AS AND
A-LEVEL
CHEMISTRY

AS (7404)
A-level (7405)

Specifications
For teaching from September 2015 onwards
For AS exams in May/June 2016 onwards
For A-level exams in May/June 2017 onwards

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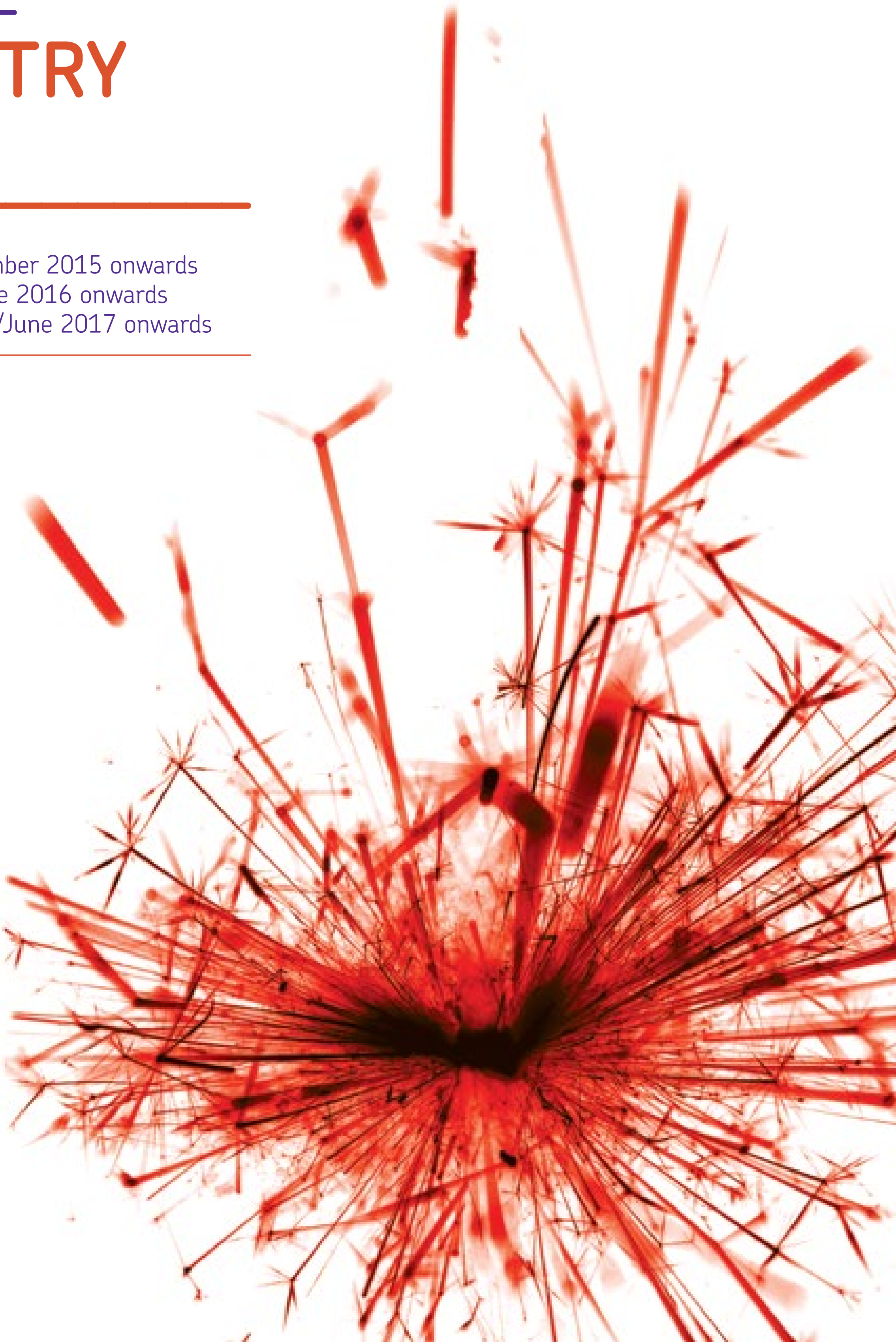

Contents

Are you using the latest version of these specifications?

- You will always find the most up-to-date version of these specifications on our website at aqa.org.uk/7405
- We will write to you if there are significant changes to these specifications.

| Vertical black lines indicate a significant change or addition to the previous version of this specification.

1 Introduction

1.1 Why choose AQA for AS and A-level Chemistry

Relevant in the classroom and the real world

We involved over a thousand teachers in developing these specifications, to ensure that the subject content is relevant to real world experiences and is interesting to teach and learn. We've also presented it in a straightforward way, giving you the freedom to teach in the way that works for your students.

These chemistry specifications are a stepping stone to future study, which is why we also consulted universities, to ensure these specifications allow students to develop the skills that they want to see.

This approach has led to specifications that will help you to inspire students, nurture their passion for chemistry and lay the groundwork for further study in courses such as chemistry, medicine and pharmacy.

The way you teach – your choice

These specifications have been written with minimal context. This means that you can select the context and applications that you feel bring the subject alive. To support you, we have also produced a range of excellent teaching resources that you can use alongside your own.

Practicals at the heart of science

Like you, we believe that chemistry is fundamentally an experimental subject. These specifications provide numerous opportunities to use practical experiences to link theory to reality, and equip students with the essential practical skills they need.

Teach AS and A-level together

We've ensured that the AS and A-level are fully co-teachable. The AS exams are similar in style to the A-level exams, testing a subset of the same content, with less difficulty. This allows your students to develop and helps you and your students decide if A-level is the right choice for them.

We've created our AS and A-level content with our GCSE in mind, to make sure that there is a seamless progression between qualifications. We've also followed the Association for Science Education (ASE) guidance on use of scientific terminology across our science subjects.

Assessment success

We've tested our specimen question papers with students, making sure they're interesting, straightforward, clear and hold no hidden surprises. To ensure that your students are rewarded for the skills and knowledge they've developed, our exams include:

- specified content tested in each of the AS papers, and in each of the first two A-level papers to help students prepare for their exams
- a variety of assessment styles so students can confidently engage with the questions
- multiple choice questions, which allow for a wide breadth of the chemistry from the specifications to be tested.

With us, your students will get the results they deserve, from the exam board you trust.

You can find out about all our science qualifications at aqa.org.uk/science

1.2 Support and resources to help you teach

We know that support and resources are vital for your teaching and that you have limited time to find or develop good quality materials. So we've worked with experienced teachers to provide you with a range of resources that will help you confidently plan, teach and prepare for exams.

Teaching resources

We have too many chemistry resources to list here, so visit aqa.org.uk/7405 to see them all. They include:

- additional practice papers to help students prepare for exams
- guidance on how to plan both the AS and A-level courses with schemes of work for co-teaching
- an additional scheme of work showing relevant applications of the theory outlined in the specifications
- several AQA-approved student textbooks, reviewed by experienced senior examiners
- guidance on maths skills requirements with additional support from Exampro
- resources to support new content with detailed lesson plans written by experienced teachers
- training courses to help you deliver AQA Chemistry qualifications
- subject expertise courses for all teachers, from newly-qualified teachers who are just getting started to experienced teachers looking for fresh inspiration.

Preparing for exams

Visit aqa.org.uk/7405 for everything you need to prepare for our exams, including:

- past papers, mark schemes and examiners' reports
- specimen papers and mark schemes for new courses
- Exampro: a searchable bank of past AQA exam questions
- exemplar student answers with examiner commentaries.

Analyse your students' results with Enhanced Results Analysis (ERA)

Find out which questions were the most challenging, how the results compare to previous years and where your students need to improve. ERA, our free online results analysis tool, will help you see where to focus your teaching. Register at aqa.org.uk/era

For information about results, including maintaining standards over time, grade boundaries and our post-results services, visit aqa.org.uk/results

Keep your skills up-to-date with professional development

Wherever you are in your career, there's always something new to learn. As well as subject-specific training, we offer a range of courses to help boost your skills.

- Improve your teaching skills in areas including differentiation, teaching literacy and meeting Ofsted requirements.
- Prepare for a new role with our leadership and management courses.

You can attend a course at venues around the country, in your school or online – whatever suits your needs and availability. Find out more at coursesandevents.aqa.org.uk

Get help and support

Visit our website for information, guidance, support and resources at aqa.org.uk/7405

You can talk directly to the Chemistry subject team

E: Alevelscience@aqa.org.uk

T: 01483 477 756

2 Specification at a glance

These qualifications are linear. Linear means that students will sit all the AS exams at the end of their AS course and all the A-level exams at the end of their A-level course.

2.1 Subject content

2.2 AS

Assessments

Paper 1

What's assessed

- Relevant Physical chemistry topics (sections 3.1.1 to 3.1.4, 3.1.6 and 3.1.7)
- Inorganic chemistry (Section 3.2.1 to 3.2.3)
- Relevant practical skills

How it’s assessed

- written exam: 1 hour 30 minutes
- 80 marks
- 50% of the AS

Questions

65 marks of short and long answer questions

15 marks of multiple choice questions

+

Paper 2

What's assessed

- Relevant Physical chemistry topics (sections 3.1.2 to 3.1.6)
- Organic chemistry (Section 3.3.1 to 3.3.6)
- Relevant practical skills

How it’s assessed

- written exam: 1 hour 30 minutes
- 80 marks
- 50% of the AS

Questions

65 marks of short and long answer questions

15 marks of multiple choice questions

2.3 A-level

Assessments

Paper 1	Paper 2	Paper 3
What's assessed • Relevant Physical chemistry topics (sections 3.1.1 to 3.1.4, 3.1.6 to 3.1.8 and 3.1.10 to 3.1.12) • Inorganic chemistry (Section 3.2) • Relevant practical skills	**What's assessed** • Relevant Physical chemistry topics (sections 3.1.2 to 3.1.6 and 3.1.9) • Organic chemistry (Section 3.3) • Relevant practical skills	**What's assessed** • Any content • Any practical skills
How it's assessed • written exam: 2 hours • 105 marks • 35% of A-level	**How it's assessed** • written exam: 2 hours • 105 marks • 35% of A-level	**How it's assessed** • written exam: 2 hours • 90 marks • 30% of A-level
Questions 105 marks of short and long answer questions	**Questions** 105 marks of short and long answer questions	**Questions** 40 marks of questions on practical techniques and data analysis 20 marks of questions testing across the specification 30 marks of multiple choice questions

3 Subject content

Sections 3.1.1 to 3.1.7 of the Physical chemistry content, sections 3.2.1 to 3.2.3 of the Inorganic chemistry content and sections 3.3.1 to 3.3.6 of the Organic chemistry content are designed to be covered in the first year of the A-level and are also the AS subject content. So you can teach AS and A-level together.

Each section begins with an overview, which puts the topic into a broader chemical context and encourages understanding of the place of each topic within the subject. The overviews are intended to encourage an overarching approach to both the teaching and learning of topic areas. As such, they will not be directly assessed.

These specifications are presented in a two-column format. The left-hand column contains the specification content that all students must cover, and that can be assessed in the written papers. The right-hand column exemplifies the opportunities for skills to be developed throughout the course. As such, knowledge of individual experiments on the right-hand side is **not** assumed knowledge for the assessment.

The codes in the right-hand column refer to the skills in the relevant appendices. **MS** refers to the Mathematical skills, **AT** refers to the Apparatus and techniques and **PS** refers to the Practical skills.

3.1 Physical chemistry

3.1.1 Atomic structure

The chemical properties of elements depend on their atomic structure and in particular on the arrangement of electrons around the nucleus. The arrangement of electrons in orbitals is linked to the way in which elements are organised in the Periodic Table. Chemists can measure the mass of atoms and molecules to a high degree of accuracy in a mass spectrometer. The principles of operation of a modern mass spectrometer are studied.

3.1.1.1 Fundamental particles

Content	Opportunities for skills development
Appreciate that knowledge and understanding of atomic structure has evolved over time. Protons, neutrons and electrons: relative charge and relative mass. An atom consists of a nucleus containing protons and neutrons surrounded by electrons.	

3.1.1.2 Mass number and isotopes

Content	Opportunities for skills development
Mass number (*A*) and atomic (proton) number (*Z*). **Students should be able to:** • determine the number of fundamental particles in atoms and ions using mass number, atomic number and charge • explain the existence of isotopes. The principles of a simple time of flight (TOF) mass spectrometer, limited to ionisation, acceleration to give all ions constant kinetic energy, ion drift, ion detection, data analysis. The mass spectrometer gives accurate information about relative isotopic mass and also about the relative abundance of isotopes. Mass spectrometry can be used to identify elements. Mass spectrometry can be used to determine relative molecular mass. **Students should be able to:** • interpret simple mass spectra of elements • calculate relative atomic mass from isotopic abundance, limited to mononuclear ions.	**MS 1.1** Students report calculations to an appropriate number of significant figures, given raw data quoted to varying numbers of significant figures. **MS 1.2** Students calculate weighted means eg calculation of an atomic mass based on supplied isotopic abundances. **MS 3.1** Students interpret and analyse spectra.

3.1.1.3 Electron configuration

Content	Opportunities for skills development
Electron configurations of atoms and ions up to *Z* = 36 in terms of shells and sub-shells (orbitals) s, p and d. Ionisation energies. **Students should be able to:** • define first ionisation energy • write equations for first and successive ionisation energies • explain how first and successive ionisation energies in Period 3 (Na–Ar) and in Group 2 (Be–Ba) give evidence for electron configuration in sub-shells and in shells.	

3.1.2 Amount of substance

When chemists measure out an amount of a substance, they use an amount in moles. The mole is a useful quantity because one mole of a substance always contains the same number of entities of the substance. An amount in moles can be measured out by mass in grams, by volume in dm^3 of a solution of known concentration and by volume in dm^3 of a gas.

3.1.2.1 Relative atomic mass and relative molecular mass

Content	Opportunities for skills development
Relative atomic mass and relative molecular mass in terms of ^{12}C. The term relative formula mass will be used for ionic compounds. **Students should be able to:** • define relative atomic mass (A_r) • define relative molecular mass (M_r).	

3.1.2.2 The mole and the Avogadro constant

Content	Opportunities for skills development
The Avogadro constant as the number of particles in a mole. The mole as applied to electrons, atoms, molecules, ions, formulas and equations. The concentration of a substance in solution, measured in mol dm^{-3}. **Students should be able to carry out calculations:** • using the Avogadro constant • using mass of substance, M_r, and amount in moles • using concentration, volume and amount of substance in a solution. Students will **not** be expected to recall the value of the Avogadro constant.	**MS 0.1** Students carry out calculations using numbers in standard and ordinary form eg using the Avogadro constant. **MS 0.4** Students carry out calculations using the Avogadro constant. **MS 1.1** Students report calculations to an appropriate number of significant figures, given raw data quoted to varying numbers of significant figures. Students understand that calculated results can only be reported to the limits of the least accurate measurement.

3.1.2.3 The ideal gas equation

Content	Opportunities for skills development
The ideal gas equation $pV = nRT$ with the variables in SI units. **Students should be able to** use the equation in calculations. Students will **not** be expected to recall the value of the gas constant, R.	**AT a, b and k** **PS 3.2** Students could be asked to find the M_r of a volatile liquid. **MS 0.0** Students understand that the correct units need to be in $pV = nRT$. **MS 2.2, 2.3 and 2.4** Students carry out calculations with the ideal gas equation, including rearranging the ideal gas equation to find unknown quantities.

3.1.2.4 Empirical and molecular formula

Content	Opportunities for skills development
Empirical formula is the simplest whole number ratio of atoms of each element in a compound. Molecular formula is the actual number of atoms of each element in a compound. The relationship between empirical formula and molecular formula. **Students should be able to:** • calculate empirical formula from data giving composition by mass or percentage by mass • calculate molecular formula from the empirical formula and relative molecular mass.	**AT a and k** **PS 2.3 and 3.3** Students could be asked to find the empirical formula of a metal oxide.

3.1.2.5 Balanced equations and associated calculations

Content	Opportunities for skills development
Equations (full and ionic). Percentage atom economy is: $\frac{\text{molecular mass of desired product}}{\text{sum of molecular masses of all reactants}} \times 100$ Economic, ethical and environmental advantages for society and for industry of developing chemical processes with a high atom economy. **Students should be able to:** • write balanced equations for reactions studied • balance equations for unfamiliar reactions when reactants and products are specified. **Students should be able to** use balanced equations to calculate: • masses • volumes of gases • percentage yields • percentage atom economies • concentrations and volumes for reactions in solutions.	**AT a, d, e, f and k** **PS 4.1** Students could be asked to find: • the concentration of ethanoic acid in vinegar • the mass of calcium carbonate in an indigestion tablet • the M_r of $MHCO_3$ • the M_r of succinic acid • the mass of aspirin in an aspirin tablet • the yield for the conversion of magnesium to magnesium oxide • the M_r of a hydrated salt (eg magnesium sulfate) by heating to constant mass. **AT a and k** Students could be asked to find the percentage conversion of a Group 2 carbonate to its oxide by heat. **AT d, e, f and k** Students could be asked to determine the number of moles of water of crystallisation in a hydrated salt by titration. **MS 0.2** Students construct and/or balance equations using ratios. Students calculate percentage yields and atom economies of reactions. **MS 1.2 and 1.3** Students select appropriate titration data (ie identify outliers) in order to calculate mean titres. Students determine uncertainty when two burette readings are used to calculate a titre value.
Required practical 1 Make up a volumetric solution and carry out a simple acid–base titration.	

3.1.3 Bonding

The physical and chemical properties of compounds depend on the ways in which the compounds are held together by chemical bonds and by intermolecular forces. Theories of bonding explain how atoms or ions are held together in these structures. Materials scientists use knowledge of structure and bonding to engineer new materials with desirable properties. These new materials may offer new applications in a range of different modern technologies.

3.1.3.1 Ionic bonding

Content	Opportunities for skills development
Ionic bonding involves electrostatic attraction between oppositely charged ions in a lattice. The formulas of compound ions eg sulfate, hydroxide, nitrate, carbonate and ammonium. **Students should be able to:** • predict the charge on a simple ion using the position of the element in the Periodic Table • construct formulas for ionic compounds.	

3.1.3.2 Nature of covalent and dative covalent bonds

Content	Opportunities for skills development
A single covalent bond contains a shared pair of electrons. Multiple bonds contain multiple pairs of electrons. A co-ordinate (dative covalent) bond contains a shared pair of electrons with both electrons supplied by one atom. **Students should be able to represent:** • a covalent bond using a line • a co-ordinate bond using an arrow.	

3.1.3.3 Metallic bonding

Content	Opportunities for skills development
Metallic bonding involves attraction between delocalised electrons and positive ions arranged in a lattice.	

3.1.3.4 Bonding and physical properties

Content	Opportunities for skills development
The four types of crystal structure: • ionic • metallic • macromolecular (giant covalent) • molecular. The structures of the following crystals as examples of these four types of crystal structure: • diamond • graphite • ice • iodine • magnesium • sodium chloride. **Students should be able to:** • relate the melting point and conductivity of materials to the type of structure and the bonding present • explain the energy changes associated with changes of state • draw diagrams to represent these structures involving specified numbers of particles.	**AT a, b, h and k** **PS 1.1** Students could be asked to find the type of structure of unknowns by experiment (eg to test solubility, conductivity and ease of melting).

3.1.3.5 Shapes of simple molecules and ions

Content	Opportunities for skills development
Bonding pairs and lone (non-bonding) pairs of electrons as charge clouds that repel each other. Pairs of electrons in the outer shell of atoms arrange themselves as far apart as possible to minimise repulsion. Lone pair–lone pair repulsion is greater than lone pair–bond pair repulsion, which is greater than bond pair–bond pair repulsion. The effect of electron pair repulsion on bond angles. **Students should be able to** explain the shapes of, and bond angles in, simple molecules and ions with up to six electron pairs (including lone pairs of electrons) surrounding the central atom.	**MS 0.3 and 4.1** Students could be given familiar and unfamiliar examples of species and asked to deduce the shape according to valence shell electron pair repulsion (VSEPR) principles.

3.1.3.6 Bond polarity

Content	Opportunities for skills development
Electronegativity as the power of an atom to attract the pair of electrons in a covalent bond. The electron distribution in a covalent bond between elements with different electronegativities will be unsymmetrical. This produces a polar covalent bond, and may cause a molecule to have a permanent dipole. **Students should be able to:** • use partial charges to show that a bond is polar • explain why some molecules with polar bonds do not have a permanent dipole.	

3.1.3.7 Forces between molecules

Content	Opportunities for skills development
Forces between molecules: • permanent dipole–dipole forces • induced dipole–dipole (van der Waals, dispersion, London) forces • hydrogen bonding. The melting and boiling points of molecular substances are influenced by the strength of these intermolecular forces. The importance of hydrogen bonding in the low density of ice and the anomalous boiling points of compounds. **Students should be able to:** • explain the existence of these forces between familiar and unfamiliar molecules • explain how melting and boiling points are influenced by these intermolecular forces.	**AT d and k** **PS 1.2** Students could try to deflect jets of various liquids from burettes to investigate the presence of different types and relative size of intermolecular forces.

3.1.4 Energetics

The enthalpy change in a chemical reaction can be measured accurately. It is important to know this value for chemical reactions that are used as a source of heat energy in applications such as domestic boilers and internal combustion engines.

3.1.4.1 Enthalpy change

Content	Opportunities for skills development
Reactions can be endothermic or exothermic. Enthalpy change (ΔH) is the heat energy change measured under conditions of constant pressure. Standard enthalpy changes refer to standard conditions ie 100 kPa and a stated temperature (eg $\Delta H_{298}^{\ominus}$). **Students should be able to:** • define standard enthalpy of combustion ($\Delta_c H^{\ominus}$) • define standard enthalpy of formation ($\Delta_f H^{\ominus}$).	

3.1.4.2 Calorimetry

Content	Opportunities for skills development
The heat change, q, in a reaction is given by the equation $q = mc\Delta T$ where m is the mass of the substance that has a temperature change ΔT and a specific heat capacity c. **Students should be able to:** • use this equation to calculate the molar enthalpy change for a reaction • use this equation in related calculations. Students will not be expected to recall the value of the specific heat capacity, c, of a substance.	**MS 0.0 and 1.1** Students understand that the correct units need to be used in $q = mc\Delta T$ Students report calculations to an appropriate number of significant figures, given raw data quoted to varying numbers of significant figures. Students understand that calculated results can only be reported to the limits of the least accurate measurement.
Required practical 2 Measurement of an enthalpy change.	**AT a and k** **PS 2.4, 3.1, 3.2, 3.3 and 4.1** Students could be asked to find ΔH for a reaction by calorimetry. Examples of reactions could include: • dissolution of potassium chloride • dissolution of sodium carbonate • neutralising NaOH with HCl • displacement reaction between $CuSO_4$ + Zn • combustion of alcohols.

3.1.4.3 Applications of Hess's law

Content	Opportunities for skills development
Hess's law. **Students should be able to** use Hess's law to perform calculations, including calculation of enthalpy changes for reactions from enthalpies of combustion or from enthalpies of formation.	**MS 2.4** Students carry out Hess's law calculations. **AT a and k** **PS 2.4, 3.2 and 4.1** Students could be asked to find Δ*H* for a reaction using Hess's law and calorimetry, then present data in appropriate ways. Examples of reactions could include: • thermal decomposition of $NaHCO_3$ • hydration of $MgSO_4$ • hydration of $CuSO_4$

3.1.4.4 Bond enthalpies

Content	Opportunities for skills development
Mean bond enthalpy. **Students should be able to:** • define the term mean bond enthalpy • use mean bond enthalpies to calculate an approximate value of Δ*H* for reactions in the gaseous phase • explain why values from mean bond enthalpy calculations differ from those determined using Hess's law.	**MS 1.2** Students understand that bond enthalpies are mean values across a range of compounds containing that bond.

3.1.5 Kinetics

The study of kinetics enables chemists to determine how a change in conditions affects the speed of a chemical reaction. Whilst the reactivity of chemicals is a significant factor in how fast chemical reactions proceed, there are variables that can be manipulated in order to speed them up or slow them down.

3.1.5.1 Collision theory

Content	Opportunities for skills development
Reactions can only occur when collisions take place between particles having sufficient energy. This energy is called the activation energy. **Students should be able to:** • define the term activation energy • explain why most collisions do not lead to a reaction.	

3.1.5.2 Maxwell–Boltzmann distribution

Content	Opportunities for skills development
Maxwell–Boltzmann distribution of molecular energies in gases. **Students should be able to** draw and interpret distribution curves for different temperatures.	

3.1.5.3 Effect of temperature on reaction rate

Content	Opportunities for skills development
Meaning of the term rate of reaction. The qualitative effect of temperature changes on the rate of reaction. **Students should be able to** use the Maxwell–Boltzmann distribution to explain why a small temperature increase can lead to a large increase in rate.	**AT a, b, k and l** **PS 2.4 and 3.1** Students could investigate the effect of temperature on the rate of reaction of sodium thiosulfate and hydrochloric acid by an initial rate method. **Research opportunity** Students could investigate how knowledge and understanding of the factors that affect the rate of chemical reaction have changed methods of storage and cooking of food.
Required practical 3 Investigation of how the rate of a reaction changes with temperature.	

3.1.5.4 Effect of concentration and pressure

Content	Opportunities for skills development
The qualitative effect of changes in concentration on collision frequency. The qualitative effect of a change in the pressure of a gas on collision frequency. **Students should be able to** explain how a change in concentration or a change in pressure influences the rate of a reaction.	**AT a, e, k and i** Students could investigate the effect of changing the concentration of acid on the rate of a reaction of calcium carbonate and hydrochloric acid by a continuous monitoring method.

3.1.5.5 Catalysts

Content	Opportunities for skills development
A catalyst is a substance that increases the rate of a chemical reaction without being changed in chemical composition or amount. Catalysts work by providing an alternative reaction route of lower activation energy. **Students should be able to** use a Maxwell–Boltzmann distribution to help explain how a catalyst increases the rate of a reaction involving a gas.	

3.1.6 Chemical equilibria, Le Chatelier's principle and K_c

In contrast with kinetics, which is a study of how quickly reactions occur, a study of equilibria indicates how far reactions will go. Le Chatelier's principle can be used to predict the effects of changes in temperature, pressure and concentration on the yield of a reversible reaction. This has important consequences for many industrial processes. The further study of the equilibrium constant, K_c, considers how the mathematical expression for the equilibrium constant enables us to calculate how an equilibrium yield will be influenced by the concentration of reactants and products.

3.1.6.1 Chemical equilibria and Le Chatelier's principle

Content	Opportunities for skills development
Many chemical reactions are reversible. In a reversible reaction at equilibrium: • forward and reverse reactions proceed at equal rates • the concentrations of reactants and products remain constant. Le Chatelier's principle. Le Chatelier's principle can be used to predict the effects of changes in temperature, pressure and concentration on the position of equilibrium in homogeneous reactions. A catalyst does not affect the position of equilibrium. **Students should be able to:** • use Le Chatelier's principle to predict qualitatively the effect of changes in temperature, pressure and concentration on the position of equilibrium • explain why, for a reversible reaction used in an industrial process, a compromise temperature and pressure may be used.	**PS 1.1** Students could carry out test-tube equilibrium shifts to show the effect of concentration and temperature (eg $Cu(H_2O)_6^{2+}$ with concentrated HCl).

3.1.6.2 Equilibrium constant K_c for homogeneous systems

Content	Opportunities for skills development
The equilibrium constant K_c is deduced from the equation for a reversible reaction. The concentration, in mol dm^{-3}, of a species X involved in the expression for K_c is represented by [X] The value of the equilibrium constant is not affected either by changes in concentration or addition of a catalyst. **Students should be able to:** • construct an expression for K_c for a homogeneous system in equilibrium • calculate a value for K_c from the equilibrium concentrations for a homogeneous system at constant temperature • perform calculations involving K_c • predict the qualitative effects of changes of temperature on the value of K_c	**MS 0.3** Students estimate the effect of changing experimental parameters on a measurable value eg how the value of K_c would change with temperature, given different specified conditions. **MS 1.1** Students report calculations to an appropriate number of significant figures, given raw data quoted to varying numbers of significant figures. Students understand that calculated results can only be reported to the limits of the least accurate measurement. **MS 2.2 and 2.3** Students calculate the concentration of a reagent at equilibrium. Students calculate the value of an equilibrium constant K_c **PS 2.3** Students could determine the equilibrium constant, K_c, for the reaction of ethanol with ethanoic acid in the presence of a strong acid catalyst to ethyl ethanoate.

3.1.7 Oxidation, reduction and redox equations

Redox reactions involve a transfer of electrons from the reducing agent to the oxidising agent. The change in the oxidation state of an element in a compound or ion is used to identify the element that has been oxidised or reduced in a given reaction. Separate half-equations are written for the oxidation or reduction processes. These half-equations can then be combined to give an overall equation for any redox reaction.

Content	Opportunities for skills development
Oxidation is the process of electron loss and oxidising agents are electron acceptors. Reduction is the process of electron gain and reducing agents are electron donors. The rules for assigning oxidation states. **Students should be able to:** • work out the oxidation state of an element in a compound or ion from the formula • write half-equations identifying the oxidation and reduction processes in redox reactions • combine half-equations to give an overall redox equation.	

3.1.8 Thermodynamics (A-level only)

The further study of thermodynamics builds on the Energetics section and is important in understanding the stability of compounds and why chemical reactions occur. Enthalpy change is linked with entropy change enabling the free-energy change to be calculated.

3.1.8.1 Born–Haber cycles (A-level only)

Content	Opportunities for skills development
Lattice enthalpy can be defined as either enthalpy of lattice dissociation or enthalpy of lattice formation. Born–Haber cycles are used to calculate lattice enthalpies using the following data: • enthalpy of formation • ionisation energy • enthalpy of atomisation • bond enthalpy • electron affinity. **Students should be able to:** • define each of the above terms and lattice enthalpy • construct Born–Haber cycles to calculate lattice enthalpies using these enthalpy changes • construct Born–Haber cycles to calculate one of the other enthalpy changes • compare lattice enthalpies from Born–Haber cycles with those from calculations based on a perfect ionic model to provide evidence for covalent character in ionic compounds. Cycles are used to calculate enthalpies of solution for ionic compounds from lattice enthalpies and enthalpies of hydration. **Students should be able to:** • define the term enthalpy of hydration • perform calculations of an enthalpy change using these cycles.	

3.1.8.2 Gibbs free-energy change, ΔG, and entropy change, ΔS (A-level only)

Content	Opportunities for skills development
ΔH, whilst important, is not sufficient to explain feasible change. The concept of increasing disorder (entropy change, ΔS). ΔS accounts for the above deficiency, illustrated by physical changes and chemical changes. The balance between entropy and enthalpy determines the feasibility of a reaction given by the relationship: $\Delta G = \Delta H - T\Delta S$ (derivation not required). For a reaction to be feasible, the value of ΔG must be zero or negative. **Students should be able to:** • calculate entropy changes from absolute entropy values • use the relationship $\Delta G = \Delta H - T\Delta S$ to determine how ΔG varies with temperature • use the relationship $\Delta G = \Delta H - T\Delta S$ to determine the temperature at which a reaction becomes feasible.	**AT a, b and k** **PS 3.2** Students could be asked to find ΔS for vaporization of water using a kettle. **MS 2.2, 2.3 and 2.4** Students rearrange the equation $\Delta G = \Delta H - T\Delta S$ to find unknown values. **MS 3.3** Students determine ΔS and ΔH from a graph of ΔG versus T.

3.1.9 Rate equations (A-level only)

In rate equations, the mathematical relationship between rate of reaction and concentration gives information about the mechanism of a reaction that may occur in several steps.

3.1.9.1 Rate equations (A-level only)

Content	Opportunities for skills development
The rate of a chemical reaction is related to the concentration of reactants by a rate equation of the form: $Rate = k[A]^m [B]^n$ where *m* and *n* are the orders of reaction with respect to reactants A and B and *k* is the rate constant. The orders *m* and *n* are restricted to the values 0, 1, and 2. The rate constant *k* varies with temperature as shown by the equation: $k = Ae^{-E_a/RT}$ where A is a constant, known as the Arrhenius constant, E_a is the activation energy and *T* is the temperature in K. **Students should be able to:** • define the terms order of reaction and rate constant • perform calculations using the rate equation • explain the qualitative effect of changes in temperature on the rate constant *k* • perform calculations using the equation $k = Ae^{-E_a/RT}$ • understand that the equation $k = Ae^{-E_a/RT}$ can be rearranged into the form $\ln k = -E_a/RT + \ln A$ and know how to use this rearranged equation with experimental data to plot a straight line graph with slope $-E_a/R$ These equations and the gas constant, *R*, will be given when required.	**MS 0.0 and 2.4** Students use given rate data and deduce a rate equation, then use some of the data to calculate the rate constant including units. Rate equations could be given and students asked to calculate rate constant or rate. **MS 3.3 and 3.4** Students use a graph of concentration–time and calculate the rate constant of a zero-order reaction by determination of the gradient.

3.1.9.2 Determination of rate equation (A-level only)

Content	Opportunities for skills development
The rate equation is an experimentally determined relationship. The orders with respect to reactants can provide information about the mechanism of a reaction. **Students should be able to:** • use concentration–time graphs to deduce the rate of a reaction • use initial concentration–time data to deduce the initial rate of a reaction • use rate–concentration data or graphs to deduce the order (0, 1 or 2) with respect to a reactant • derive the rate equation for a reaction from the orders with respect to each of the reactants • use the orders with respect to reactants to provide information about the rate determining/limiting step of a reaction.	**AT a, b, k and l** **PS 2.4 and 3.1** Students could determine the order of reaction for a reactant in the iodine clock reaction. **MS 3.1** Students could be given data to plot and interpret in terms of order with respect to a reactant. Alternatively, students could just be given appropriate graphs and asked to derive order(s). **MS 3.3 and 3.4** Students calculate the rate constant of a zero-order reaction by determining the gradient of a concentration–time graph. **MS 3.5** Students plot concentration–time graphs from collected or supplied data and draw an appropriate best-fit curve. Students draw tangents to such curves to deduce rates at different times.
Required practical 7 Measuring the rate of reaction: • by an initial rate method • by a continuous monitoring method.	

3.1.10 Equilibrium constant K_p for homogeneous systems (A-level only)

The further study of equilibria considers how the mathematical expression for the equilibrium constant K_p enables us to calculate how an equilibrium yield will be influenced by the partial pressures of reactants and products. This has important consequences for many industrial processes.

Content	Opportunities for skills development
The equilibrium constant K_p is deduced from the equation for a reversible reaction occurring in the gas phase. K_p is the equilibrium constant calculated from partial pressures for a system at constant temperature. **Students should be able to:** • derive partial pressure from mole fraction and total pressure • construct an expression for K_p for a homogeneous system in equilibrium • perform calculations involving K_p • predict the qualitative effects of changes in temperature and pressure on the position of equilibrium • predict the qualitative effects of changes in temperature on the value of K_p • understand that, whilst a catalyst can affect the rate of attainment of an equilibrium, it does not affect the value of the equilibrium constant.	**MS 1.1** Students report calculations to an appropriate number of significant figures, given raw data quoted to varying numbers of significant figures. Students understand that calculated results can only be reported to the limits of the least accurate measurement. **MS 2.2 and 2.3** Students calculate the partial pressures of reactants and products at equilibrium. Students calculate the value of an equilibrium constant K_p

3.1.11 Electrode potentials and electrochemical cells (A-level only)

Redox reactions take place in electrochemical cells where electrons are transferred from the reducing agent to the oxidising agent indirectly via an external circuit. A potential difference is created that can drive an electric current to do work. Electrochemical cells have very important commercial applications as a portable supply of electricity to power electronic devices such as mobile phones, tablets and laptops. On a larger scale, they can provide energy to power a vehicle.

3.1.11.1 Electrode potentials and cells (A-level only)

Content	Opportunities for skills development
IUPAC convention for writing half-equations for electrode reactions. The conventional representation of cells. Cells are used to measure electrode potentials by reference to the standard hydrogen electrode. The importance of the conditions when measuring the electrode potential, *E* (Nernst equation **not** required). Standard electrode potential, $E^\ominus$, refers to conditions of 298 K, 100 kPa and 1.00 mol dm^{-3} solution of ions. Standard electrode potentials can be listed as an electrochemical series. **Students should be able to:** • use $E^\ominus$ values to predict the direction of simple redox reactions • calculate the EMF of a cell • write and apply the conventional representation of a cell.	**AT j and k** **PS 1.1** Students could make simple cells and use them to measure unknown electrode potentials. **AT a, b, j and k** **PS 2.1 and 2.4** Students could be asked to plan and carry out an experiment to investigate the effect of changing conditions, such as concentration or temperature, in a voltaic cell such as $Zn|Zn^{2+}||Cu^{2+}|Cu$ **AT j and k** **PS 2.2** Students could use $E^\ominus$ values to predict the direction of simple redox reactions, then test these predictions by simple test-tube reactions.
Required practical 8 Measuring the EMF of an electrochemical cell.	

3.1.11.2 Commercial applications of electrochemical cells (A-level only)

Content	Opportunities for skills development
Electrochemical cells can be used as a commercial source of electrical energy. The simplified electrode reactions in a lithium cell: Positive electrode: $Li^+ + CoO_2 + e^- \rightarrow Li^+[CoO_2]^-$ Negative electrode: $Li \rightarrow Li^+ + e^-$ Cells can be non-rechargeable (irreversible), rechargeable or fuel cells. Fuel cells are used to generate an electric current and do not need to be electrically recharged. The electrode reactions in an alkaline hydrogen–oxygen fuel cell. The benefits and risks to society associated with using these cells. **Students should be able to:** • use given electrode data to deduce the reactions occurring in non-rechargeable and rechargeable cells • deduce the EMF of a cell • explain how the electrode reactions can be used to generate an electric current.	**Research opportunity** Students could investigate how knowledge and understanding of electrochemical cells has evolved from the first voltaic battery.

3.1.12 Acids and bases (A-level only)

Acids and bases are important in domestic, environmental and industrial contexts. Acidity in aqueous solutions is caused by hydrogen ions and a logarithmic scale, pH, has been devised to measure acidity. Buffer solutions, which can be made from partially neutralised weak acids, resist changes in pH and find many important industrial and biological applications.

3.1.12.1 Brønsted–Lowry acid–base equilibria in aqueous solution (A-level only)

Content	Opportunities for skills development
An acid is a proton donor. A base is a proton acceptor. Acid–base equilibria involve the transfer of protons.	

3.1.12.2 Definition and determination of pH (A-level only)

Content	Opportunities for skills development
The concentration of hydrogen ions in aqueous solution covers a very wide range. Therefore, a logarithmic scale, the pH scale, is used as a measure of hydrogen ion concentration. $\mathrm{pH} = -\log_{10}[\mathrm{H}^+]$ **Students should be able to:** • convert concentration of hydrogen ions into pH and vice versa • calculate the pH of a solution of a strong acid from its concentration.	**MS 0.4** Students carry out pH calculations. **MS 2.5** Students could be given concentration values and asked to calculate pH or vice versa.

3.1.12.3 The ionic product of water, K_W (A-level only)

Content	Opportunities for skills development
Water is slightly dissociated. K_W is derived from the equilibrium constant for this dissociation. $K_W = [\mathrm{H}^+][\mathrm{OH}^-]$ The value of K_W varies with temperature. **Students should be able to** use K_W to calculate the pH of a strong base from its concentration.	**MS 0.1** Students use an appropriate number of decimal places in pH calculations. Students understand standard form when applied to areas such as (but not limited to) K_W **MS 2.2** Students use $K_W = [\mathrm{H}^+][\mathrm{OH}^-]$ to find the pH of strong bases.

3.1.12.4 Weak acids and bases K_a for weak acids (A-level only)

Content	Opportunities for skills development
Weak acids and weak bases dissociate only slightly in aqueous solution. K_a is the dissociation constant for a weak acid. $pK_a = -\log_{10} K_a$ **Students should be able to:** • construct an expression for K_a • perform calculations relating the pH of a weak acid to the concentration of the acid and the dissociation constant, K_a • convert K_a into pK_a and vice versa.	**MS 0.0** Students carry out pK_a calculations and give appropriate units. **MS 0.1** Students understand standard form when applied to areas such as (but not limited to) K_a **AT a, c, d, e, f and k** **PS 2.3** Students could calculate K_a of a weak acid by measuring the pH at half neutralisation.

3.1.12.5 pH curves, titrations and indicators (A-level only)

Content	Opportunities for skills development
Titrations of acids with bases. **Students should be able to** perform calculations for these titrations based on experimental results. Typical pH curves for acid–base titrations in all combinations of weak and strong monoprotic acids and bases. **Students should be able to:** • sketch and explain the shapes of typical pH curves • use pH curves to select an appropriate indicator.	**MS 3.2** **AT a, c, d and k** **PS 3.2 and 4.1** Students could plot pH curves to show how pH changes during reactions.
Required practical 9 Investigate how pH changes when a weak acid reacts with a strong base and when a strong acid reacts with a weak base.	

3.1.12.6 Buffer action (A-level only)

Content	Opportunities for skills development
A buffer solution maintains an approximately constant pH, despite dilution or addition of small amounts of acid or base. Acidic buffer solutions contain a weak acid and the salt of that weak acid. Basic buffer solutions contain a weak base and the salt of that weak base. Applications of buffer solutions. **Students should be able to:** • explain qualitatively the action of acidic and basic buffers • calculate the pH of acidic buffer solutions.	**AT a, c, e and k** **PS 1.1** Students could be asked to prepare and test a buffer solution with a specific pH value. **MS 0.4** Students make appropriate mathematical approximations in buffer calculations.

3.2 Inorganic chemistry

3.2.1 Periodicity

The Periodic Table provides chemists with a structured organisation of the known chemical elements from which they can make sense of their physical and chemical properties. The historical development of the Periodic Table and models of atomic structure provide good examples of how scientific ideas and explanations develop over time.

3.2.1.1 Classification

Content	Opportunities for skills development
An element is classified as s, p, d or f block according to its position in the Periodic Table, which is determined by its proton number.	

3.2.1.2 Physical properties of Period 3 elements

Content	Opportunities for skills development
The trends in atomic radius, first ionisation energy and melting point of the elements Na–Ar The reasons for these trends in terms of the structure of and bonding in the elements. **Students should be able to:** • explain the trends in atomic radius and first ionisation energy • explain the melting point of the elements in terms of their structure and bonding.	

3.2.2 Group 2, the alkaline earth metals

The elements in Group 2 are called the alkaline earth metals. The trends in the solubilities of the hydroxides and the sulfates of these elements are linked to their use. Barium sulfate, magnesium hydroxide and magnesium sulfate have applications in medicines whilst calcium hydroxide is used in agriculture to change soil pH, which is essential for good crop production and maintaining the food supply.

Content	Opportunities for skills development
The trends in atomic radius, first ionisation energy and melting point of the elements Mg–Ba **Students should be able to:** • explain the trends in atomic radius and first ionisation energy • explain the melting point of the elements in terms of their structure and bonding. The reactions of the elements Mg–Ba with water. The use of magnesium in the extraction of titanium from $TiCl_4$ The relative solubilities of the hydroxides of the elements Mg–Ba in water. $Mg(OH)_2$ is sparingly soluble. The use of $Mg(OH)_2$ in medicine and of $Ca(OH)_2$ in agriculture. The use of CaO or $CaCO_3$ to remove SO_2 from flue gases. The relative solubilities of the sulfates of the elements Mg–Ba in water. $BaSO_4$ is insoluble. The use of acidified $BaCl_2$ solution to test for sulfate ions. The use of $BaSO_4$ in medicine. **Students should be able to** explain why $BaCl_2$ solution is used to test for sulfate ions and why it is acidified.	**AT c and k** **PS 2.2** Students could test the reactions of Mg–Ba with water and Mg with steam and record their results. **AT d and k** **PS 2.2** Students could test the solubility of Group 2 hydroxides by mixing solutions of soluble Group 2 salts with sodium hydroxide and record their results. Students could test the solubility of Group 2 sulfates by mixing solutions of soluble Group 2 salts with sulfuric acid and record their results. Students could test for sulfate ions using acidified barium chloride and record their results. **Research opportunity** Students could investigate the use of $BaSO_4$ in medicine.

3.2.3 Group 7(17), the halogens

The halogens in Group 7 are very reactive non-metals. Trends in their physical properties are examined and explained. Fluorine is too dangerous to be used in a school laboratory but the reactions of chlorine are studied. Challenges in studying the properties of elements in this group include explaining the trends in ability of the halogens to behave as oxidising agents and the halide ions to behave as reducing agents.

3.2.3.1 Trends in properties

Content	Opportunities for skills development
The trends in electronegativity and boiling point of the halogens. **Students should be able to:** • explain the trend in electronegativity • explain the trend in the boiling point of the elements in terms of their structure and bonding. The trend in oxidising ability of the halogens down the group, including displacement reactions of halide ions in aqueous solution. The trend in reducing ability of the halide ions, including the reactions of solid sodium halides with concentrated sulfuric acid. The use of acidified silver nitrate solution to identify and distinguish between halide ions. The trend in solubility of the silver halides in ammonia. **Students should be able to explain why:** • silver nitrate solution is used to identify halide ions • the silver nitrate solution is acidified • ammonia solution is added.	**AT d and k** **PS 2.2** Students could carry out test-tube reactions of solutions of the halogens (Cl_2, Br_2, I_2) with solutions containing their halide ions (eg KCl, KBr, KI). Students could record observations from reactions of NaCl, NaBr and NaI with concentrated sulfuric acid. Students could carry out tests for halide ions using acidified silver nitrate, including the use of ammonia to distinguish the silver halides formed.

3.2.3.2 Uses of chlorine and chlorate(I)

Content	Opportunities for skills development
The reaction of chlorine with water to form chloride ions and chlorate(I) ions. The reaction of chlorine with water to form chloride ions and oxygen. Appreciate that society assesses the advantages and disadvantages when deciding if chemicals should be added to water supplies. The use of chlorine in water treatment. Appreciate that the benefits to health of water treatment by chlorine outweigh its toxic effects. The reaction of chlorine with cold, dilute, aqueous NaOH and uses of the solution formed.	**Research opportunity** Students could investigate the treatment of drinking water with chlorine. Students could investigate the addition of sodium fluoride to water supplies.
Required practical 4 Carry out simple test-tube reactions to identify: • cations – Group 2, NH_4^+ • anions – Group 7 (halide ions), OH^-, CO_3^{2-}, SO_4^{2-}	

3.2.4 Properties of Period 3 elements and their oxides (A-level only)

The reactions of the Period 3 elements with oxygen are considered. The pH of the solutions formed when the oxides react with water illustrates further trends in properties across this period. Explanations of these reactions offer opportunities to develop an in-depth understanding of how and why these reactions occur.

Content	Opportunities for skills development
The reactions of Na and Mg with water. The trends in the reactions of the elements Na, Mg, Al, Si, P and S with oxygen, limited to the formation of Na_2O, MgO, Al_2O_3, SiO_2, P_4O_{10}, SO_2 and SO_3 The trend in the melting point of the highest oxides of the elements Na–S The reactions of the oxides of the elements Na–S with water, limited to Na_2O, MgO, Al_2O_3, SiO_2, P_4O_{10}, SO_2 and SO_3, and the pH of the solutions formed. The structures of the acids and the anions formed when P_4O_{10}, SO_2 and SO_3 react with water. **Students should be able to:** • explain the trend in the melting point of the oxides of the elements Na–S in terms of their structure and bonding • explain the trends in the reactions of the oxides with water in terms of the type of bonding present in each oxide • write equations for the reactions that occur between the oxides of the elements Na–S and given acids and bases.	**AT a, c and k** **PS 2.2** Students could carry out reactions of elements with oxygen and test the pH of the resulting oxides.

3.2.5 Transition metals (A-level only)

The 3d block contains 10 elements, all of which are metals. Unlike the metals in Groups 1 and 2, the transition metals Ti to Cu form coloured compounds and compounds where the transition metal exists in different oxidation states. Some of these metals are familiar as catalysts. The properties of these elements are studied in this section with opportunities for a wide range of practical investigations.

3.2.5.1 General properties of transition metals (A-level only)

Content	Opportunities for skills development
Transition metal characteristics of elements Ti–Cu arise from an incomplete d sub-level in atoms or ions. The characteristic properties include: • complex formation • formation of coloured ions • variable oxidation state • catalytic activity. A ligand is a molecule or ion that forms a co-ordinate bond with a transition metal by donating a pair of electrons. A complex is a central metal atom or ion surrounded by ligands. Co-ordination number is number of co-ordinate bonds to the central metal atom or ion.	

3.2.5.2 Substitution reactions (A-level only)

Content	Opportunities for skills development
H_2O, NH_3 and Cl^- can act as monodentate ligands. The ligands NH_3 and H_2O are similar in size and are uncharged. Exchange of the ligands NH_3 and H_2O occurs without change of co-ordination number (eg Co^{2+} and Cu^{2+}). Substitution may be incomplete (eg the formation of $[Cu(NH_3)_4(H_2O)_2]^{2+}$). The Cl^- ligand is larger than the uncharged ligands NH_3 and H_2O Exchange of the ligand H_2O by Cl^- can involve a change of co-ordination number (eg Co^{2+}, Cu^{2+} and Fe^{3+}). Ligands can be bidentate (eg $H_2NCH_2CH_2NH_2$ and $C_2O_4^{2-}$). Ligands can be multidentate (eg $EDTA^{4-}$). Haem is an iron(II) complex with a multidentate ligand. Oxygen forms a co-ordinate bond to Fe(II) in haemoglobin, enabling oxygen to be transported in the blood. Carbon monoxide is toxic because it replaces oxygen co-ordinately bonded to Fe(II) in haemoglobin. Bidentate and multidentate ligands replace monodentate ligands from complexes. This is called the chelate effect. **Students should be able to** explain the chelate effect, in terms of the balance between the entropy and enthalpy change in these reactions.	**AT d and k** **PS 1.2** Students could carry out test-tube reactions of complexes with monodentate, bidentate and multidentate ligands to compare ease of substitution. **AT d and k** **PS 2.2** Students could carry out test-tube reactions of solutions of metal aqua ions with ammonia or concentrated hydrochloric acid.

3.2.5.3 Shapes of complex ions (A-level only)

Content	Opportunities for skills development
Transition metal ions commonly form octahedral complexes with small ligands (eg H_2O and NH_3). Octahedral complexes can display *cis–trans* isomerism (a special case of *E–Z* isomerism) with monodentate ligands and optical isomerism with bidentate ligands. Transition metal ions commonly form tetrahedral complexes with larger ligands (eg Cl^-). Square planar complexes are also formed and can display *cis–trans* isomerism. Cisplatin is the *cis* isomer. Ag^+ forms the linear complex $[Ag(NH_3)_2]^+$ as used in Tollens' reagent.	**MS 4.1 and 4.2** Students understand and draw the shape of complex ions. **MS 4.3** Students understand the origin of *cis–trans* and optical isomerism. Students draw *cis–trans* and optical isomers. Students describe the types of stereoisomerism shown by molecules/complexes.

3.2.5.4 Formation of coloured ions (A-level only)

Content	Opportunities for skills development
Transition metal ions can be identified by their colour. Colour arises when some of the wavelengths of visible light are absorbed and the remaining wavelengths of light are transmitted or reflected. d electrons move from the ground state to an excited state when light is absorbed. The energy difference between the ground state and the excited state of the d electrons is given by: $\Delta E = h\nu = hc/\lambda$ Changes in oxidation state, co-ordination number and ligand alter ΔE and this leads to a change in colour. The absorption of visible light is used in spectroscopy. A simple colorimeter can be used to determine the concentration of coloured ions in solution.	**PS 3.1 and 3.2** Students could determine the concentration of a solution of copper(II) ions by colorimetry. **MS 3.1 and 3.2** Students determine the concentration of a solution from a graph of absorption versus concentration. **AT a, e and k** Students could determine the concentration of a coloured complex ion by colorimetry.

3.2.5.5 Variable oxidation states (A-level only)

Content	Opportunities for skills development
Transition elements show variable oxidation states. Vanadium species in oxidation states IV, III and II are formed by the reduction of vanadate(V) ions by zinc in acidic solution. The redox potential for a transition metal ion changing from a higher to a lower oxidation state is influenced by pH and by the ligand. The reduction of $[Ag(NH_3)_2]^+$ (Tollens' reagent) to metallic silver is used to distinguish between aldehydes and ketones. The redox titrations of Fe^{2+} and $C_2O_4^{2-}$ with MnO_4^- **Students should be able to** perform calculations for these titrations and similar redox reactions.	**AT d and k** **PS 1.2** Students could reduce vanadate(V) with zinc in acidic solution. **AT b, d and k** **PS 4.1** Students could carry out test-tube reactions of Tollens' reagent to distinguish aldehydes and ketones. **AT a, d, e and k** **PS 2.3, 3.2 and 3.3** Students could carry out redox titrations. Examples include, finding: • the mass of iron in an iron tablet • the percentage of iron in steel • the M_r of hydrated ammonium iron(II) sulfate • the M_r of ethanedioic acid • the concentration of H_2O_2 in hair bleach.

3.2.5.6 Catalysts (A-level only)

Content	Opportunities for skills development
Transition metals and their compounds can act as heterogeneous and homogeneous catalysts. A heterogeneous catalyst is in a different phase from the reactants and the reaction occurs at active sites on the surface. The use of a support medium to maximise the surface area of a heterogeneous catalyst and minimise the cost. V_2O_5 acts as a heterogeneous catalyst in the Contact process. Fe is used as a heterogeneous catalyst in the Haber process. Heterogeneous catalysts can become poisoned by impurities that block the active sites and consequently have reduced efficiency; this has a cost implication. A homogeneous catalyst is in the same phase as the reactants. When catalysts and reactants are in the same phase, the reaction proceeds through an intermediate species. **Students should be able to:** • explain the importance of variable oxidation states in catalysis • explain, with the aid of equations, how V_2O_5 acts as a catalyst in the Contact process • explain, with the aid of equations, how Fe^{2+} ions catalyse the reaction between I^- and $S_2O_8^{2-}$ • explain, with the aid of equations, how Mn^{2+} ions autocatalyse the reaction between $C_2O_4^{2-}$ and MnO_4^-	**AT d and k** **PS 4.1** Students could investigate Mn^{2+} as the autocatalyst in the reaction between ethanedioic acid and acidified potassium manganate(VII).

3.2.6 Reactions of ions in aqueous solution (A-level only)

The reactions of transition metal ions in aqueous solution provide a practical opportunity for students to show and to understand how transition metal ions can be identified by test-tube reactions in the laboratory.

Content	Opportunities for skills development
In aqueous solution, the following metal-aqua ions are formed: $[M(H_2O)_6]^{2+}$, limited to M = Fe and Cu $[M(H_2O)_6]^{3+}$, limited to M = Al and Fe The acidity of $[M(H_2O)_6]^{3+}$ is greater than that of $[M(H_2O)_6]^{2+}$ Some metal hydroxides show amphoteric character by dissolving in both acids and bases (eg hydroxides of Al^{3+}). **Students should be able to:** • explain, in terms of the charge/size ratio of the metal ion, why the acidity of $[M(H_2O)_6]^{3+}$ is greater than that of $[M(H_2O)_6]^{2+}$ • describe and explain the simple test-tube reactions of: $M^{2+}(aq)$ ions, limited to M = Fe and Cu, and of $M^{3+}(aq)$ ions, limited to M = Al and Fe, with the bases OH^-, NH_3 and CO_3^{2-}	**AT d and K** **PS 1.2** Students could carry out test-tube reactions of metal-aqua ions with NaOH, NH_3 and Na_2CO_3 **AT d and k** **PS 2.2** Students could carry out test-tube reactions to identify the positive and negative ions in this specification. **PS 1.1** Students could identify unknown substances using reagents.
Required practical 11 Carry out simple test-tube reactions to identify transition metal ions in aqueous solution.	

3.3 Organic chemistry

3.3.1 Introduction to organic chemistry

Organic chemistry is the study of the millions of covalent compounds of the element carbon.

These structurally diverse compounds vary from naturally occurring petroleum fuels to DNA and the molecules in living systems. Organic compounds also demonstrate human ingenuity in the vast range of synthetic materials created by chemists. Many of these compounds are used as drugs, medicines and plastics.

Organic compounds are named using the International Union of Pure and Applied Chemistry (IUPAC) system and the structure or formula of molecules can be represented in various different ways. Organic mechanisms are studied, which enable reactions to be explained.

In the search for sustainable chemistry, for safer agrochemicals and for new materials to match the desire for new technology, chemistry plays the dominant role.

3.3.1.1 Nomenclature

Content	Opportunities for skills development
Organic compounds can be represented by: • empirical formula • molecular formula • general formula • structural formula • displayed formula • skeletal formula. The characteristics of a homologous series, a series of compounds containing the same functional group. IUPAC rules for nomenclature. **Students should be able to:** • draw structural, displayed and skeletal formulas for given organic compounds • apply IUPAC rules for nomenclature to name organic compounds limited to chains and rings with up to six carbon atoms each • apply IUPAC rules for nomenclature to draw the structure of an organic compound from the IUPAC name limited to chains and rings with up to six carbon atoms each.	

3.3.1.2 Reaction mechanisms

Content	Opportunities for skills development
Reactions of organic compounds can be explained using mechanisms. Free-radical mechanisms: • the unpaired electron in a radical is represented by a dot • the use of curly arrows is not required for radical mechanisms. **Students should be able to** write balanced equations for the steps in a free-radical mechanism. Other mechanisms: • the formation of a covalent bond is shown by a curly arrow that starts from a lone electron pair or from another covalent bond • the breaking of a covalent bond is shown by a curly arrow starting from the bond. **Students should be able to** outline mechanisms by drawing the structures of the species involved and curly arrows to represent the movement of electron pairs.	

3.3.1.3 Isomerism

Content	Opportunities for skills development
Structural isomerism. Stereoisomerism. *E*–*Z* isomerism is a form of stereoisomerism and occurs as a result of restricted rotation about the planar carbon–carbon double bond. Cahn–Ingold–Prelog (CIP) priority rules. **Students should be able to:** • define the term structural isomer • draw the structures of chain, position and functional group isomers • define the term stereoisomer • draw the structural formulas of *E* and *Z* isomers • apply the CIP priority rules to *E* and *Z* isomers.	**MS 4.2** Students could be given the structure of one isomer and asked to draw further isomers. Various representations could be used to give the opportunity to identify those that are isomeric. **MS 4.1, 4.2 and 4.3** Students understand the origin of *E*–*Z* isomerism. Students draw different forms of isomers.

3.3.2 Alkanes

Alkanes are the main constituent of crude oil, which is an important raw material for the chemical industry. Alkanes are also used as fuels and the environmental consequences of this use are considered in this section.

3.3.2.1 Fractional distillation of crude oil

Content	Opportunities for skills development
Alkanes are saturated hydrocarbons. Petroleum is a mixture consisting mainly of alkane hydrocarbons that can be separated by fractional distillation.	**AT a, d and k** **PS 1.2** Fractional distillation of a crude oil substitute.

3.3.2.2 Modification of alkanes by cracking

Content	Opportunities for skills development
Cracking involves breaking C–C bonds in alkanes. Thermal cracking takes place at high pressure and high temperature and produces a high percentage of alkenes (mechanism not required). Catalytic cracking takes place at a slight pressure, high temperature and in the presence of a zeolite catalyst and is used mainly to produce motor fuels and aromatic hydrocarbons (mechanism not required). **Students should be able to** explain the economic reasons for cracking alkanes.	

3.3.2.3 Combustion of alkanes

Content	Opportunities for skills development
Alkanes are used as fuels. Combustion of alkanes and other organic compounds can be complete or incomplete. The internal combustion engine produces a number of pollutants including NO_x, CO, carbon and unburned hydrocarbons. These gaseous pollutants from internal combustion engines can be removed using catalytic converters. Combustion of hydrocarbons containing sulfur leads to sulfur dioxide that causes air pollution. **Students should be able to** explain why sulfur dioxide can be removed from flue gases using calcium oxide or calcium carbonate.	

3.3.2.4 Chlorination of alkanes

Content	Opportunities for skills development
The reaction of methane with chlorine. **Students should be able to** explain this reaction as a free-radical substitution mechanism involving initiation, propagation and termination steps.	

3.3.3 Halogenoalkanes

Halogenoalkanes are much more reactive than alkanes. They have many uses, including as refrigerants, as solvents and in pharmaceuticals. The use of some halogenoalkanes has been restricted due to the effect of chlorofluorocarbons (CFCs) on the atmosphere.

3.3.3.1 Nucleophilic substitution

Content	Opportunities for skills development
Halogenoalkanes contain polar bonds. Halogenoalkanes undergo substitution reactions with the nucleophiles OH^-, CN^- and NH_3 **Students should be able to:** • outline the nucleophilic substitution mechanisms of these reactions • explain why the carbon–halogen bond enthalpy influences the rate of reaction.	**AT a, b and k** **PS 4.1** Students could follow instructions when carrying out test-tube hydrolysis of halogenoalkanes to show their relative rates of reaction. **AT d, g and k** Students could prepare a chloroalkane, purifying the product using a separating funnel and distillation.

3.3.3.2 Elimination

Content	Opportunities for skills development
The concurrent substitution and elimination reactions of a halogenoalkane (eg 2-bromopropane with potassium hydroxide). **Students should be able to:** • explain the role of the reagent as both nucleophile and base • outline the mechanisms of these reactions.	

3.3.3.3 Ozone depletion

Content	Opportunities for skills development
Ozone, formed naturally in the upper atmosphere, is beneficial because it absorbs ultraviolet radiation. Chlorine atoms are formed in the upper atmosphere when ultraviolet radiation causes C–Cl bonds in chlorofluorocarbons (CFCs) to break. Chlorine atoms catalyse the decomposition of ozone and contribute to the hole in the ozone layer. Appreciate that results of research by different groups in the scientific community provided evidence for legislation to ban the use of CFCs as solvents and refrigerants. Chemists have now developed alternative chlorine-free compounds. **Students should be able to** use equations, such as the following, to explain how chlorine atoms catalyse decomposition of ozone: $Cl\bullet + O_3 \rightarrow ClO\bullet + O_2$ and $ClO\bullet + O_3 \rightarrow 2O_2 + Cl\bullet$	**Research opportunity** Students could investigate the role of chemists in the introduction of legislation to ban the use of CFCs and in finding replacements.

3.3.4 Alkenes

In alkenes, the high electron density of the carbon–carbon double bond leads to attack on these molecules by electrophiles. This section also covers the mechanism of addition to the double bond and introduces addition polymers, which are commercially important and have many uses in modern society.

3.3.4.1 Structure, bonding and reactivity

Content	Opportunities for skills development
Alkenes are unsaturated hydrocarbons. Bonding in alkenes involves a double covalent bond, a centre of high electron density.	

3.3.4.2 Addition reactions of alkenes

Content	Opportunities for skills development
Electrophilic addition reactions of alkenes with HBr, H_2SO_4 and Br_2 The use of bromine to test for unsaturation. The formation of major and minor products in addition reactions of unsymmetrical alkenes. **Students should be able to:** • outline the mechanisms for these reactions • explain the formation of major and minor products by reference to the relative stabilities of primary, secondary and tertiary carbocation intermediates.	**AT d and k** **PS 4.1** Students could test organic compounds for unsaturation using bromine water and record their observations.

3.3.4.3 Addition polymers

Content	Opportunities for skills development
Addition polymers are formed from alkenes and substituted alkenes. The repeating unit of addition polymers. IUPAC rules for naming addition polymers. Addition polymers are unreactive. Appreciate that knowledge and understanding of the production and properties of polymers has developed over time. Typical uses of poly(chloroethene), commonly known as PVC, and how its properties can be modified using a plasticiser. **Students should be able to:** • draw the repeating unit from a monomer structure • draw the repeating unit from a section of the polymer chain • draw the structure of the monomer from a section of the polymer • explain why addition polymers are unreactive • explain the nature of intermolecular forces between molecules of polyalkenes.	**AT k** **PS 1.2** Making poly(phenylethene) from phenylethene.

3.3.5 Alcohols

Alcohols have many scientific, medicinal and industrial uses. Ethanol is one such alcohol and it is produced using different methods, which are considered in this section. Ethanol can be used as a biofuel.

3.3.5.1 Alcohol production

Content	Opportunities for skills development
Alcohols are produced industrially by hydration of alkenes in the presence of an acid catalyst. Ethanol is produced industrially by fermentation of glucose. The conditions for this process. Ethanol produced industrially by fermentation is separated by fractional distillation and can then be used as a biofuel. **Students should be able to:** • explain the meaning of the term biofuel • justify the conditions used in the production of ethanol by fermentation of glucose • write equations to support the statement that ethanol produced by fermentation is a carbon-neutral fuel and give reasons why this statement is not valid • outline the mechanism for the formation of an alcohol by the reaction of an alkene with steam in the presence of an acid catalyst • discuss the environmental (including ethical) issues linked to decision making about biofuel use.	**AT a, d and k** **PS 1.2** Students could produce ethanol by fermentation, followed by purification by fractional distillation.

3.3.5.2 Oxidation of alcohols

Content	Opportunities for skills development
Alcohols are classified as primary, secondary and tertiary. Primary alcohols can be oxidised to aldehydes which can be further oxidised to carboxylic acids. Secondary alcohols can be oxidised to ketones. Tertiary alcohols are not easily oxidised. Acidified potassium dichromate(VI) is a suitable oxidising agent. **Students should be able to:** • write equations for these oxidation reactions (equations showing [O] as oxidant are acceptable) • explain how the method used to oxidise a primary alcohol determines whether an aldehyde or carboxylic acid is obtained • use chemical tests to distinguish between aldehydes and ketones including Fehling's solution and Tollens' reagent.	**AT b, d and k** Students could carry out the preparation of an aldehyde by the oxidation of a primary alcohol. Students could carry out the preparation of a carboxylic acid by the oxidation of a primary alcohol.

3.3.5.3 Elimination

Content	Opportunities for skills development
Alkenes can be formed from alcohols by acid-catalysed elimination reactions. Alkenes produced by this method can be used to produce addition polymers without using monomers derived from crude oil. **Students should be able to** outline the mechanism for the elimination of water from alcohols.	**AT b, d, g and k** **PS 4.1** Students could carry out the preparation of cyclohexene from cyclohexanol, including purification using a separating funnel and by distillation.
Required practical 5 Distillation of a product from a reaction.	

3.3.6 Organic analysis

Our understanding of organic molecules, their structure and the way they react, has been enhanced by organic analysis. This section considers some of the analytical techniques used by chemists, including test-tube reactions and spectroscopic techniques.

3.3.6.1 Identification of functional groups by test-tube reactions

Content	Opportunities for skills development
The reactions of functional groups listed in the specification. **Students should be able to** identify the functional groups using reactions in the specification.	**AT b, d and k** **PS 2.2, 2.3 and 4.1** Students could carry out test-tube reactions in the specification to distinguish alcohols, aldehydes, alkenes and carboxylic acids.
Required practical 6 Tests for alcohol, aldehyde, alkene and carboxylic acid.	

3.3.6.2 Mass spectrometry

Content	Opportunities for skills development
Mass spectrometry can be used to determine the molecular formula of a compound. **Students should be able to** use precise atomic masses and the precise molecular mass to determine the molecular formula of a compound.	

3.3.6.3 Infrared spectroscopy

Content	Opportunities for skills development
Bonds in a molecule absorb infrared radiation at characteristic wavenumbers. ‘Fingerprinting’ allows identification of a molecule by comparison of spectra. **Students should be able to:** • use infrared spectra and the Chemistry Data Sheet or Booklet to identify particular bonds, and therefore functional groups, and also to identify impurities. The link between absorption of infrared radiation by bonds in CO_2, methane and water vapour and global warming.	Students should be able to use data in the Chemistry Data Sheet or Booklet to suggest possible structures for molecules.

3.3.7 Optical isomerism (A-level only)

Compounds that contain an asymmetric carbon atom form stereoisomers that differ in their effect on plane polarised light. This type of isomerism is called optical isomerism.

Content	Opportunities for skills development
Optical isomerism is a form of stereoisomerism and occurs as a result of chirality in molecules, limited to molecules with a single chiral centre. An asymmetric carbon atom is chiral and gives rise to optical isomers (enantiomers), which exist as non super-imposable mirror images and differ in their effect on plane polarised light. A mixture of equal amounts of enantiomers is called a racemic mixture (racemate). **Students should be able to:** • draw the structural formulas and displayed formulas of enantiomers • understand how racemic mixtures (racemates) are formed and why they are optically inactive.	**MS 4.1, 4.2 and 4.3** Students could be asked to recognise the presence of a chiral centre in a given structure in 2D or 3D forms. They could also be asked to draw the 3D representation of chiral centres in various species. Students understand the origin of optical isomerism. **AT a and k** **PS 1.2** Passing polarised light through a solution of sucrose.

3.3.8 Aldehydes and ketones (A-level only)

Aldehydes, ketones, carboxylic acids and their derivatives all contain the carbonyl group which is attacked by nucleophiles. This section includes the addition reactions of aldehydes and ketones.

Content	Opportunities for skills development
Aldehydes are readily oxidised to carboxylic acids. Chemical tests to distinguish between aldehydes and ketones including Fehling's solution and Tollens' reagent. Aldehydes can be reduced to primary alcohols, and ketones to secondary alcohols, using $NaBH_4$ in aqueous solution. These reduction reactions are examples of nucleophilic addition. The nucleophilic addition reactions of carbonyl compounds with KCN, followed by dilute acid, to produce hydroxynitriles. Aldehydes and unsymmetrical ketones form mixtures of enantiomers when they react with KCN followed by dilute acid. The hazards of using KCN. **Students should be able to:** • write overall equations for reduction reactions using [H] as the reductant • outline the nucleophilic addition mechanism for reduction reactions with $NaBH_4$ (the nucleophile should be shown as H^-) • write overall equations for the formation of hydroxynitriles using HCN • outline the nucleophilic addition mechanism for the reaction with KCN followed by dilute acid • explain why nucleophilic addition reactions of KCN, followed by dilute acid, can produce a mixture of enantiomers.	**AT b, d and k** **PS 2.2** Students could carry out test-tube reactions of Tollens' reagent and Fehling's solution to distinguish aldehydes and ketones.

3.3.9 Carboxylic acids and derivatives (A-level only)

Carboxylic acids are weak acids but strong enough to liberate carbon dioxide from carbonates. Esters occur naturally in vegetable oils and animal fats. Important products obtained from esters include biodiesel, soap and glycerol.

3.3.9.1 Carboxylic acids and esters (A-level only)

Content	Opportunities for skills development
The structures of: • carboxylic acids • esters. Carboxylic acids are weak acids but will liberate CO_2 from carbonates. Carboxylic acids and alcohols react, in the presence of an acid catalyst, to give esters. Common uses of esters (eg in solvents, plasticisers, perfumes and food flavourings). Vegetable oils and animal fats are esters of propane-1,2,3-triol (glycerol). Esters can be hydrolysed in acid or alkaline conditions to form alcohols and carboxylic acids or salts of carboxylic acids. Vegetable oils and animal fats can be hydrolysed in alkaline conditions to give soap (salts of long-chain carboxylic acids) and glycerol. Biodiesel is a mixture of methyl esters of long-chain carboxylic acids. Biodiesel is produced by reacting vegetable oils with methanol in the presence of a catalyst.	**AT b, d, g and k** **PS 4.1** Students could make esters by reacting alcohols with carboxylic acids, purifying the product using a separating funnel and by distillation. **AT b, d, g, h and k** Students could identify an ester by measuring its boiling point, followed by hydrolysis to form the carboxylic acid, which is purified by recrystallisation, and determine its melting point. **AT b, c, d and k** Students could make soap. **AT b and k** Students could make biodiesel.

3.3.9.2 Acylation (A-level only)

Content	Opportunities for skills development
The structures of: • acid anhydrides • acyl chlorides • amides. The nucleophilic addition–elimination reactions of water, alcohols, ammonia and primary amines with acyl chlorides and acid anhydrides. The industrial advantages of ethanoic anhydride over ethanoyl chloride in the manufacture of the drug aspirin. **Students should be able to** outline the mechanism of nucleophilic addition–elimination reactions of acyl chlorides with water, alcohols, ammonia and primary amines.	**AT d and k** **PS 2.2** Students could record observations from reaction of ethanoyl chloride and ethanoic anhydride with water, ethanol, ammonia and phenylamine. **AT b, d, g and h** **PS 2.1, 2.3 and 4.1** Students could carry out the preparation of aspirin, purification by recrystallisation and determination of its melting point. Students could carry out the purification of impure benzoic acid and determination of its melting point.
Required practical 10 Preparation of: • a pure organic solid and test of its purity • a pure organic liquid.	

3.3.10 Aromatic chemistry (A-level only)

Aromatic chemistry takes benzene as an example of this type of molecule and looks at the structure of the benzene ring and its substitution reactions.

3.3.10.1 Bonding (A-level only)

Content	Opportunities for skills development
The nature of the bonding in a benzene ring, limited to planar structure and bond length intermediate between single and double. Delocalisation of p electrons makes benzene more stable than the theoretical molecule cyclohexa-1,3,5-triene. **Students should be able to:** • use thermochemical evidence from enthalpies of hydrogenation to account for this extra stability • explain why substitution reactions occur in preference to addition reactions.	

3.3.10.2 Electrophilic substitution (A-level only)

Content	Opportunities for skills development
Electrophilic attack on benzene rings results in substitution, limited to monosubstitutions. Nitration is an important step in synthesis, including the manufacture of explosives and formation of amines. Friedel–Crafts acylation reactions are also important steps in synthesis. **Students should be able to** outline the electrophilic substitution mechanisms of: • nitration, including the generation of the nitronium ion • acylation using $AlCl_3$ as a catalyst.	**AT b, d, g and h** **PS 2.1, 2.3 and 4.1** Students could carry out the preparation of methyl 3-nitrobenzoate by nitration of methyl benzoate, purification by recrystallisation and determination of melting point.

3.3.11 Amines (A-level only)

Amines are compounds based on ammonia where hydrogen atoms have been replaced by alkyl or aryl groups. This section includes their reactions as nucleophiles.

3.3.11.1 Preparation (A-level only)

Content	Opportunities for skills development
Primary aliphatic amines can be prepared by the reaction of ammonia with halogenoalkanes and by the reduction of nitriles. Aromatic amines, prepared by the reduction of nitro compounds, are used in the manufacture of dyes.	

3.3.11.2 Base properties (A-level only)

Content	Opportunities for skills development
Amines are weak bases. The difference in base strength between ammonia, primary aliphatic and primary aromatic amines. **Students should be able to** explain the difference in base strength in terms of the availability of the lone pair of electrons on the N atom.	

3.3.11.3 Nucleophilic properties (A-level only)

Content	Opportunities for skills development
Amines are nucleophiles. The nucleophilic substitution reactions of ammonia and amines with halogenoalkanes to form primary, secondary, tertiary amines and quaternary ammonium salts. The use of quaternary ammonium salts as cationic surfactants. The nucleophilic addition–elimination reactions of ammonia and primary amines with acyl chlorides and acid anhydrides. **Students should be able to** outline the mechanisms of: • these nucleophilic substitution reactions • the nucleophilic addition–elimination reactions of ammonia and primary amines with acyl chlorides.	

3.3.12 Polymers (A-level only)

The study of polymers is extended to include condensation polymers. The ways in which condensation polymers are formed are studied, together with their properties and typical uses. Problems associated with the reuse or disposal of both addition and condensation polymers are considered.

3.3.12.1 Condensation polymers (A-level only)

Content	Opportunities for skills development
Condensation polymers are formed by reactions between: • dicarboxylic acids and diols • dicarboxylic acids and diamines • amino acids. The repeating units in polyesters (eg Terylene) and polyamides (eg nylon 6,6 and Kevlar) and the linkages between these repeating units. Typical uses of these polymers. **Students should be able to:** • draw the repeating unit from monomer structure(s) • draw the repeating unit from a section of the polymer chain • draw the structure(s) of the monomer(s) from a section of the polymer • explain the nature of the intermolecular forces between molecules of condensation polymers.	**AT k** **PS 1.2** Making nylon 6,6

3.3.12.2 Biodegradability and disposal of polymers (A-level only)

Content	Opportunities for skills development
Polyalkenes are chemically inert and non-biodegradable. Polyesters and polyamides can be broken down by hydrolysis and are biodegradable. The advantages and disadvantages of different methods of disposal of polymers, including recycling. **Students should be able to** explain why polyesters and polyamides can be hydrolysed but polyalkenes cannot.	**Research opportunity** Students could research problems associated with the disposal of different polymers.

3.3.13 Amino acids, proteins and DNA (A-level only)

Amino acids, proteins and DNA are the molecules of life. In this section, the structure and bonding in these molecules and the way they interact is studied. Drug action is also considered.

3.3.13.1 Amino acids (A-level only)

Content	Opportunities for skills development
Amino acids have both acidic and basic properties, including the formation of zwitterions. **Students should be able to** draw the structures of amino acids as zwitterions and the ions formed from amino acids: • in acid solution • in alkaline solution.	

3.3.13.2 Proteins (A-level only)

Content	Opportunities for skills development
Proteins are sequences of amino acids joined by peptide links. The importance of hydrogen bonding and sulfur–sulfur bonds in proteins. The primary, secondary (α-helix and β–pleated sheets) and tertiary structure of proteins. Hydrolysis of the peptide link produces the constituent amino acids. Amino acids can be separated and identified by thin-layer chromatography. Amino acids can be located on a chromatogram using developing agents such as ninhydrin or ultraviolet light and identified by their R_f values. **Students should be able to:** • draw the structure of a peptide formed from up to three amino acids • draw the structure of the amino acids formed by hydrolysis of a peptide • identify primary, secondary and tertiary structures in diagrams • explain how these structures are maintained by hydrogen bonding and S–S bonds • calculate R_f values from a chromatogram.	

3.3.13.3 Enzymes (A-level only)

Content	Opportunities for skills development
Enzymes are proteins. The action of enzymes as catalysts, including the concept of a stereospecific active site that binds to a substrate molecule. The principle of a drug acting as an enzyme inhibitor by blocking the active site. Computers can be used to help design such drugs. **Students should be able to** explain why a stereospecific active site can only bond to one enantiomeric form of a substrate or drug.	

3.3.13.4 DNA (A-level only)

Content	Opportunities for skills development
The structures of the phosphate ion, 2-deoxyribose (a pentose sugar) and the four bases adenine, cytosine, guanine and thymine are given in the Chemistry Data Booklet. A nucleotide is made up from a phosphate ion bonded to 2-deoxyribose which is in turn bonded to one of the four bases adenine, cytosine, guanine and thymine. A single strand of DNA (deoxyribonucleic acid) is a polymer of nucleotides linked by covalent bonds between the phosphate group of one nucleotide and the 2-deoxyribose of another nucleotide. This results in a sugar-phosphate-sugar-phosphate polymer chain with bases attached to the sugars in the chain. DNA exists as two complementary strands arranged in the form of a double helix. **Students should be able to** explain how hydrogen bonding between base pairs leads to the two complementary strands of DNA.	

3.3.13.5 Action of anticancer drugs (A-level only)

Content	Opportunities for skills development
The Pt(II) complex cisplatin is used as an anticancer drug. Cisplatin prevents DNA replication in cancer cells by a ligand replacement reaction with DNA in which a bond is formed between platinum and a nitrogen atom on guanine. Appreciate that society needs to assess the balance between the benefits and the adverse effects of drugs, such as the anticancer drug cisplatin. **Students should be able to:** • explain why cisplatin prevents DNA replication • explain why such drugs can have adverse effects.	

3.3.14 Organic synthesis (A-level only)

The formation of new organic compounds by multi-step syntheses using reactions included in the specification is covered in this section.

Content	Opportunities for skills development
The synthesis of an organic compound can involve several steps. **Students should be able to:** • explain why chemists aim to design processes that do not require a solvent and that use non-hazardous starting materials • explain why chemists aim to design production methods with fewer steps that have a high percentage atom economy • use reactions in this specification to devise a synthesis, with up to four steps, for an organic compound.	

3.3.15 Nuclear magnetic resonance spectroscopy (A-level only)

Chemists use a variety of techniques to deduce the structure of compounds. In this section, nuclear magnetic resonance spectroscopy is added to mass spectrometry and infrared spectroscopy as an analytical technique. The emphasis is on the use of analytical data to solve problems rather than on spectroscopic theory.

Content	Opportunities for skills development
Appreciation that scientists have developed a range of analytical techniques which together enable the structures of new compounds to be confirmed. Nuclear magnetic resonance (NMR) gives information about the position of ^{13}C or ^{1}H atoms in a molecule. ^{13}C NMR gives simpler spectra than ^{1}H NMR. The use of the δ scale for recording chemical shift. Chemical shift depends on the molecular environment. Integrated spectra indicate the relative numbers of ^{1}H atoms in different environments. ^{1}H NMR spectra are obtained using samples dissolved in deuterated solvents or CCl_4 The use of tetramethylsilane (TMS) as a standard. **Students should be able to:** • explain why TMS is a suitable substance to use as a standard • use ^{1}H NMR and ^{13}C NMR spectra and chemical shift data from the Chemistry Data Booklet to suggest possible structures or part structures for molecules • use integration data from ^{1}H NMR spectra to determine the relative numbers of equivalent protons in the molecule • use the n+1 rule to deduce the spin–spin splitting patterns of adjacent, non-equivalent protons, limited to doublet, triplet and quartet formation in aliphatic compounds.	Students should be able to use data in the Chemistry Data Booklet to suggest possible structures for molecules.

3.3.16 Chromatography (A-level only)

Chromatography provides an important method of separating and identifying components in a mixture. Different types of chromatography are used depending on the composition of mixture to be separated.

Content	Opportunities for skills development
Chromatography can be used to separate and identify the components in a mixture. Types of chromatography include: • thin-layer chromatography (TLC) – a plate is coated with a solid and a solvent moves up the plate • column chromatography (CC) – a column is packed with a solid and a solvent moves down the column • gas chromatography (GC) – a column is packed with a solid or with a solid coated by a liquid, and a gas is passed through the column under pressure at high temperature. Separation depends on the balance between solubility in the moving phase and retention by the stationary phase. Retention times and R_f values are used to identify different substances. The use of mass spectrometry to analyse the components separated by GC. **Students should be able to:** • calculate R_f values from a chromatogram • compare retention times and R_f values with standards to identify different substances.	**AT a, i and k** **PS 1.2, 3.2 and 4.1** Students could use thin-layer chromatography to identify analgesics. Students could use thin-layer chromatography to identify transition metal ions in a solution.
Required practical 12 Separation of species by thin-layer chromatography.	

4 Scheme of assessment

Find past papers and mark schemes, and specimen papers for new courses, on our website at aqa.org.uk/pastpapers

The AS specification is designed to be taken over one or two years with all assessments taken at the end of the course. The A-level specification is designed to be taken over two years with all assessments taken at the end of the course.

Assessments and certification for the AS specification are available for the first time in May/June 2016 and then every May/June for the life of the specification.

Assessments and certification for the A-level specification are available for the first time in May/June 2017 and then every May/June for the life of the specification.

These are linear qualifications. In order to achieve the award, students must complete all exams in May/June in a single year. All assessments must be taken in the same series.

Questions for these specifications will be set which require students to demonstrate:

- their knowledge and understanding of the content developed in one section or topic, including the associated mathematical and practical skills or
- the ability to apply mathematical and practical skills to areas of content they are not normally developed in or
- the ability to draw together different areas of knowledge and understanding within one answer.

A range of question types will be used, including those that require extended responses. Extended response questions will allow students to demonstrate their ability to construct and develop a sustained line of reasoning which is coherent, relevant, substantiated and logically structured. Extended responses may be in written English, extended calculations, or a combination of both, as appropriate to the question.

All materials are available in English only.

4.1 Aims

Courses based on these specifications should encourage students to:

- develop their interest in and enthusiasm for the subject, including developing an interest in further study and careers associated with the subject
- develop essential knowledge and understanding of different areas of the subject and how they relate to each other
- develop and demonstrate a deep appreciation of the skills, knowledge and understanding of scientific methods
- develop competence and confidence in a variety of practical, mathematical and problem solving skills
- understand how society makes decisions about scientific issues and how the sciences contribute to the success of the economy and society
- use theories, models and ideas to develop scientific explanations
- use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas
- use appropriate methodology, including information and communication technology (ICT), to answer scientific questions and solve scientific problems

- carry out experimental and investigative activities, including appropriate risk management, in a range of contexts
- analyse and interpret data to provide evidence, recognising correlations and causal relationships
- evaluate methodology, evidence and data, and resolve conflicting evidence
- know that scientific knowledge and understanding develops over time
- communicate information and ideas in appropriate ways using appropriate terminology
- consider applications and implications of science and evaluate their associated benefits and risks
- consider ethical issues in the treatment of humans, other organisms and the environment
- evaluate the role of the scientific community in validating new knowledge and ensuring integrity
- evaluate the ways in which society uses science to inform decision making.

4.2 Assessment objectives

Assessment objectives (AOs) are set by Ofqual and are the same across all AS and A-level Chemistry specifications and all exam boards.

The exams will measure how students have achieved the following assessment objectives.

- AO1: Demonstrate knowledge and understanding of scientific ideas, processes, techniques and procedures.
- AO2: Apply knowledge and understanding of scientific ideas, processes, techniques and procedures:
  - in a theoretical context
  - in a practical context
  - when handling qualitative data
  - when handling quantitative data.
- AO3: Analyse, interpret and evaluate scientific information, ideas and evidence, including in relation to issues, to:
  - make judgements and reach conclusions
  - develop and refine practical design and procedures.

Weighting of assessment objectives for AS Chemistry

Assessment objectives (AOs)	Component weightings (approx %)		Overall weighting (approx %)
	Paper 1	Paper 2	
AO1	35	35	35
AO2	43	43	43
AO3	22	22	22
Overall weighting of components	50	50	100

20% of the overall assessment of AS Chemistry will contain mathematical skills equivalent to Level 2 or above.

At least 15% of the overall assessment of AS Chemistry will assess knowledge, skills and understanding in relation to practical work.

Weighting of assessment objectives for A-level Chemistry

Assessment objectives (AOs)	Component weightings (approx %)			Overall weighting (approx %)
	Paper 1	Paper 2	Paper 3	
AO1	30	30	32	30
AO2	48	48	34	45
AO3	22	22	34	25
Overall weighting of components	35	35	30	100

20% of the overall assessment of A-level Chemistry will contain mathematical skills equivalent to Level 2 or above.

At least 15% of the overall assessment of A-level Chemistry will assess knowledge, skills and understanding in relation to practical work.

4.3 Assessment weightings

The marks awarded on the papers will be scaled to meet the weighting of the components. Students' final marks will be calculated by adding together the scaled marks for each component. Grade boundaries will be set using this total scaled mark. The scaling and total scaled marks are shown in the table below.

AS

Component	Maximum raw mark	Scaling factor	Maximum scaled mark
Paper 1	80	×1	80
Paper 2	80	×1	80
		Total scaled mark:	160

A-level

Component	Maximum raw mark	Scaling factor	Maximum scaled mark
Paper 1	105	×1	105
Paper 2	105	×1	105
Paper 3	90	×1	90
		Total scaled mark:	300

5 General administration

You can find information about all aspects of administration, as well as all the forms you need, at aqa.org.uk/examsadmin

5.1 Entries and codes

You only need to make one entry for each qualification.

Every specification is given a national discount (classification) code by the Department for Education (DfE), which indicates its subject area.

If a student takes two specifications with the same discount code, Further and Higher Education providers are likely to take the view that they have only achieved one of the two qualifications. Please check this before your students start their course.

Qualification title	AQA entry code	DfE discount code
AQA Advanced Subsidiary GCE in Chemistry	7404	1110 (post-16), RD1 (KS4)
AQA Advanced Level GCE in Chemistry	7405	1110

These specifications comply with Ofqual's:

- *General conditions of recognition* that apply to all regulated qualifications
- GCE qualification level conditions that apply to all GCEs
- GCE subject level conditions that apply to all GCEs in this subject
- all relevant regulatory documents.

Ofqual has accredited these specifications. The qualification accreditation number (QAN) for the AS is 601/5730/6. The QAN for the A-level is 601/5731/8.

5.2 Overlaps with other qualifications

There is overlapping content in the AS and A-level Chemistry specifications. This helps you teach the AS and A-level together.

5.3 Awarding grades and reporting results

The AS qualification will be graded on a five-point scale: A, B, C, D and E.

The A-level qualification will be graded on a six-point scale: A*, A, B, C, D and E.

Students who fail to reach the minimum standard for grade E will be recorded as U (unclassified) and will not receive a qualification certificate.

5.4 Re-sits and shelf life

Students can re-sit these qualifications as many times as they wish, within the shelf life of the qualifications.

5.5 Previous learning and prerequisites

There are no previous learning requirements. Any requirements for entry to a course based on these specifications are at the discretion of schools and colleges.

However, we recommend that students should have the skills and knowledge associated with at least GCSE Science and Additional Science or a GCSE Chemistry course or equivalent.

5.6 Access to assessment: diversity and inclusion

General qualifications are designed to prepare students for a wide range of occupations and further study. Therefore our qualifications must assess a wide range of competences.

The subject criteria have been assessed to see if any of the skills or knowledge required present any possible difficulty to any students, whatever their ethnic background, religion, sex, age, disability or sexuality. If any difficulties were encountered, the criteria were reviewed again to make sure that tests of specific competences were only included if they were important to the subject.

As members of the Joint Council for Qualifications (JCQ) we participate in the production of the JCQ document *Access Arrangements and Reasonable Adjustments: General and Vocational qualifications*. We follow these guidelines when assessing the needs of individual students who may require an access arrangement or reasonable adjustment. This document is published on the JCQ website at jcq.org.uk

Students with disabilities and special needs

We can make arrangements for disabled students and students with special needs to help them access the assessments, as long as the competences being tested are not changed. Access arrangements must be agreed **before** the assessment. For example, a Braille paper would be a reasonable adjustment for a Braille reader but not for a student who does not read Braille.

We are required by the Equality Act 2010 to make reasonable adjustments to remove or lessen any disadvantage that affects a disabled student.

If you have students who need access arrangements or reasonable adjustments, you can apply using the Access arrangements online service at aqa.org.uk/eaqa

Special consideration

We can give special consideration to students who have been disadvantaged at the time of the assessment through no fault of their own – for example a temporary illness, injury or serious problem such as the death of a relative. We can only do this **after** the assessment.

Your exams officer should apply online for special consideration at aqa.org.uk/eaqa

For more information and advice about access arrangements, reasonable adjustments and special consideration please see aqa.org.uk/access or email accessarrangementsqueries@aqa.org.uk

5.7 Working with AQA for the first time

If your school or college has not previously offered any AQA specification, you need to register as an AQA centre to offer our specifications to your students. Find out how at aqa.org.uk/becomeacentre

If your school or college is new to these specifications, please let us know by completing an Intention to enter form. The easiest way to do this is via e-AQA at aqa.org.uk/eaqa

5.8 Private candidates

A private candidate is someone who enters for exams through an AQA-approved school or college but is not enrolled as a student there.

If you are a private candidate you may be self-taught, home-schooled or have private tuition, either with a tutor or through a distance learning organisation. You must be based in the UK.

If you have any queries as a private candidate, you can:

- speak to the exams officer at the school or college where you intend to take your exams
- visit our website at aqa.org.uk/examsadmin
- email: privatecandidates@aqa.org.uk

6 Mathematical requirements and exemplifications

In order to be able to develop their skills, knowledge and understanding in chemistry, students need to have been taught, and to have acquired competence in, the appropriate areas of mathematics as indicated in the table of coverage below.

Overall, at least 20% of the marks in assessments for chemistry will require the use of mathematical skills. These skills will be applied in the context of chemistry and will be at least the standard of higher tier GCSE Mathematics.

The following tables illustrate where these mathematical skills may be developed during teaching or could be assessed. Those shown in **bold type** would only be tested in the full A-level course.

This list of examples is not exhaustive. These skills could be developed or assessed in other areas of specification content. Other areas where these skills could be developed have been exemplified throughout the specifications.

6.1 Arithmetic and numerical computation

	Mathematical skills	Exemplification of mathematical skill in the context of chemistry
MS 0.0	Recognise and make use of appropriate units in calculation	Students may be tested on their ability to: • convert between units eg cm^3 to dm^3 as part of volumetric calculations • give units for an equilibrium constant **or a rate constant** • understand that different units are used in similar topic areas, so that conversions may be necessary, eg entropy in $J\ mol^{-1}\ K^{-1}$ and enthalpy changes in $kJ\ mol^{-1}$.
MS 0.1	Recognise and use expressions in decimal and ordinary form	Students may be tested on their ability to: • use an appropriate number of decimal places in calculations eg for pH • carry out calculations using numbers in standard and ordinary form eg use of Avogadro's number • understand standard form when applied to areas such as (but not limited to) K_w • convert between numbers in standard and ordinary form • understand that significant figures need retaining when making conversions between standard and ordinary form eg 0.0050 $mol\ dm^{-3}$ is equivalent to $5.0 \times 10^{-3}\ mol\ dm^{-3}$.

	Mathematical skills	Exemplification of mathematical skill in the context of chemistry
MS 0.2	Use ratios, fractions and percentages	Students may be tested on their ability to: • calculate percentage yields • calculate the atom economy of a reaction • construct and/or balance equations using ratios.
MS 0.3	Estimate results	Students may be tested on their ability to: • evaluate the effect of changing experimental parameters on measurable values eg how the value of K_c would change with temperature given different specified conditions.
MS 0.4	Use calculators to find and use power, **exponential and logarithmic functions**	Students may be tested on their ability to: • carry out calculations using the Avogadro constant • **carry out pH and pK_a calculations** • **make appropriate mathematical approximations in buffer calculations**.

6.2 Handling data

	Mathematical skills	Exemplification of mathematical skill in the context of chemistry
MS 1.1	Use an appropriate number of significant figures	Students may be tested on their ability to: • report calculations to an appropriate number of significant figures, given raw data quoted to varying numbers of significant figures • understand that calculated results can only be reported to the limits of the least accurate measurement.
MS 1.2	Find arithmetic means	Students may be tested on their ability to: • calculate weighted means eg calculation of an atomic mass based on supplied isotopic abundances • select appropriate titration data (ie identification of outliers) in order to calculate mean titres.
MS 1.3	Identify uncertainties in measurements and use simple techniques to determine uncertainty when data are combined	Students may be tested on their ability to: • determine uncertainty when two burette readings are used to calculate a titre value.

6.3 Algebra

	Mathematical skills	Exemplification of mathematical skill in the context of chemistry
MS 2.1	Understand and use the symbols: =, <, <<, >>, >, ∝, ~, equilibrium sign	No exemplification required.
MS 2.2	Change the subject of an equation	Students may be tested on their ability to: • carry out structured and unstructured mole calculations **eg calculate a rate constant *k* from a rate equation**.
MS 2.3	Substitute numerical values into algebraic equations using appropriate units for physical quantities	Students may be tested on their ability to: • carry out structured and unstructured mole calculations • calculate the value of an equilibrium constant K_c • **carry out rate calculations**.
MS 2.4	Solve algebraic equations	Students may be tested on their ability to: • carry out Hess's law calculations • **calculate a rate constant *k* from a rate equation**.
MS 2.5	**Use logarithms in relation to quantities that range over several orders of magnitude**	Students may be tested on their ability to: • **carry out pH and pK_a calculations**.

6.4 Graphs

	Mathematical skills	Exemplification of mathematical skill in the context of chemistry
MS 3.1	Translate information between graphical, numerical and algebraic forms	Students may be tested on their ability to: • interpret and analyse spectra • **determine the order of a reaction from a graph** • **derive a rate expression from a graph.**
MS 3.2	Plot two variables from experimental or other data	Students may be tested on their ability to: • plot concentration–time graphs from collected or supplied data and draw an appropriate best-fit curve.
MS 3.3	**Determine the slope and intercept of a linear graph**	Students may be tested on their ability to: • **calculate the rate constant of a zero-order reaction by determination of the gradient of a concentration–time graph.**
MS 3.4	**Calculate rate of change from a graph showing a linear relationship**	Students may be tested on their ability to: • **calculate the rate constant of a zero-order reaction by determination of the gradient of a concentration–time graph.**
MS 3.5	**Draw and use the slope of a tangent to a curve as a measure of rate of change**	Students may be tested on their ability to: • **determine the order of a reaction using the initial rates method.**

6.5 Geometry and trigonometry

	Mathematical skills	Exemplification of mathematical skill in the context of chemistry
MS 4.1	Use angles and shapes in regular 2D and 3D structures	Students may be tested on their ability to: • predict/identify shapes of and bond angles in molecules with and without a lone pair(s), for example NH_3, CH_4, H_2O etc.
MS 4.2	Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects	Students may be tested on their ability to: • draw different forms of isomers • **identify chiral centres from a 2D or 3D representation.**
MS 4.3	Understand the symmetry of 2D and 3D shapes	Students may be tested on their ability to: • describe the types of stereoisomerism shown by molecules/complexes • **identify chiral centres from a 2D or 3D representation.**

7 AS practical assessment

Practical work is at the heart of chemistry, so we have placed it at the heart of this specification.

Assessment of practical skills in this AS specification will be by written exams only.

The practical endorsement does not apply to the AS specification. A rich diet of practical work is essential to develop students' manipulative skills and understanding of the processes of scientific investigation. It also contributes to teaching and learning of the concepts within this specification.

Questions in the papers have been written in the expectation that students have carried out at least the six required practical activities in Section 7.2.

15% of the marks in the papers will relate to practical work.

7.1 Use of apparatus and techniques

All students taking this specification are expected to have carried out the required practical activities in Section 7.2. These develop skills in the use of many of the following apparatus and techniques. This list is a compulsory element of the full A-level course. It is reproduced here for reference and to aid co-teaching the AS and A-level specifications.

	Apparatus and techniques
AT a	Use appropriate apparatus to record a range of measurements (to include mass, time, volume of liquids and gases, temperature)
AT b	Use water bath or electric heater or sand bath for heating
AT c	Measure pH using pH charts, or pH meter, or pH probe on a data logger
AT d	Use laboratory apparatus for a variety of experimental techniques including: • titration, using burette and pipette • distillation and heating under reflux, including setting up glassware using retort stand and clamps • qualitative tests for ions and organic functional groups • filtration, including use of fluted filter paper, or filtration under reduced pressure
AT e	Use volumetric flask, including accurate technique for making up a standard solution
AT f	Use acid–base indicators in titrations of weak/strong acids with weak/strong alkalis
AT g	Purify: • a solid product by recrystallisation • a liquid product, including use of separating funnel
AT h	Use melting point apparatus
AT i	Use thin-layer or paper chromatography
AT j	Set up electrochemical cells and measuring voltages
AT k	Safely and carefully handle solids and liquids, including corrosive, irritant, flammable and toxic substances
AT l	Measure rates of reaction by at least two different methods, for example: • an initial rate method such as a clock reaction • a continuous monitoring method

7.2 Required practical activities

The following practicals must be carried out by all students taking this course. Written papers will assess knowledge and understanding of these, and the skills exemplified within each practical.

Required activity	Apparatus and technique reference
1 Make up a volumetric solution and carry out a simple acid–base titration	a, d, e, f, k
2 Measurement of an enthalpy change	a, d, k
3 Investigation of how the rate of a reaction changes with temperature	a, b, k
4 Carry out simple test-tube reactions to identify: • cations – Group 2, NH_4^+ • anions – Group 7 (halide ions), OH^-, CO_3^{2-}, SO_4^{2-}	d, k
5 Distillation of a product from a reaction	b, d, k
6 Tests for alcohol, aldehyde, alkene and carboxylic acid	b, d, k

Teachers are encouraged to vary their approach to these practical activities. Some are more suitable for highly structured approaches that develop key techniques. Others allow opportunities for students to develop investigative approaches.

This list is not designed to limit the practical activities carried out by students. A rich practical experience for students will include more than the six required practical activities. The explicit teaching of practical skills will build students' competence. Many teachers will also use practical approaches to the introduction of content knowledge in the course of their normal teaching.

7.3 Practical skills to be assessed in written papers

Overall, at least 15% of the marks for all AS Chemistry courses will require the assessment of practical skills.

In order to be able to answer these questions, students need to have been taught, and to have acquired competence in, the appropriate areas of practical skills as indicated in the tables of coverage below.

7.3.1 Independent thinking

	Practical skill
PS 1.1	Solve problems set in practical contexts
PS 1.2	Apply scientific knowledge to practical contexts

7.3.2 Use and application of scientific methods and practices

	Practical skill
PS 2.1	Comment on experimental design and evaluate scientific methods
PS 2.2	Present data in appropriate ways
PS 2.3	Evaluate results and draw conclusions with reference to measurement uncertainties and errors
PS 2.4	Identify variables including those that must be controlled

7.3.3 Numeracy and the application of mathematical concepts in a practical context

	Practical skill
PS 3.1	Plot and interpret graphs
PS 3.2	Process and analyse data using appropriate mathematical skills as exemplified in the mathematical appendix for each science
PS 3.3	Consider margins of error, accuracy and precision of data

7.3.4 Instruments and equipment

	Practical skill
PS 4.1	Know and understand how to use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in the specification

8 A-level practical assessment

Practical work is at the heart of chemistry, so we have placed it at the heart of this specification.

Practical assessments have been divided into those that can be assessed in written exams and those that can only be directly assessed whilst students are carrying out experiments.

A-level grades will be based only on marks from written exams.

A separate endorsement of practical skills will be taken alongside the A-level. This will be assessed by teachers and will be based on direct observation of students' competency in a range of skills that are not assessable in written exams.

8.1 Use of apparatus and techniques

All students taking an A-level Chemistry qualification are expected to have had opportunities to use the following apparatus and develop and demonstrate these techniques. These apparatus and techniques are common to all A-level Chemistry specifications.

Carrying out the 12 required practicals in Section 8.2 means that students will have experienced use of each of these apparatus and techniques. However, teachers are encouraged to develop students' abilities by inclusion of other opportunities for skills development, as exemplified in the right-hand column of the content section of this specification.

	Apparatus and techniques
AT a	Use appropriate apparatus to record a range of measurements (to include mass, time, volume of liquids and gases, temperature)
AT b	Use water bath or electric heater or sand bath for heating
AT c	Measure pH using pH charts, or pH meter, or pH probe on a data logger
AT d	Use laboratory apparatus for a variety of experimental techniques including: • titration, using burette and pipette • distillation and heating under reflux, including setting up glassware using retort stand and clamps • qualitative tests for ions and organic functional groups • filtration, including use of fluted filter paper, or filtration under reduced pressure
AT e	Use volumetric flask, including accurate technique for making up a standard solution
AT f	Use acid–base indicators in titrations of weak/strong acids with weak/strong alkalis
AT g	Purify: • a solid product by recrystallisation • a liquid product, including use of separating funnel
AT h	Use melting point apparatus
AT i	Use thin-layer or paper chromatography
AT j	Set up electrochemical cells and measuring voltages
AT k	Safely and carefully handle solids and liquids, including corrosive, irritant, flammable and toxic substances
AT l	Measure rates of reaction by at least two different methods, for example: • an initial rate method such as a clock reaction • a continuous monitoring method

8.2 Required practical activities

The following practicals must be carried out by all students taking this course. Written papers will assess knowledge and understanding of these, and the skills exemplified within each practical.

Required activity	Apparatus and technique reference
1 Make up a volumetric solution and carry out a simple acid–base titration	a, d, e, f, k
2 Measurement of an enthalpy change	a, d, k
3 Investigation of how the rate of a reaction changes with temperature	a, b, k
4 Carry out simple test-tube reactions to identify: • cations – Group 2, NH_4^+ • anions – Group 7 (halide ions), OH^-, CO_3^{2-}, SO_4^{2-}	d, k
5 Distillation of a product from a reaction	b, d, k
6 Tests for alcohol, aldehyde, alkene and carboxylic acid	b, d, k
7 Measuring the rate of reaction: • by an initial rate method • by a continuous monitoring method	a, k, l a, k, l
8 Measuring the EMF of an electrochemical cell	j, k
9 Investigate how pH changes when a weak acid reacts with a strong base and when a strong acid reacts with a weak base	a, c, d, k
10 Preparation of: • a pure organic solid and test of its purity • a pure organic liquid	a, b, d, g, h, k b, d, g, k
11 Carry out simple test-tube reactions to identify transition metal ions in aqueous solution	b, d, k
12 Separation of species by thin-layer chromatography	i, k

Teachers are encouraged to vary their approach to these practical activities. Some are more suitable for highly structured approaches that develop key techniques. Others allow opportunities for students to develop investigative approaches.

This list is not designed to limit the practical activities carried out by students. A rich practical experience for students will include more than the 12 required practical activities. The explicit teaching of practical skills will build students' competence. Many teachers will also use practical approaches to the introduction of content knowledge in the course of their normal teaching. Students' work in these activities can also contribute towards the endorsement of practical skills.

8.3 Practical skills to be assessed in written papers

Overall, at least 15% of the marks for all A-level Chemistry courses will require the assessment of practical skills.

In order to be able to answer these questions, students need to have been taught, and to have acquired competence in, the appropriate areas of practical skills as indicated in the tables of coverage below.

8.3.1 Independent thinking

	Practical skill
PS 1.1	Solve problems set in practical contexts
PS 1.2	Apply scientific knowledge to practical contexts

8.3.2 Use and application of scientific methods and practices

	Practical skill
PS 2.1	Comment on experimental design and evaluate scientific methods
PS 2.2	Present data in appropriate ways
PS 2.3	Evaluate results and draw conclusions with reference to measurement uncertainties and errors
PS 2.4	Identify variables including those that must be controlled

8.3.3 Numeracy and the application of mathematical concepts in a practical context

	Practical skill
PS 3.1	Plot and interpret graphs
PS 3.2	Process and analyse data using appropriate mathematical skills as exemplified in the mathematical appendix for each science
PS 3.3	Consider margins of error, accuracy and precision of data

8.3.4 Instruments and equipment

	Practical skill
PS 4.1	Know and understand how to use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in the specification

8.4 A-level practical skills to be assessed via endorsement

8.4.1 Cross-board statement on practical endorsement

The assessment of practical skills is a compulsory requirement of the course of study for A-level qualifications in biology, chemistry and physics. It will appear on all students' certificates as a separately reported result, alongside the overall grade for the qualification. The arrangements for the assessment of practical skills will be common to all awarding organisations. These arrangements will include:

- A minimum of 12 practical activities to be carried out by each student which, together, meet the requirements of Appendices 5b (Practical skills identified for direct assessment and developed through teaching and learning) and 5c (Use of apparatus and techniques) from the prescribed subject content, published by the Department for Education. The required practical activities will be defined by each awarding organisation.
- Teachers will assess students against Common Practical Assessment Criteria (CPAC) issued jointly by the awarding organisations. The CPAC (see below) are based on the requirements of Appendices 5b and 5c of the subject content requirements published by the Department for Education, and define the minimum standard required for the achievement of a pass.
- Each student will keep an appropriate record of their practical work, including their assessed practical activities.
- Students who demonstrate the required standard across all the requirements of the CPAC will receive a 'pass' grade.
- There will be no separate assessment of practical skills for AS qualifications.
- Students will answer questions in the AS and A-level exam papers that assess the requirements of Appendix 5a (Practical skills identified for indirect assessment and developed through teaching and learning) from the prescribed subject content, published by the Department for Education. These questions may draw on, or range beyond, the practical activities included in the specification.

8.4.2 Criteria for the assessment of practical competency in A-level Biology, Chemistry and Physics

Competency	Practical mastery
	In order to be awarded a Pass a Learner must, by the end of the practical science assessment, consistently and routinely meet the criteria in respect of each competency listed below. A Learner may demonstrate the competencies in any practical activity undertaken as part of that assessment throughout the course of study. Learners may undertake practical activities in groups. However, the evidence generated by each Learner must demonstrate that he or she independently meets the criteria outlined below in respect of each competency. Such evidence: (a) will comprise both the Learner's performance during each practical activity and his or her contemporaneous record of the work that he or she has undertaken during that activity, and (b) must include evidence of independent application of investigative approaches and methods to practical work.
1. Follows written procedures	(a) Correctly follows written instructions to carry out the experimental techniques or procedures.
2. Applies investigative approaches and methods when using instruments and equipment	(a) Correctly uses appropriate instrumentation, apparatus and materials (including ICT) to carry out investigative activities, experimental techniques and procedures with minimal assistance or prompting. (b) Carries out techniques or procedures methodically, in sequence and in combination, identifying practical issues and making adjustments where necessary. (c) Identifies and controls significant quantitative variables where applicable, and plans approaches to take account of variables that cannot readily be controlled. (d) Selects appropriate equipment and measurement strategies in order to ensure suitably accurate results.
3. Safely uses a range of practical equipment and materials	(a) Identifies hazards and assesses risks associated with those hazards, making safety adjustments as necessary, when carrying out experimental techniques and procedures in the lab or field. (b) Uses appropriate safety equipment and approaches to minimise risks with minimal prompting.

Competency	Practical mastery
4. Makes and records observations	(a) Makes accurate observations relevant to the experimental or investigative procedure. (b) Obtains accurate, precise and sufficient data for experimental and investigative procedures and records this methodically using appropriate units and conventions.
5. Researches, references and reports	(a) Uses appropriate software and/or tools to process data, carry out research and report findings. (b) Cites sources of information demonstrating that research has taken place, supporting planning and conclusions.

Realising potential

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