"> • At a certain temperature, there are two main ways of obtaining data from experiments from which the orders of reactions may be obtained. • Method of initial rates: in this method several experiments are performed, each time on the same reaction system, and the concentrations of reactants are investigated. • A single reaction is performed, and its progress followed, and data obtained from it. <p>This page discusses various practical approaches to finding rates of reactions: www.chemguide.co.uk/physical/basicrates/experimental.html [includes question and answer sheets to test knowledge]</p> <p>For graphs of first order and second order kinetics: www.chemistryrules.me.uk/hfhf/hfhf3.htm</p> <p>Video (theoretical), working out order and rate equation from initial rates tables: www.youtube.com/watch?v=ysMXaDREBUc [easier questions] www.youtube.com/watch?v=Z-igduAXhqU [challenging question]</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>(d) Calculate an initial rate using concentration data.</p> <p>(e) Construct a rate equation.</p>	<p>Experimental work: This experiment uses the hydrochloric acid / marble chip experiment. It provides a bridge from previous knowledge to finding the order of reaction with respect to hydrochloric acid: www.nuffieldfoundation.org/sites/default/files/files/Rates%20of%20reaction%20-%20merged%20PDF.pdf</p> <p>Finding the order of reaction with respect to sodium thiosulfate: www.flinnsci.com/api/library/Download/78da6c8204aa48a294bd9a51844543ad</p> <p>Investigating the kinetics of the iodine clock reaction: www.bellevuecollege.edu/wp-content/uploads/sites/140/2014/06/162_Lab_IodineClockReaction_20140227GF1.pdf</p> <p>Investigating the iodination of propanone by a colourimetric method: cd1.edb.hkedcity.net/cd/science/chemistry/s67chem/pdf/sDL_2_Iodination.pdf</p> <p>Video of experiments: www.youtube.com/watch?v=TdXamAGRHe4 [iodide/persulfate clock reaction] www.youtube.com/watch?v=N_zXI9n9SKA [sampling method for the hydrolysis of an ester] www.youtube.com/watch?v=4kwtEB-uoU [colourimetry experiment to study the kinetics of the iodine/propanone reaction] www.youtube.com/watch?v=tcv5Xk9ZXpg [colourimetry experiment to find the order of reaction with respect to crystal violet]</p>
<p>26.1 Simple rate equations, orders of reaction and rate constants</p> <p>KC3</p>	<p>26.1.3 (a) Show understanding that the half-life of a first-order reaction is independent of concentration. (b) Use the half-life of a first-order reaction in calculations.</p>	<p>Learners should now be familiar with the differences in the shapes of concentration–time graphs for deciding the orders of reaction. Specifically, for first-order reactions the half-life is independent of concentration. Provide learners with data to plot and show that the half-lives are constant.</p> <p>Shows a graph of equal half-lives and explanation: chem.libretexts.org [search 'Radioactive decay kinetics']</p> <p>(b) Learners need to learn and use the following equation: $k = 0.693/t_{1/2}$</p> <p>Worked examples: www.chemguideforcie.co.uk/section8/learningh.html</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
26.1 Simple rate equations, orders of reaction and rate constants KC2 KC3	26.1.4 Calculate the numerical value of a rate constant, for example by: (a) using the initial rates and the rate equation (b) using the half-life, $t_{1/2}$, and the equation $k = 0.693/t_{1/2}$ 26.1.6 Describe qualitatively the effect of temperature change on the rate constant and hence the rate of a reaction.	The rate constant can be calculated by rearranging data obtained in initial rates experiments. Worked examples of this: www.docbrown.info/page03/ASA2rates1b.htm (b) as in 26.1.3 above. The Arrhenius equation shows the effect of changing the temperature on the rate constant. Although calculations are not required using this equation, display it to learners so that they see the interconnection of terms. This should help learners appreciate the relationship better. www.chemguide.co.uk/physical/basicrates/arrhenius.html [displays the equation and explains the terms] It can be seen that if the temperature increases, the rate constant and hence the rate of reaction increases. Experimental work: Finding the energy of activation and rate constant: webs.wofford.edu/arringtonca/gchem/Activation_Energy_of_a_Chemical_Reaction.pdf Further help to find k : cssac.unc.edu/programs/learning-center/Resources/Study/Guides/Chemistry%20102/Arrhenius%20Equation
26.1 Simple rate equations, orders of reaction and rate constants KC2 KC3	26.1.5 For a multi-step reaction: (a) Suggest a reaction mechanism that is consistent with the rate equation and the equation for the overall reaction. (b) Predict the order that would result from a given reaction mechanism and rate-determining step. (c) Deduce a rate equation using a given reaction mechanism and	With the aim of connecting to previous AS Level topics, ask learners if they can recall when the term 'reaction mechanism' was used, and what it meant to them. Hopefully they will be able to recall S_N1 and S_N2 reactions (and perhaps the free-radical substitution of alkanes and electrophilic addition in alkenes). In this topic, learners have the opportunity to verify a reaction mechanism by experiment. Choose a reaction system, for example, comparing the hydrolysis of primary and tertiary halogenoalkanes. Display proven reaction mechanisms to learners, and explain why it is vital to be able to identify the slow step in each mechanism, called the rate-determining step. A clear understanding of the rate-determining step is very important in understanding this topic. This video will help learners understand how the position of the slow step affects the overall reaction: www.youtube.com/watch?v=a41_oq0SB3I Once the rate-determining step is identified, the rate equation can be written. The individual steps of the mechanism should add up to give the overall chemical equation for the reaction. At first, choose reaction

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>rate-determining step for a given reaction.</p> <p>(d) Identify an intermediate or catalyst from a given reaction mechanism.</p> <p>(e) Identify the rate-determining step from a rate equation and a given reaction mechanism.</p>	<p>mechanisms where the rate-determining step is the first step in the mechanism since this is easiest to work with.</p> <p>Next, provide an example where the rate-determining step is not the first step of the mechanism. Explain to learners that the intermediate can be traced back to the first step of the reaction and the intermediate cancelled out, affording the rate expression which is in accordance with the overall equation for the reaction.</p> <p>This link explains how the difference between an intermediate and a catalyst in a reaction mechanism can be identified: socratic.org/questions/for-the-following-reaction-which-species-is-acting-as-a-catalyst-which-is-an-int</p> <p>Learners are expected to be able to propose a mechanism based on a particular rate equation for a given overall reaction. This is often quite challenging for learners.</p> <p>Discuss an organic chemistry mechanism example. There is also a downloadable question and answer sheet: www.chemguide.co.uk/physical/basicrates/ordermech.html</p> <p>Further examples: www.khanacademy.org/science/chemistry/chem-kinetics/arrhenius-equation/a/reaction-mechanisms</p> <p>This video explains how the rate equation can be determined from a proposed reaction mechanism, also how to choose which of a number of proposed mechanisms fits the rate equation for a reaction: www.youtube.com/watch?v=I_yY3H-hVmk</p> <p>This video explains how you can differentiate between a catalyst and intermediate in a multi-step reaction mechanism: www.youtube.com/watch?v=UkolmD80-BM</p> <p>Experimental work: By investigating the hydrolysis of a tertiary halogenoalkane, the order and mechanism of reaction is determined: edu.rsc.org/feature/the-hydrolysis-of-2-bromo-2-methylpropane/2020254.article</p>
26.2	26.2.1 Explain that catalysts can be	Learners recall and define the words homogeneous and heterogeneous catalysts from topic 8.3 (of the same name) in the AS Level course.

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
Homogeneous and heterogeneous catalysts KC2 KC3 KC4	<p>homogeneous or heterogeneous.</p> <p>26.2.2 Describe the mode of action of a heterogeneous catalyst to include adsorption of reactants, bond weakening and desorption of products, for example:</p> <p>(a) iron in the Haber process (b) palladium, platinum and rhodium in the catalytic removal of oxides of nitrogen from the exhaust gases of car engines.</p> <p>26.2.3 Describe the mode of action of a homogeneous catalyst by being used in one step and reformed in a later step, for example:</p> <p>(a) atmospheric oxides of nitrogen in the oxidation of atmospheric sulfur dioxide (b) Fe^{2+} or Fe^{3+} in the I^-/S^{2-} reaction</p>	<p><u>Heterogeneous catalysts</u> Explain diagrammatically how a reactant is adsorbed and desorbed on/off a catalyst. Show how the process causes bonds to be weakened in the reactant.</p> <p>Diagram of the mechanism for the hydrogenation of ethene using a nickel catalyst: www.docbrown.info/page03/ASA2rates1a.htm The ideas in the mechanism here are similar to those that occur in the Haber process and in the catalytic converter.</p> <p>Diagrams and descriptions explaining how heterogeneous catalysts function: www.researchgate.net/figure/Schematic-diagram-of-the-reaction-pathes-in-homogeneous-heterogeneous-catalysis_fig1_27345444 opentextbc.ca/chemistry/chapter/12-7-catalysis/ www.youtube.com/watch?v=1NwwaqR-SDc [go to 06:35]</p> <p><u>Homogeneous catalysts</u> Explain that there is no solid catalyst surface in these reactions, instead the catalyst is in the same phase as the reactants.</p> <p>A general background reference about both classes of catalyst: www.essentialchemicalindustry.org/processes/catalysis-in-industry.html</p> <p>Experimental work: Investigation into the homogeneous iron salt catalysis of the I^-/S^{2-} reaction: www.academia.edu/4762280/Assessed Practical Investigating the effect of two iron catalysts on the rate of $\text{S}_2\text{O}_8^{2-}/\text{I}^-$ reaction</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

27 Group 2

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
27.1 Similarities and trends in the properties of the Group 2 metals, magnesium to barium, and their compounds KC4	27.1.1 Describe and explain qualitatively the trend in the thermal stability of the nitrates and carbonates including the effect of ionic radius on the polarisation of the large anion.	Learners recall the trend in stabilities of the carbonates and nitrates (discussed in topic 10.1.3 Similarities and trends in the properties of the Group 2 metals). Learners propose a structure for the carbonate ion based on their knowledge of bonding. They then draw the full structural formula, to help them understand why temperature of decomposition of the carbonates decreases going down the group. This page explains the polarisation of the carbonate ion diagrammatically: www.chemguide.co.uk/inorganic/group2/thermstab.html#top Video explaining the trends for carbonates, nitrates (and hydroxides): www.youtube.com/watch?v=fjmSM_qs--M
27.1 Similarities and trends in the properties of the Group 2 metals, magnesium to	27.1.2 Describe and explain qualitatively the variation in solubility and of enthalpy change of solution, $\Delta H^{\ominus}_{\text{sol}}$, of the hydroxides and sulfates	Recap with learners that the pattern of solubility of the hydroxides and sulfates are opposite to each other going down Group 2. This page offers an explanation for the patterns observed: www.chemguideforcie.co.uk/2016section10/learning10p1g.html

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
barium, and their compounds	in terms of relative magnitudes of the enthalpy change of hydration and the lattice energy.	
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

28 Chemistry of transition elements

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
<p>28.1 General physical and chemical properties of the first row of transition elements, titanium to copper</p> <p>KC2</p> <p>KC3</p>	<p>28.1.3 Understand that transition elements have the following properties:</p> <p>(a) they have variable oxidation states</p> <p>(b) they behave as catalysts</p> <p>(c) they form complex ions</p> <p>(d) they form coloured compounds.</p> <p>28.1.1 Define a transition element as a d-block element which forms one or more stable ions with incomplete d orbitals.</p>	<p>Ask learners to point to the region of the Periodic Table in which the transition metals are located in order to quote a few examples of elements they are familiar with.</p> <p>Learners can work in pairs for a few minutes to research, find and write down the physical and chemical properties of the transition metals.</p> <p>Ask learners to list the full electron configurations for each of the elements titanium to copper. Make sure that they are aware of the irregularities for the elements chromium and copper.</p> <p>Next, ask learners to write the electron configurations of some ions of the elements, underlining that the 4s electrons are lost first.</p> <p>Define a transition element.</p>
<p>28.1 General physical and chemical properties of the first row of transition elements, titanium to copper</p> <p>KC1</p>	<p>28.1.2 Sketch the shape of a $3d_{xy}$ orbital and $3d_{z^2}$ orbital</p>	<p>Before sketching these orbitals, it would be good revision for learners to sketch the shapes of s and p orbitals. After doing this, confirm that learners are able to recall that there are five 3d orbitals of equal energy.</p> <p>Next, learners can sketch the $3d_{xy}$ orbital (which is the same shape as the $3d_{xz}$ and $3d_{yz}$ orbitals) and $3d_{z^2}$ orbital.</p> <p>It is important to note that for the $3d_{xy}$, $3d_{xz}$ and $3d_{yz}$ orbitals, the lobes point between the axes not along them. In the $3d_{z^2}$ orbital, the lobes point along the z axis. [This is important in the understanding of crystal field theory later on].</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
KC1	<p>28.1.4 Explain why transition elements have variable oxidation states in terms of the similarity in energy of the 3d and the 4s sub-shells.</p> <p>28.1.3 Explain why transition elements behave as catalysts in terms of having more than one stable oxidation state, and vacant d orbitals that are energetically accessible and can form dative bonds with ligands.</p> <p>28.1.3 Explain why transition elements form complex ions in terms of vacant d orbitals that are energetically accessible.</p>	<p>Pair learners, asking them to note down compounds of various common first row transition elements, and the oxidation states in these compounds, for example, iron (II) chloride and iron (III) chloride.</p> <p>Ask learners to suggest why there are so many examples of variable oxidation states in these elements. [You could also highlight that variable oxidation states, although very common in the transition elements, exist in other elements, for example, sulfur and nitrogen.]</p> <p>To explain this common observation in first row transition elements, point learners to page 74 of the data section in the syllabus. Ask them to compare the first three ionisation energies of calcium and the first three ionisation energies of iron. Using these, ask them to explain why calcium forms CaCl_2 and not CaCl_3, whereas iron commonly forms Fe (III) compounds. The key point here is that for iron, the 3d and 4s sub-shells are of similar energy whereas the 4s and 3p sub-shells are of very different energies. This is all explained in detail here: www.chemguide.co.uk/inorganic/transition/features.html#top</p> <p>An informative chart displaying the possible oxidation states of the first row transition metals: www.chemhume.co.uk/A2CHEM/Unit%202b/11%20Transition%20elements/Ch11TransitionEc.htm</p> <p>A good research activity is for learners to find out why transition metals behave as catalysts. This reference explains some of the main ideas: sciencing.com/why-are-transition-metals-good-catalysts-12342816.html</p> <p>Ask learners if they can recall what a dative covalent bond is, and how it differs from a normal covalent bond. It may be necessary to draw an example of a complex ion on the board, since this is probably a new area of chemistry to learners, for example, $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$. As water is a neutral species, ask learners why a water molecule might form bonds to a Fe^{2+} ion. In this initial discussion, just explain that water molecules (via one of their lone pairs of electrons) form dative covalent bonds to the iron using vacant d orbitals. (More advanced learners might point out that there are six water molecules and only five vacant d orbitals].</p>
28.2 General characteristic chemical properties of the first set of	28.2.1 Describe and explain the reactions of transition elements with ligands to form complexes, including the complexes of copper (II)	<p>Define a complex ion: It is a species which consists of a central metal ion with a specific number of ions or molecules surrounding it, bound by coordinate bonds. The molecules or ions surrounding the metal ion are called ligands, which always contain at least one lone pair of electrons.</p> <p>Consider the hydrated iron complex: Explain that in this case six water molecules (ligands) are attached to the central iron (II) ion.</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
transition elements, titanium to copper	and cobalt (II) ions with water and ammonia molecules and hydroxide and chloride ions.	$[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$ Use the term coordination number (CN) to signify that six ligands have attached, producing an octahedral shape in space.
KC2	28.2.2 Define the term ligand as a species that contains a lone pair of electrons that forms a dative covalent bond to a central metal atom / ion.	Explain that water and ammonia are examples of neutral monodentate ligands, and that the chloride ion and the cyanide ion are examples of negatively charged ligands. Learners commonly forget that it is a lone pair of electrons that forms the dative covalent bond to the central metal, regardless of whether the ligand is negatively charged or neutral.
KC3	28.2.3 Understand and use the terms:	Demonstrate the qualitative analysis reaction between aqueous copper (II) ions and hydroxide ions (and with ammonia solution). Ask learners about the differences between these two reactions when hydroxide ions and ammonia solution are added in excess. Explain to them that the deep blue solution formed when copper hydroxide dissolves in excess ammonia solution is a complex ion with formula $[\text{Cu}(\text{NH}_3)_4]^{2+}$.
KC4	(a) monodentate ligand including as examples H_2O , NH_3 , Cl^- and CN^-	Next, build models of a variety of complex ions if available. (Molymod make specific kits for transition complexes.) If they not available, you can show the four common shapes of transition metal complexes: www.4college.co.uk/a/ss/complexform.php
	(b) bidentate ligand including as examples 1,2-diaminoethane, <i>en</i> , $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$ and the ethanedioate ion, $\text{C}_2\text{O}_4^{2-}$	Learners individually: (I) <ul style="list-style-type: none"> • research and find out the bond angles in octahedral, square planar, tetrahedral and linear complexes • state the coordination number each time • justify the charge on each complex ion. [Learners frequently miss out or miscalculate the overall charges on complex ions so some practice in this area may be needed.]
	(c) polydentate ligand including as an example EDTA^{4-} .	Next explain bidentate and polydentate ligands, showing their basic structures to learners: www.chemguide.co.uk/inorganic/complexions/whatis.html
	28.2.4 Define the term complex as a molecule or ion formed by a central metal atom / ion surrounded by one or more ligands.	Emphasise that EDTA is a hexadentate species which donates six lone pairs of electrons to the central metal ion.
		<u>General reference about transition metal elements</u> www.chemhume.co.uk/A2CHEM/Unit%202b/11%20Transition%20elements/Ch11TransitionEc.htm www.docbrown.info/page07/appendixtrans02.htm opentextbc.ca/chemistry/chapter/19-2-coordination-chemistry-of-transition-metals/ www.knockhardy.org.uk/sci_htm_files/15tmet2.pdf

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>28.2.5 Describe the geometry (shape and bond angles) of transition element complexes which are linear, square planar, tetrahedral or octahedral.</p> <p>28.2.6 (a) state what is meant by coordination number. (b) predict the formula and charge of a complex ion, given the metal ion, its charge or oxidation state, the ligand and its coordination number or geometry.</p> <p>28.2.7 Explain qualitatively that ligand exchange can occur, including the complexes of copper(II) ions and cobalt(II) ions with water and ammonia molecules and hydroxide and chloride ions.</p>	<p>Experimental work:</p> <ul style="list-style-type: none"> Preparation of the complex: $[\text{Co}(\text{NH}_3)_5\text{Cl}]\text{Cl}_2$ <p>Resource Plus</p> <p>Carry out the <i>Preparation of a transition metal complex</i> experiment referring to the Teaching Pack for lesson plans and resources.</p> <ul style="list-style-type: none"> Test tube reactions can be carried out with copper (II) and cobalt (II), exploring the colour changes that occur by adding solutions of ammonia, sodium hydroxide and hydrochloric acid. These videos can be used for reference: www.youtube.com/watch?v=LNqGihWBkc8 This video additionally shows the result of adding chloride ions to copper (II) sulfate solution: www.youtube.com/watch?v=6yyIpS3mXr8 This video explores the colour changes involved with cobalt (II): www.youtube.com/watch?v=EDdQGcjAKhk Even if the following experiment has already been performed (in topic 7 Equilibria), you should still refer to it here, emphasising that this ligand exchange reaction involves an equilibrium reaction: edu.rsc.org/resources/the-equilibrium-between-two-coloured-cobalt-species/1_article
<p>28.3 Colour of complexes</p> <p>KC1</p>	<p>28.3.1 Define and use the terms degenerate and non-degenerate d orbitals.</p>	<p>Introduce this topic by showing learners a range of bottles of available chemicals. Place them into two groups: white crystalline solids; and those which are coloured compounds. Learners observe that it is the transition metal compounds which are coloured, not the metals themselves.</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
KC5	<p>28.3.2 Describe the splitting of degenerate d orbitals into two non-degenerate sets of d orbitals of higher energy, and use of Δ_e in:</p> <p>(a) octahedral complexes, two higher and three lower d orbitals</p> <p>(b) tetrahedral complexes, three higher and two lower d orbitals</p> <p>28.3.2 Explain why transition elements form coloured compounds in terms of the frequency of light absorbed as an electron is promoted between two non-degenerate d orbitals.</p> <p>28.3.3 Describe, in qualitative terms, the effects of different ligands on Δ_e, frequency of light absorbed, and hence the complementary colour that is observed.</p> <p>28.3.4 Use the complexes of copper(ii)</p>	<p>Before going into the detail required about the colours of complexes, first discuss with learners how we see compounds as coloured. Centre the discussion around how we see coloured objects, a topic which most learners should have covered in previous learning. This could be set as a research activity where you provide key words for guidance, for example: complementary colours, absorption, reflection, spectrum, primary colours, secondary colours, frequency.</p> <p>The first part of this page is useful for preliminary understanding: people.wou.edu/~courtna/ch462/tmcolors.htm</p> <p>Make sure that learners have a basic knowledge of the electromagnetic spectrum and know that light with a higher frequency has a higher energy, and the higher the frequency the lower the wavelength. They should also be aware that ultraviolet has higher energy than infra-red radiation.</p> <p><u>Octahedral complexes</u> This is the most common type of transition metal complex. On this page learners can see how the d electrons are arranged before and after six water ligands are attached to the central metal ion: www.chemguide.co.uk/inorganic/complexions/colour2.html</p> <p>An important detail is discussed which relates to 28.1.2 (sketching d orbital): the orientation of the lobes of the individual orbitals along or between the x, y and z axes. This is important because the interaction with the incoming ligands causes the degenerate d orbitals in the ion to become non-degenerate in the complex.</p> <p><u>Tetrahedral complexes</u> In the link below, learners can see that a different splitting pattern arises when four ligands are involved: vlab.amrita.edu/?sub=2&brch=193&sim=610&cnt=1</p> <p>Discuss with learners that the geometry of the complex, the type and arrangement of ligands, and the oxidation state of the central metal ion, can all affect the colour we see.</p> <p>To understand the colour of transition metal complexes in more detail, return to the importance of d orbitals. The key point to emphasise is that in transition metal compounds, there are vacant d orbitals, which allow for electron transitions between them, resulting in them appearing coloured, for example, Cu^{2+} ($3d^9$).</p> <p><u>d-d splitting</u> Discuss with learners that when light passes through a solution of a transition metal compound, some light energy is absorbed, dependent on the type and extent of the splitting of the d orbitals. The light energy</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>ions and cobalt(ii) ions with water and ammonia molecules and hydroxide and chloride ions as examples of ligand exchange affecting the colour observed.</p>	<p>incident on the solution causes d-d transitions. What we see is the light that is not absorbed by the complex ion solution.</p> <p><u>Ligand exchange</u> Explanation of the ligand exchange reactions of cobalt and copper: www.chemguide.co.uk/inorganic/complextions/ligandexch.html</p> <p>Video showing the approach of ligands towards a central metal ion and the resulting splitting of d orbitals: www.youtube.com/watch?v=xNXRSE7pxXM</p> <p>Video showing greater detail for more advanced learners: www.youtube.com/watch?v=8IT21wKoXyQ</p> <p>Extension activity: Understanding the colour of transition metal compounds is a very complicated area of chemistry. Learners wishing to know more may wish to research the terms: crystal field theory and the spectrochemical series.</p>
<p>28.4 Stereoisomerism in transition element complexes</p> <p>KC4</p>	<p>28.4.1 Describe the types of stereoisomerism shown by complexes, including those associated with bidentate ligands:</p> <p>(a) geometrical (cis-trans) isomerism, e.g. square planar such as $[\text{Pt}(\text{NH}_3)_2\text{Cl}_2]$ and octahedral such as $[\text{Co}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ and $[\text{Ni}(\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2)_2(\text{H}_2\text{O})_2]^{2+}$</p> <p>(b) optical isomerism, e.g. $[\text{Ni}(\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2)_3]^{2+}$ and</p>	<p>Ask learners to draw an example each of geometrical and optical isomers to remind themselves of these different types of stereoisomers from topic 13.4 Isomerism: structural and stereoisomerism.</p> <p>Learners research and draw the examples in this objective. Cis-platin: draw both isomers and by drawing dipole moments prove which is the polar, and which is the non-polar isomer. Learners can learn more about this drug by listening to this podcast: www.chemistryworld.com/podcasts/cisplatin/3005739.article</p> <p>Learners could build models to help them visualise how geometrical isomerism arises in complexes such as $[\text{Co}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ and $[\text{Ni}(\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2)_2(\text{H}_2\text{O})_2]^{2+}$. They should try to suggest which are cis and which are trans. As long as they recall that 'cis' means 'same side', they should be able to suggest some possible structures.</p> <p>Discuss that optical isomers exist in transition metal complexes and that pairs of isomers are not superimposable on their mirror images and do rotate the plane of polarised light.</p> <p>Examples to look at:</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>$[\text{Ni}(\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2)_2(\text{H}_2\text{O})_2]^{2+}$</p> <p>28.4.2 Deduce the overall polarity of complexes such as those described in 28.4.1(a) and 28.4.1(b).</p>	<p>www.knockhardy.org.uk/ppoints.htm [PowerPoint presentation. Choose 'Transition metals' from the PowerPoint menu; view slides 37 onwards]</p>
<p>28.5 Stability constants, K_{stab}</p> <p>KC5</p>	<p>28.5.1 Define the stability constant, K_{stab}, of a complex as the equilibrium constant for the formation of the complex ion in a solvent (from its constituent ions or molecules).</p> <p>28.5.2 Write an expression for a K_{stab} of a complex ($[\text{H}_2\text{O}]$ should not be included).</p> <p>28.5.3 Use K_{stab} expressions to perform calculations.</p> <p>28.5.4 Describe and explain ligand exchanges in terms of K_{stab} values and understand that a large K_{stab} is due to the formation of a stable complex ion.</p>	<p>Learners should become familiar with deriving the stability constant equilibrium expression given a complex ion substitution reaction such as the one mentioned in the following page: www.docbrown.info/page07/appendixtrans08.htm</p> $[\text{Zn}(\text{H}_2\text{O})_4^{2+}] + 4\text{CN}^- \rightleftharpoons [\text{Zn}(\text{CN})_4^{2-}] + 4\text{H}_2\text{O}$ <p>The expression written for $K_{\text{stab}} = \frac{[\text{Zn}(\text{CN})_4^{2-}]}{[\text{Zn}(\text{H}_2\text{O})_4^{2+}] + 4\text{CN}^-}$</p> <p>Note that since the concentration of water is almost constant it is omitted from the equilibrium expression. Learners should know that the greater the value of K_{stab} the more easily the target complex ion is formed.</p> <p>Another useful reference page: www.chemguide.co.uk/inorganic/complexions/stabconst.html</p> <p>Video with theory and calculation examples: www.youtube.com/watch?v=DhigC1IL2hc</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
28.2 General characteristic chemical properties of the first set of transition elements, titanium to copper KC5	28.2.8 Predict, using E^\ominus values, the feasibility of redox reactions involving transition elements and their ions. 28.2.9 Describe the reactions of, and perform calculations involving: (a) $\text{MnO}_4^- / \text{C}_2\text{O}_4^{2-}$ in acid solution given suitable data (b) $\text{MnO}_4^- / \text{Fe}^{2+}$ in acid solution given suitable data (c) $\text{Cu}^{2+} / \text{I}^-$ given suitable data. 28.2.10 Perform calculations involving other redox systems given suitable data.	Learners have already seen standard electrode potentials, and their use in predicting the feasibility of a reaction, in relation to electrochemical cells (see 24.2.4). Discuss that E^\ominus values can be applied to any redox reaction system to predict the feasibility of any redox reaction, including those of transition metal elements. For each of the following reactions, learners practise combining the redox half equations and writing full equations, as discussed in 24.2.7. They should also use the E^\ominus tables given in the syllabus to calculate overall cell reaction voltages (just as in 24.2.4). Experimental work: Perform each test tube experiment or watch the video: (a) www.youtube.com/watch?v=LWImPbXuRrY (b) www.youtube.com/watch?v=iCy5AwRbqI0 (c) www.youtube.com/watch?v=DlbrF4b9LLc <u>Additional practical investigations:</u> Each of the above reactions can be performed as redox titrations if time allows.
Past and specimen papers		
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29 An introduction to A Level organic chemistry

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
<p>29.1 Formulae, functional groups and the naming of organic compounds</p>	<p>29.1.1 Understand that the compounds in the table on page 42 contain a functional group which dictates their physical and chemical properties.</p> <p>29.1.2 Interpret and use the general, structural, displayed and skeletal formulae of the classes of compound stated in the table on page 42.</p> <p>29.1.3 Understand and use systematic nomenclature of simple aliphatic organic molecules (including cyclic compounds containing a single ring of up to six carbon atoms) with functional groups detailed in the table on page 42, up to six carbon atoms (six plus six for esters and amides, straight chains only for esters and nitriles)</p> <p>29.1.4 Understand and use systematic nomenclature of simple aromatic molecules with</p>	<p>The name of each of the functional groups is taught in the appropriate topic 30–35.</p> <p>Each of the four types of formulae have been explained and exemplified in Organic synthesis (1). In sections 30–35 try to make sure that learners use each type frequently.</p> <p>The naming of compounds should become a routine part of organic chemistry. In accordance with the parameters stated here, each organic compound should be named by learners. As with all areas of organic chemistry, plenty of practice is needed.</p> <p>The naming of aromatic compounds was not discussed in AS Level organic chemistry. Therefore, special emphasis should be made to correctly name compounds in the following units:</p> <ul style="list-style-type: none"> • arenes in 30 Hydrocarbons • halogenarenes in 31 Halogen compounds • phenols in 32 Hydroxy compounds • benzoic acid, phenyl benzoate and benzoyl chloride in 33 Carboxylic acids and derivatives • phenylamine in 34 Nitrogen compounds.

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	one benzene ring and one or more simple substituents, for example 3-nitrobenzoic acid or 2,4,6-tribromophenol	
29.2 Characteristic organic reactions	29.2.1 Understand and use the following terminology associated with types of organic mechanisms: (a) electrophilic substitution (b) addition-elimination.	Electrophilic substitution is discussed in detail in topics 30.1.2 and 30.1.4 of Arenes. Addition-elimination is covered in topic 33.3.3 of Acyl chlorides.
29.3 Shapes of aromatic organic molecules; σ and π bonds	29.3.1 Describe and explain the shape of benzene and other aromatic molecules, including sp^2 hybridisation, in terms of σ bonds and a delocalised π system.	This is detailed in 'Introduction to arenes' in 30 Hydrocarbons.
29.4.1 Isomerism: optical	29.4.1 Understand that enantiomers have identical physical and chemical properties apart from their ability to rotate plane polarised light and their potential biological activity. 29.4.2 Understand and use the terms optically	Optical isomerism is a feature of many molecules, and is perhaps the most challenging form of isomerism for learners to appreciate. Optical isomers are also known as stereoisomers or enantiomers. Explain that 'stereo' means 'space' and stereoisomers are molecules which have the same number of atoms and bonds, so they are connected in the same way, but the spatial arrangement of the atoms is different. <u>Building enantiomers</u> Learners build a molecular model with four different atoms attached to the central carbon atom. They look at this model in a plane mirror and build its mirror image. They should try to superimpose one model onto the other: they do not superimpose. They now have two enantiomers which have different arrangements in space.

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>active and racemic mixture.</p> <p>29.4.3 Describe the effect on plane polarised light of the two optical isomers of a single substance.</p> <p>29.4.4 Explain the relevance of chirality to the synthetic preparation of drug molecules including:</p> <p>(a) the potential different biological activity of the two enantiomers (b) the need to separate a racemic mixture into two pure enantiomers (c) the use of chiral catalysts to produce a single pure optical isomer.</p> <p>(Candidates should appreciate that compounds can contain more than one chiral centre.)</p>	<p>Another way of checking the model is to check for a plane of symmetry. If there is no plane of symmetry then the molecule is chiral. This can be seen in in the following video: www.khanacademy.org/science/organic-chemistry/stereochemistry-topic/chirality-r-s-system/v/chiral-achiral-jay</p> <p>Another explanation of chirality using a plane mirror: www.youtube.com/watch?v=JS-iAuClexk</p> <p>If models are not available, the following animated models may be rotated to achieve the same goal: www.chem.purdue.edu/jmol/cchem/opti.html</p> <p><u>The polarimeter</u> Discuss the polarimeter, explaining the terms racemic mixture, plane polarised light, rotation of polarised light and optically active.</p> <p>This video explains how plane polarised light is achieved in the polarimeter: www.youtube.com/watch?v=HuHphmJw-fA</p> <p>This one explains optical rotation using solutions of sugars: www.youtube.com/watch?v=GchTURvBz68</p> <p>This video explains how a specific rotation is measured using a polarimeter: www.youtube.com/watch?v=eybotSiyXRQ</p> <p>This simulation demonstrates the optical activity of tartaric acid stereoisomers: demonstrations.wolfram.com/OpticalActivityOfTartaricAcidStereoisomers/</p> <p><u>Chirality in the pharmaceutical industry</u> Often, molecules contain more than one chiral centre and it is therefore important to be able to recognise each one. Give learners practice identifying chiral centres in a variety of complex molecules.</p> <p>Use thalidomide as the basis for this topic. It is the drug which established the importance of understanding stereochemistry. Learners research which enantiomer confers the desired activity (and which is harmful).</p> <p>Discuss the need to separate a racemic mixture in pharmaceutical drugs or design chiral synthesis (called asymmetric synthesis). Also discuss chiral catalysts. Learners should also be aware that chiral compounds in natural materials often exist as just one enantiomer. Learners may make presentations to the class.</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
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Past and specimen papers

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30 Hydrocarbons

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
30.1 Arenes	Introduction to arenes.	<p>If possible build a molecular structure of benzene using molecular model (Molymod) kits.</p> <p>This page describes how the sp^2 hybridised structure arises: www.chemguide.co.uk/basicorg/bonding/benzene2.html</p> <p>It is important that learners understand the significance of the delocalised electron π system and the σ bond framework. Finally, explain the shape of benzene.</p> <p>This video explains the bonding in benzene in detail and shows molecular models of benzene if you do not possess them: www.youtube.com/watch?v=3bZ7bpS6ksw</p> <p>Extension activity: Learners research the history of the benzene structure and what it was originally thought to be. Ask learners why the original structure, proposed by Kekulé, is not entirely satisfactory.</p>
30.1 Arenes KC2 KC3	<p>30.1.1 Describe the chemistry of arenes as exemplified by the following reactions of benzene and methylbenzene:</p> <p>(a) substitution reactions with Cl_2 and with Br_2 in the presence of a catalyst, $AlCl_3$ or $AlBr_3$, to form halogenoarenes (aryl halides)</p> <p>(b) nitration with a mixture of concentrated HNO_3 and concentrated H_2SO_4 at a temperature between $25^\circ C$ and $60^\circ C$</p>	<p><u>Electrophilic aromatic substitution reactions</u> Learners inspect a model of benzene (or place a large image of it on screen). Ask them why the molecule is very stable [presence of pi electrons above and below the ring].</p> <p>Since benzene has such a rich pool of electrons, ask learners which class of reagent can attack the ring. [electrophiles] Set learners a short, paired task to research and find the names and structures of some common electrophiles.</p> <p>Learners research and explain why addition reactions are not favourable and that most of the chemistry of arenes is concerned with substitution reactions. Most of the reactions involve positively charged electrophiles and most are quite similar.</p> <p><u>Nitration</u> Reaction mechanism for the nitration of benzene. This simulation helps learners understand the stages of the process: demonstrations.wolfram.com/ElectrophilicAromaticSubstitutionReactionsOfBenzene/</p> <p>Web reference: chemdictionary.org/nitration-of-benzene/</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>(c) Friedel–Crafts alkylation by CH_3Cl and AlCl_3 and heat</p> <p>(d) Friedel–Crafts acylation by CH_3COCl and AlCl_3 and heat</p> <p>(e) complete oxidation of the side-chain using hot alkaline KMnO_4 and then dilute acid to give a benzoic acid</p> <p>(f) hydrogenation of the benzene ring using H_2 and Pt/Ni catalyst and heat to form a cyclohexane ring.</p> <p>30.1.2 Describe the mechanism of electrophilic substitution in arenes:</p> <p>(a) as exemplified by the formation of nitrobenzene and bromobenzene</p> <p>(b) with regards to the effect of delocalisation (aromatic stabilisation) of electrons in arenes to explain the predomination of substitution over addition.</p>	<p>Simulation: www.chemtube3d.com/electrophilic-aromatic-substitution-nitration-of-benzene/</p> <p>Video of mechanism: www.youtube.com/watch?v=7tsHis091IM</p> <p>In methylbenzene, nitration occurs by the same mechanism but faster due to the directing effect of the alkyl group. Use this opportunity to discuss objective 30.1.3. Learners should study the following page: chem.libretexts.org/ [search for '16.3: Directing Effects of Substituents in Conjugation with the Benzene Ring'].</p> <p>Ask learners to find out whether the methyl group is activating or deactivating and why. Based on this, ask them to decide what the product(s) are. (In fact, a mixture of 2- and 4-nitromethylbenzene results.)</p> <p><u>Bromination</u></p> <ul style="list-style-type: none"> • Bromination of benzene can be achieved with the help of the Lewis acid AlBr_3 which acts as a catalyst. This reaction is discussed here: www.chemguide.co.uk/mechanisms/elsub/halogenation.html#top • The key point to emphasise to learners is that on approach of the non-polar bromine molecule to the benzene ring, it becomes polarised with a partial positive (and partial negative charge). It is the positive end of the molecule that becomes the electrophile in the reaction. Learners also need to appreciate the role of the AlBr_3 in the process. • Bromination of methylbenzene occurs in the same way and a mixture of the 2- and 4- substituted products are formed as with the nitration reaction above. • Bromination in the side chain of methylbenzene Ask learners where else in the molecule bromination might occur and what products might result. Once you have established that halogenation can occur in the side-chain (methyl group), learners can make notes, comparing and contrasting the two reactions which are discussed here: www.chemguide.co.uk/organicprops/arenes/halogenation.html <p><u>Friedel–Crafts alkylation and acylation reactions for benzene</u> Learners draw a table to compare these two reactions (which are often confused), highlighting the structure of the reagent, electrophile, reaction conditions and mechanism. Learners should also be able to name the products formed.</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>30.1.3 Predict whether halogenation will occur in the side-chain or in the aromatic ring in arenes depending on reaction conditions.</p> <p>30.1.4 Describe that in the electrophilic substitution of arenes, different substituents direct to different ring positions (limited to the directing effects of $-\text{NH}_2$, $-\text{OH}$, $-\text{R}$, $-\text{NO}_2$, $-\text{COOH}$ AND $-\text{COR}$)</p>	<p>Animation of the mechanisms: www.chemtube3d.com/electrophilic-aromatic-substitution-friedel-crafts-alkylation/ www.chemtube3d.com/electrophilic-aromatic-substitution-friedel-crafts-acylation/</p> <p><u>Other useful reactions</u> Learners should be aware that methylbenzene treated with hot alkaline KMnO_4 and then dilute acid produces benzoic acid. The benzene ring can be hydrogenated to form a cyclohexane ring (using H_2 and Pt/Ni catalyst and heat).</p>
<p>Past and specimen papers</p>		
<p>Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)</p>		

31 Halogen compounds

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
31.1 Halogen compounds KC2 KC3	31.1.1 Recall the reactions by which halogenoarenes can be produced: (a) substitution of an arene with Cl ₂ or Br ₂ in the presence of a catalyst, AlCl ₃ or AlBr ₃ to form a halogenoarene, exemplified by benzene to form chlorobenzene and methylbenzene to form 2-chloromethylbenzene and 4-chloromethylbenzene. 31.1.2 Explain the difference in reactivity between a halogenoalkane and a halogenoarene as exemplified by chloroethane and chlorobenzene.	(a) Covered in topic 30.1 Arenes. Learners research why chlorobenzene is much less reactive than chloroethane and make notes. [because the carbon-chlorine bond in chlorobenzene is much stronger than the carbon-chlorine bond in chloroethane]. They then compare the conditions necessary for nucleophilic substitution to occur. One reference is: www.chemguide.co.uk/organicprops/arylhalides/background.html#top

Past and specimen papers

Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)

32 Hydroxy compounds

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
32.1	32.1.1 Describe the reaction with acyl chlorides to form esters using ethyl ethanoate.	See 33.2 Esters.
32.2 Phenols KC2 KC3	32.2.1 Recall the reactions (reagents and conditions) by which phenol can be produced: (a) reaction of phenylamine with HNO_2 or NaNO_2 and dilute acid below 10°C to produce the diazonium salt; further warming of the diazonium salt with H_2O to give phenol.	<p>Display the structure of phenol and ask learners to think of a name for it. Discuss that benzenol and hydroxybenzene are all names which are used, but that phenol is the commonly used name derived from the phenyl group. Likewise, whereas benzeneamine is a possible name, phenylamine (also known as aniline) is the preferred name today.</p> <p>Learners need to know that this is a two-stage process.</p> <ol style="list-style-type: none"> 1. Reaction of phenylamine with HNO_2 or NaNO_2 and dilute acid below 10°C to produce the diazonium salt 2. Reaction of the diazonium salt with the water in the reaction as it warms to room temperature. <p>Ask them to write the equations for the two reactions, including the full structure of the intermediate diazonium salt.</p>
32.2 Phenols	32.2.3 Explain the acidity of phenol. 32.2.4 Describe and explain the relative acidities of water, phenol and ethanol.	<p>Ask learners what data they could look up in data tables to compare the acidity of water, phenol and ethanol. When you have established that the answer is pK_a values, ask learners to assign pK_a values to each substance and place them in order of least to most acidic.</p> <p>Make clear that phenol is a very weak acid as shown by its lack of reactivity with sodium carbonate (or hydrogen carbonate). Add some sodium carbonate to a solution of phenol and ask learners to explain how they know there is no reaction. [lack of bubbles of carbon dioxide produced]</p> <p>Encourage learners to research the reason why phenol is weakly acidic. Their discussion should be centred around the stability of the phenoxide anion. www.chemguide.co.uk/organicprops/phenol/acidity.html</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
32.2 Phenols KC4	<p>32.2.2 Recall the chemistry of phenol, as exemplified by the following reactions:</p> <p>(a) with bases, for example NaOH(aq) to produce sodium phenoxide</p> <p>(b) with Na(s) to produce sodium phenoxide and H₂(g)</p> <p>(c) in NaOH(aq) with diazonium salts, to give azo compounds</p> <p>(d) nitration of the aromatic ring with dilute HNO₃(aq) at room temperature to give a mixture of 2-nitrophenol and 4-nitrophenol</p> <p>(e) bromination of the aromatic ring with Br₂(aq) to form 2,4,6-tribromophenol.</p> <p>32.2.5 Explain why the reagents and conditions for the nitration and bromination of phenol are</p>	<p>Learners need to know that the reactions of phenol in this objective can be classified according to:</p> <p>(i) reactions possible because of the acidity of the phenolic -OH group</p> <p>(ii) ring substitution reactions</p> <p><u>Reactions possible because of the acidity of the phenolic -OH group</u></p> <p>Explain that phenol can react with sodium hydroxide because sodium hydroxide is a strong base and is able to remove the proton from the phenol producing the phenoxide ion. The reaction of phenol with sodium also produces sodium phenoxide.</p> <p>Demonstrate the reaction of phenol by melting a small quantity (in a fume cupboard). Then add a small piece of sodium to it. Fizzing will be observed of hydrogen gas. The resulting product is sodium phenoxide.</p> <p>Azo compounds can be prepared by the reaction of sodium hydroxide and diazonium salts. This reaction is covered in topic 34.2 Phenylamine and azo compounds.</p> <p><u>Ring substitution reactions</u></p> <p><u>Nitration</u></p> <p>Ask learners to predict and explain the effect of having an -OH group on the benzene ring. Learners should be able to explain that the -OH group is activating and 2, 4 directing. They should compare the conditions needed for the nitration of phenol, to benzene. Finally, ask learners to suggest why the use of concentrated nitric acid is not recommended.</p> <p><u>Bromination</u></p> <p>Learners predict what product is formed again noting the ease of reaction. This reaction can be demonstrated in the fume cupboard:</p> <p>Bromine water is carefully added to an aqueous solution of phenol. A white precipitate of 2, 4, 6 - tribromophenol is formed and the bromine water is decolourised.</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>different from those for benzene.</p> <p>32.2.6 Recall that the hydroxyl group of a phenol directs to the 2, 4 and 6 positions.</p>	
<p>32.2 Phenols</p> <p>KC4</p>	<p>32.2.7 Apply knowledge of the reactions of phenol to those of other phenolic compounds, e.g. naphthol.</p>	<p>On the basis of the ring reactions above, ask learners to predict what products would be formed in the nitration or bromination of 1-naphthol, for example. They should predict analogous reactions to those for phenol.</p> <p>Similarly, ask learners about reactions due to the acidity of the -OH group, which can also be assumed as being analogous.</p>
<p>Past and specimen papers</p>		
<p>Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)</p>		

33 Carboxylic acids and derivatives

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
33.1 Carboxylic acids	33.1.1 Recall the reaction by which benzoic acid can be produced: (a) reaction of an alkylbenzene with hot alkaline KMnO_4 and then dilute acid, exemplified by methylbenzene	Covered in 30 Hydrocarbons.
33.1 Carboxylic acids KC2 KC3	33.1.2 Describe the reaction of carboxylic acids with PCl_3 and heat, PCl_5 , or SOCl_2 to form acyl chlorides.	When carboxylic acids react with any of the mentioned reagents, the acid chloride is produced. Ask learners to research and write down equations for each. They should compare the additional products obtained in the reaction and make sure equations are balanced.
33.1 Carboxylic acids KC2 KC3 KC4	33.1.3 Recognise that some carboxylic acids can be further oxidised: (a) the oxidation of methanoic acid, HCOOH , with Fehling's reagent or Tollens' reagent or acidified KMnO_4 or acidified $\text{K}_2\text{Cr}_2\text{O}_7$ to carbon dioxide and water (b) the oxidation of ethanedioic acid, HOOC-COOH , with warm	<u>The oxidation of methanoic acid</u> First ask learners if the most common reaction of carboxylic acids is oxidation or reduction. [it is reduction]. Go on to explain that methanoic acid is unique in that it can be oxidised. Ask learners how it is different from the other members of the homologous series. Next ask learners what Fehling's and Tollens' reagents and KMnO_4 and $\text{K}_2\text{Cr}_2\text{O}_7$ have in common. [all oxidising agents]. $\text{HCOOH} + [\text{O}] \rightarrow \text{CO}_2 + \text{H}_2\text{O}$ Learners have already covered the reactions of Fehling's and Tollens' reagents in topic 17.1.5 Aldehydes and ketones, so link practical details to this objective for revision. Acidified KMnO_4 and $\text{K}_2\text{Cr}_2\text{O}_7$ solutions are powerful oxidising agents and also effect this transformation. <u>The oxidation of ethanedioic acid (oxalic acid)</u>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	acidified KMnO_4 to carbon dioxide.	<p>Start by asking learners to write the full structural formula of this molecule.</p> <p>Experimental work:</p> <ul style="list-style-type: none"> Learners could perform a redox titration using acidified KMnO_4 and ethanedioic acid and in doing so practise writing half equations for the reactions: vedu.rsc.org/resources/investigating-the-reaction-between-manganatevii-and-ethanedioate-ions/2322.article Learners can try test tube reactions of methanoic acid with Fehling's, Tollens' and acidified KMnO_4 and $\text{K}_2\text{Cr}_2\text{O}_7$ solutions.
33.1 Carboxylic acids KC2 KC3	33.1.4 Describe and explain the relative acidities of carboxylic acids, phenols and alcohols. 33.1.5 Describe and explain the relative acidities of chlorine-substituted carboxylic acids.	<p><u>Start by comparing ethanoic acid, phenol and ethanol</u></p> <p>Ask learners to make predictions about the acidity of these compounds based on their previous knowledge, They then check their predictions by finding pK_a values from the literature. They should find that carboxylic acids are more acidic than the others and that phenol is a stronger acid than ethanol for example (see 32.2.4)</p> <p>Emphasise to learners that they should always consider the strength of the bond being broken and the stability of the ion being formed.</p> <p>Extension activity: More advanced learners try to explain how the strength in acid properties varies across the homologous series. You could give learners a hint, asking them what effect the alkyl group will have on the stability of the carboxylate anion. Reveal this page revealed once they have thought about it: www.chemguide.co.uk/basicorg/acidbase/acids.html</p> <p>Learners draw out the full structural formula for mono-, di- and tri- substituted ethanoic acids and consider the effect of adding more chlorine atoms. Once again, they should consider the stability of the resulting anion once it has lost a proton. Learners check their predictions by sourcing pK_a values.</p> <p>Finally, recap the fact that a chlorine atom has an electron-withdrawing effect, in contrast to an alkyl group.</p>
33.2 Esters KC2	33.2.1 Recall the reaction by which esters can be produced: (a) reaction of alcohols with acyl chlorides using	<p>Check that learners can write the full structural formulae and correctly name a given selection of esters.</p> <p>If possible, learners build molecular models of the reactants and the ester to appreciate that hydrogen chloride is eliminated in the reaction.</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
KC3 KC4	the formation of ethyl ethanoate and phenyl benzoate as examples.	Contrast this reaction with the esterification reaction of making esters from alcohols (18.1.2). Learners should note how fast and vigorous the reaction is using acyl chlorides, as an indication of their reactivity.
33.3 Acyl chlorides KC2 KC3	33.3.1 Recall the reactions (reagents and conditions) by which acyl chlorides can be produced: (a) reaction of carboxylic acids with PCl_3 and heat, PCl_5 , or $SOCl_2$.	Covered in topic 33.1.2 Carboxylic acids.
33.3.2 Acyl chlorides KC2 KC3 KC4	33.3.2 Describe the following reactions of acyl chlorides: (a) hydrolysis on addition of water at room temperature to give the carboxylic acid and HCl (b) reaction with an alcohol at room temperature to produce an ester and HCl (c) reaction with phenol at room temperature to produce an ester and HCl (d) reaction with ammonia at room temperature to	The reactions covered in this section are called addition-elimination reactions but are also known as condensation reactions. Note that reaction (b) is covered in topic 33.1.1 Carboxylic acids. Ask learners to write the structures of water, ethanol, phenol, ammonia and methylamine (a primary amine) and dimethylamine (a secondary amine). Ask them what they all have in common and what the general name for this class of organic reagents is called in organic chemistry. [lone pair(s), nucleophiles] Experimental work: In a fume cupboard, learners perform test tube reactions with small quantities of reagents like those detailed in the video: www.youtube.com/watch?v=KgYAvLNqBmU [examples reaction for (a), (b), (d) and (e) are covered in this video]. <u>Mechanism of the addition-elimination reactions</u> The first thing learners need to identify is the site of attack / why the nucleophiles attack the acyl chloride. Next it is important to realise that there are two clear stages to the reactions: 1. addition, followed by 2. elimination. Learners practise writing out these mechanisms until they are correct.

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>produce an amide and HCl</p> <p>(e) reaction with a primary or secondary amine at room temperature to produce an amide and HCl.</p> <p>33.3.3 Describe the addition-elimination mechanism of acyl chlorides in reactions in 33.3.2(a) – (e).</p> <p>33.3.4 Explain the relative ease of hydrolysis of acyl chlorides, alkyl chlorides and halogenoarenes (aryl chlorides).</p>	<p>www.chemguide.co.uk/mechanisms/addelim/whatis.html [explains the mechanism of these reactions]</p> <p>Question and answer sheets to test understanding of addition-elimination reactions in general.</p> <p>www.chemguide.co.uk/mechanisms/addelimmenu.html#top</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

34 Nitrogen compounds

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
34.1 Primary and secondary amines KC2 KC3	34.1.1 Recall the reactions (reagents and conditions) by which primary and secondary amines are produced: (a) reaction of halogenoalkanes with NH_3 in ethanol heated under pressure (b) reaction of halogenoalkanes with primary amines in ethanol, heated in a sealed tube / under pressure (c) the reduction of amides with LiAlH_4 (d) the reduction of nitriles with LiAlH_4 or H_2 / Ni .	Learners research all the transformations, reagents and conditions. They could produce this work as a mini-poster or collaborative project. (I) Make sure that learners know the structure of each functional group and how to describe the difference between a primary and secondary (and tertiary) amine. Use molecular models if possible to help in learning these transformations and in understanding the difference between the classes of amines. None of these reactions can be performed in a school laboratory by learners for safety reasons.
34.1 Primary and secondary amines KC2 KC3	34.1.2 Describe the condensation reaction of ammonia or an amine with an acyl chloride at room temperature to give an amide.	Ask learners to predict the structure of the products formed when ammonia and methylamine react with ethanoyl chloride, and which condensation product is produced in each case. Making models may help with understanding these transformations. Extension activity: More able learners may wish to try to write a mechanism for the reaction: www.docbrown.info/page06/OrgMechs3g.htm

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
KC2 KC3	34.1.3 Describe and explain the basicity of aqueous solutions of amines.	Ask learners what they understand by the word 'basicity' and why amines are basic substances. Only a very simple treatment of this topic is needed and there is no need for learners to try to justify the order of basicity from ammonia to primary, secondary and tertiary amines.
34.2 Phenylamine and azo compounds KC2 KC3	34.2.1 Describe the preparation of phenylamine via the nitration of benzene to form nitrobenzene followed by reduction with hot Sn/concentrated HCl, followed by NaOH(aq).	<p>Introduce this preparation by discussing with learners that phenylamine (aniline) is a chemical used widely in industry and that it is prepared industrially by a very similar method to the one outlined here.</p> <p>As revision, ask learners if they can recall the mechanism of the reaction for the nitration of benzene (covered in 30.1.1 Arenes.)</p> <p>The second stage of the reaction is reduction of the -NO₂ group to -NH₂. It is important to stress that, because the reaction is carried out under acidic conditions and phenylamine is a base, the initial product is an amine salt. The desired product is liberated by making the mixture basic with sodium hydroxide.</p> <p>The process is described in detail here: www.chemguide.co.uk/organicprops/aniline/preparation.html [there is a free question and answer sheet available for download]</p> <p>This preparation is unsuitable for learners to perform because of the toxicity of the chemicals.</p> <p>Video with the stepwise preparation: www.youtube.com/watch?v=nKWOZajmAQo</p>
34.2 Phenylamine and azo compounds KC2 KC3	34.2.2 Describe: (a) the reaction of phenylamine with Br ₂ (aq) at room temperature (b) the reaction of phenylamine with HNO ₂ or NaNO ₂ and dilute acid below 10°C to produce the diazonium salt; further warming of the diazonium	<p><u>The reaction of phenylamine with bromine water</u> As learners have already studied the reaction of phenol with bromine water, (topic 32.2 Phenol) ask them to predict the product of the reaction on the understanding that the -NH₂ group is activating like the -OH group. The bromine water is decolourised and a white precipitate of 2,4,6-tribromophenylamine is formed, analogous to the reaction with phenol and bromine water.</p> <p>As phenylamine is toxic, watch this video of the preparation: www.youtube.com/watch?v=4fmlqhkGmKk</p> <p><u>The production of a diazonium salt and its subsequent reactions</u></p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>salt with H₂O to give phenol.</p> <p>34.2.4 Recall the following about azo compounds:</p> <p>(a) describe the coupling of benzenediazonium chloride with phenol in NaOH(aq) to form an azo compound</p> <p>(b) identify the azo group</p> <p>(c) state that azo compounds are often used as dyes</p> <p>(d) that other azo dyes can be formed via a similar route.</p>	<p>Discuss with learners that the temperature conditions must be carefully controlled in this preparation. Learners should know the full structure of the diazonium salt produced and that it is unstable above 10°C. If it is allowed to warm up to room temperature, it reacts with the water (solvent) producing phenol.</p> <p><u>Coupling reactions to form azo compounds</u> The reaction with phenol is described in this page: www.chemguide.co.uk/organicprops/aniline/propsdiazo.html#top</p> <p>Highlight to learners that:</p> <ol style="list-style-type: none"> the diazonium salt is prepared first and kept below 10°C phenol is dissolved in sodium hydroxide to give sodium phenoxide and then cooled the diazonium salt is added to sodium phenoxide producing a yellow-orange precipitate. <p>This compound is known as an azo compound. Many variations are possible giving a variety of different colours.</p> <p>Learners look at the formation of different azo dyes. Some indicators are azo dyes, including methyl orange, methyl red and methyl yellow.</p> <p>Experimental work: You could demonstrate the preparation of the diazonium salt in a fume cupboard and its subsequent reaction with sodium phenoxide: www.rod.beavon.org.uk/diazotisation.htm [contains preparation details for the diazo salt only]</p> <p>This video details the preparation of benzene diazonium chloride from phenylamine and its subsequent reactions with phenol (and beta-naphthol): www.youtube.com/watch?v=101sftzNnck</p>
<p>34.2 Phenylamine and azo compounds</p> <p>KC2</p> <p>KC3</p>	<p>34.2.3 Describe and explain the relative basicities of aqueous ammonia, ethylamine and phenylamine.</p>	<p>Ask learners to research and write down the structures and pK_b values of these bases. Explain to learners that the smaller the number, the stronger the base. They will find that ethylamine is the strongest base.</p> <p>A full treatment of relative basicities is described here: www.chemguide.co.uk/basicorg/acidbase/bases.html [describes ammonia, methylamine and phenylamine]</p>
<p>34.3 Amides</p>	<p>34.3.1 Recall the reactions (reagents and</p>	<p>This is covered in topic 33.3.2 Amines.</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
KC2 KC3	<p>conditions) by which amides are produced:</p> <p>(a) the reaction between ammonia and an acyl chloride at room temperature</p> <p>(b) the reaction between a primary amine and an acyl chloride at room temperature.</p>	
34.3 Amides KC2 KC3	<p>34.3.2 Describe the reactions of amides:</p> <p>(a) hydrolysis with aqueous alkali or aqueous acid</p> <p>(b) the reduction of the CO group in amides with LiAlH₄ to form an amine.</p>	<p>Start by asking learners how amides are made and elicit from learners that when the amide linkage is formed during the reaction, water is eliminated. Explain to them that hydrolysis is the opposite process and that only severe conditions are able to break the amide link because it is very stable.</p> <p>www.chemguide.co.uk/organicprops/amides/hydrolysis.html</p> <p>LiAlH₄ is an extremely reactive substance and must be used in a non-polar solvent (ethoxyethane) which is completely dry. Ask learners why it must be dry and what reaction would happen with water.</p> <p>The reaction proceeds at room temperature. Reduction may be represented as 4[H] for simplicity.</p> $\text{CH}_3\text{CONH}_2 + 4[\text{H}] \longrightarrow \text{CH}_3\text{CH}_2\text{NH}_2 + \text{H}_2\text{O}$ <p>Building models will help learners understand the transformation more easily. This reaction is too dangerous to be performed in a school lab.</p>
34.3 Amides KC2 KC3	<p>34.3.3 State and explain why amides are much weaker bases than amines.</p>	<p>Ask learners to draw the amide link showing all of the bonds and lone pairs of electrons. Then ask for reasons why the basicity of the nitrogen atom in an amide is greatly reduced compared to an amine. [Answer: The lone pair in an amine is much more easily donated than in an amide. In an amide the C=O group withdraws electrons from the C-N bond thus reducing the capability of the amide as a base.]</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
34.4 Amino acids KC2 KC3	34.4.1 Describe the acid / base properties of amino acids and the formation of zwitterions, to include the isoelectric point.	<p>Learners spend a few minutes researching what amino acids are and how they are useful in the human body.</p> <p>Ask each learner to write down the structure of an amino acid, name it and circle the two functional groups it contains.</p> <p>General information and structures of amino acids: aminoacidsguide.com/</p> <p>Following this, learners research the meaning of the term 'zwitterion'. They write down the structure of the zwitterion of the amino acid they chose and explain how it occurs.</p> <p>Next, bearing in mind that amino acids contain both an amine and a carboxylic acid group, ask learners to predict the structure of the resulting compound when the following solutions are added to two separate solutions of the amino acid they chose:</p> <ul style="list-style-type: none"> • OH⁻ ions • H⁺ ions. <p>A summary of the acid/base properties of amino acids is included on this page: www.chemguide.co.uk/organicprops/aminoacids/acidbase.html</p> <p>Define the term 'isoelectric point' as the point at which a molecule carries no net electrical charge i.e. it is overall electrically neutral.</p> <p>Discuss that in an electric field, if an amino acid is at its isoelectric point, it will neither move towards the positive nor the negative plates. Under all other circumstances, when the ion is not at its isoelectric point, it will move towards the negative or positive plates. This is explained diagrammatically here: a-levelchem.com/aqa_a_level_chemistry/unit3.4/s3408/01.htm</p>
34.4 Amino acids KC2 KC3 KC4	34.4.2 Describe the formation of amide (peptide) bonds between amino acids to give di- and tripeptides.	<p>Learners choose any two amino acids and combine them to form a dipeptide (and water). Next they choose any three or more amino acids and combine them to form a tripeptide (the shortest polypeptide).</p> <p>Discuss that a protein chain may contain 50 – 2,000 amino acids combined together in this way.</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
34.4 Amino acids KC2 KC5	34.4.3 Interpret and predict the results of electrophoresis on mixtures of amino acids and dipeptides at varying pHs	<p>Discuss with learners that for complex reasons different amino acids have varying isoelectric points. This fact can be used to help mixtures of amino acids be separated by electrophoresis as described here: www.usetute.com.au/ephoresis.html</p> <p>A similar separation should also be possible with dipeptides as they also contain both an amino group and a carboxylic acid group.</p> <p>A short video explaining the electrophoresis of amino acids: www.youtube.com/watch?v=GyO1FQFM_OE</p>
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

35 Polymerisation

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
35.1 Condensation polymerisation KC3 KC4	35.1.1 Describe the formation of polyesters: (a) the reaction between a diol and a dicarboxylic acid or diol chloride (b) the reaction of a hydroxycarboxylic acid. 35.1.2 Describe the formation of polyamides: (a) the reaction between a diamine and a dicarboxylic acid or diol chloride (b) the reaction of an aminocarboxylic acid (c) the reaction between amino acids. 35.1.3 Deduce the repeat unit of a condensation polymer obtained from a given monomer or pair of monomers. 35.1.4 Identify the monomer(s) present in a given section of a	As revision, ask learners what the two main types of polymers are. [Answer: addition (covered in topic 20.1 Addition polymerisation) and condensation] <u>Polyesters</u> To appreciate the size of this industry, learners spend a few minutes researching the uses of polyesters. Ask them to find the name of the most common polyester used today. [Terylene/PET] www.essentialchemicalindustry.org/polymers/polyesters.html Ask learners to write out molecules of benzene-1,4-dicarboxylic acid and ethane-1,2-diol alternately across the top of the page [full structural formulae]. Next, tell them to circle each molecule of water that will be 'condensed out' on reaction forming ester linkages. Finally, write the structure of the polymer. This reaction could also be performed with the diol chloride instead of the diacid In a molecule like 2-hydroxypropanoic acid (lactic acid), the same molecule contains two functional groups. Challenge learners to write several of these molecules across the top of their page and write the structure of the resulting condensation polymer. <u>Polyamides</u> Background information, including uses: www.essentialchemicalindustry.org/polymers/polyamides.html Similar to the preparation of polyesters, these condensation polymers can be made by reacting a diamine with a dicarboxylic acid (or acid chloride) as in (a) or with molecules which contain both functional groups in the same molecule as in (b) and (c). Provide learners with a variety of molecules and they show the formation of the resulting polyamides. For 35.1.1 and 35.1.2, give learners plenty of opportunity to work out which monomer or monomers were used to make a particular polymer.

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	condensation polymer molecule.	
35.2 Predicting the type of polymerisation KC4	35.2.1 Predict the type of polymerisation reaction for a given monomer or pair of monomers. 35.2.1 Deduce the type of polymerisation reaction which produces a given section of a polymer molecule.	Give learners plenty of examples to solve.
35.3 Degradable polymers	35.3.1 Recognise that poly(alkenes) are chemically inert and can therefore be difficult to biodegrade. 35.3.2 Recognise that some polymers can be degraded by the action of light. 35.3.3 Recognise that polyesters and polyamides are biodegradable by acidic and alkaline hydrolysis.	Learners carry out project-based research. (I) Possible topics include: <ul style="list-style-type: none"> • Discovery • Chemistry: <ul style="list-style-type: none"> ○ polymers degraded by hydrolysis ○ polymers degraded by light ○ polymers that are difficult to biodegrade • Current use • Economics/cost • Hopes for the future
Past and specimen papers		
Past/specimen papers and mark schemes are available to download at www.cambridgeinternational.org/support (F)		

36 Organic synthesis (2)

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
36.1 Organic synthesis KC3	36.1.1 For an organic molecule containing several functional groups: (a) identify organic functional groups using the reactions in the syllabus (b) predict properties and reactions.	Check that learners can recall the functional groups, reagents and conditions to effect all of the transformations covered in the Cambridge International AS & A Level Chemistry syllabus. Learners should summarise this work using mind maps or tables or reactions. Learners could also create their own quiz to test their friends, or use the example given here: quizlet.com/7468964/organic-chemistry-functional-groups-flash-cards/ [free but you have to become a member of quizlet]
36.1 Organic synthesis	36.1.2 Devise multi-step synthetic routes for preparing organic molecules using the reactions in the syllabus. 36.1.3 Analyse a given synthetic route in terms of type of reaction and reagents used for each step of it, and possible by-products.	Using all of the transformations necessary to make products via two-step organic syntheses in 36.1.1, learners try to produce a reaction pathways map, drawing arrows between functional groups, including reagents and conditions above the arrows. 'Synthesis explorer' to help learners organise and plan syntheses. edu.rsc.org/resources/synthesis-explorer/3.article Extension activity: For those wishing to learn more about this topic, the 'disconnection approach' is a method chemists use to design organic syntheses. edu.rsc.org/resources/designing-an-organic-synthesis/2361.article
Past and specimen papers		
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37 Analytical techniques

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
37.1 Thin-layer chromatography KC2 KC3	37.1.1 Describe and understand the terms (a) stationary phase, for example aluminium oxide (on a solid support) (b) mobile phase; a polar or non-polar solvent (c) R_f value (d) solvent front and baseline. 37.1.2 Interpret R_f values 37.1.3 Explain the differences in R_f values in terms of interaction with the stationary phase and of relative solubility in the mobile phase	<p>Check that learners understand the terms, R_f value, solvent front and baseline.</p> <p>Show learners a thin-layer chromatography (TLC) plate and discuss its construction. Define the stationary phase and indicate the silica gel or alumina used to make the plate. (Scrape off a small amount using a spatula so learners can see that it is compacted powder stuck to a backing of aluminium.)</p> <p>Next discuss the mobile phase, which flows through the stationary phase. It may be a polar solvent, for example, water or ethanol or a non-polar solvent, for example, hexane or methyl benzene. Discuss solvents and what makes them polar/non-polar at this point.</p> <p>The way the experiment is set up closely resembles that for paper chromatography, except that the TLC tank has a lid which must be used to maintain an atmosphere of saturated solvent vapour inside the tank.</p> <p>Discuss with learners the types of mixtures which can be separated by TLC, which goes far beyond separating pen inks. [plant extracts, mixtures of amino acids, mixtures of compounds produced in a chemical reaction]</p> <p>The reasons why some spots run faster and some slower on the plate (the separation of the components), depends on two factors, which learners can investigate further in the articles below. These are:</p> <ul style="list-style-type: none"> • solubility of the component in the mixture (attraction between component molecules and the solvent chosen) • the extent to which the component sticks to the stationary phase. <p>Next, discuss how you might view the separated components of the mixture. If the components are not coloured, then various chemical sprays are used to make spots visible. Other times, placing the spots under a UV lamp allows them to be seen.</p> <p>This article discusses every aspect of TLC in detail: chemistryhall.com/thin-layer-chromatography/</p> <p>Questions and answer sheets on the topic: www.chemguide.co.uk/analysis/chromatography/thinlayer.html</p> <p>Experimental work:</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
		<ul style="list-style-type: none"> Apparatus guide for TLC, simulations of R_f value and a simulation of a TLC in progress. There is also a video guide which explains how to make a spotter using a capillary tube: edu.rsc.org/resources/thin-layer-chromatography/1074.article Step-by-step guide of how to prepare a plate, run it and measure the R_f value: chemistryhall.com/thin-layer-chromatography/ [there are also key video suggestions]
37.2 Gas / liquid chromatography KC2 KC3	37.2.1 Describe and understand the terms: (a) stationary phase; a high boiling point non-polar liquid (on a solid support) (b) mobile phase; an unreactive gas (c) retention time. 37.2.2 Interpret gas / liquid chromatograms in terms of the percentage composition of a mixture. 37.2.3 Explain retention times in terms of interaction with the stationary phase.	<p>Explain that this type of chromatography is an extremely powerful analytical technique used across many industries.</p> <p>Compare the similarities with TLC in 37.1 in terms of having a stationary phase and a mobile phase. Highlight that the mobile phase is an unreactive gas and the stationary phase is a high boiling point liquid adsorbed onto a solid.</p> <p>Also highlight the fact that the idea of retention is important. Not retention factor but retention time. This is defined as the total time a certain component takes to travel through the column to the detector. Notice this for the compound ethanol in the sample of blood in the following video: www.youtube.com/watch?v=uSG8ANBTaN0 [explains the process of GC] www.youtube.com/watch?v=ZpPzImDSfqc [view inside a GC machine showing the coiled column through which the sample travels]</p> <p>The key to being able to calculate the % composition of a mixture is to calculate the area under each peak. Each peak should be treated as a simple triangle. The process is explained here: www.webassign.net/sample/ncsumeorgchem1/lab_4/manual.html [go to 'How to Calculate the % Composition of a Mixture from a GC Printout']</p>
37.3 Carbon-13 NMR spectroscopy	37.3.1 Analyse and interpret a carbon-13 NMR spectrum of a simple molecule to deduce:	<p>Before discussing the way in which spectra are determined, check that learners know the difference between carbon-12, carbon-13 and carbon-14. [they may need to be reminded about isotopes]</p> <p>This site provides a link to a PowerPoint presentation which includes a section on carbon-13 NMR: www.knockhardy.org.uk/ppoints.htm [search for 'Spectroscopy - NMR'] It discusses the different environments of the carbon atom and gives examples of organic molecules and the peaks they give]</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>(a) the different environments of the carbon atoms present</p> <p>(b) the possible structures for the molecule</p> <p>37.3.2 Predict or explain the number of peaks in a carbon-13 NMR spectrum for a given molecule</p>	<p>A visual guide to carbon-13 chemical shifts: i0.wp.com/www.compoundchem.com/wp-content/uploads/2015/04/Analytical-Chemistry-13-C-NMR-Chemical-Shifts.png?ssl=1</p> <p>Learners practise some questions about carbon-13 NMR: www.chemguide.co.uk/analysis/nmr/backgroundc13.html [downloadable question and answer sheets]. www.ocr.org.uk/Images/170187-carbon-13-nmr.pdf</p>
37.4 Proton (¹ H) NMR spectroscopy	<p>37.4.1 Analyse and interpret a proton (¹H) NMR spectrum of a simple molecule to deduce:</p> <p>(a) the different environments of proton present using chemical shift values</p> <p>(b) the relative numbers of each type of proton present from relative peak areas</p> <p>(c) the number of equivalent protons on the carbon atom adjacent to the one to which the given proton is attached from the splitting pattern, using the n + 1 rule (limited to singlet,</p>	<p>Ideally, learners observe a proton NMR machine in operation, but listed below are various other possibilities to appreciate how it works. [Simulation, PowerPoint and videos].</p> <p>This PowerPoint explains the basic theory covering all aspects of this learning objective: www.knockhardy.org.uk/ppoints.htm [search for 'Spectroscopy - NMR']</p> <p>This link has a general discussion of NMR followed by interpreting low-resolution spectra and then high-resolution spectra. www.chemguide.co.uk/analysis/nmr/background.html#top [downloadable question and answer sheets]</p> <p>With this tool, learners can enter any molecule of their choice and produce a ¹³C and/or ¹H spectrum: web.chemdoodle.com/demos/simulate-nmr-and-ms/</p> <p>Experimental work: If you don't have access to a proton NMR machine, consider making links with local universities and/or businesses so that your learners can see working machines and real spectra being produced.</p>

Syllabus ref. and Key Concepts (KC)	Learning outcomes	Suggested teaching activities
	<p>doublet, triplet, quartet and multiplet)</p> <p>(d) the possible structures for the molecule.</p> <p>37.4.2 Predict the chemical shifts and splitting patterns of the protons in a given molecule.</p> <p>37.4.3 Describe the use of tetramethylsilane, TMS, as the standard for chemical shift measurements.</p> <p>37.4.4 State the need for deuterated solvents, e.g. CDCl_3, when obtaining a proton NMR spectrum.</p> <p>37.4.5 Describe the identification of O–H and N–H protons by proton exchange using D_2O.</p>	
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