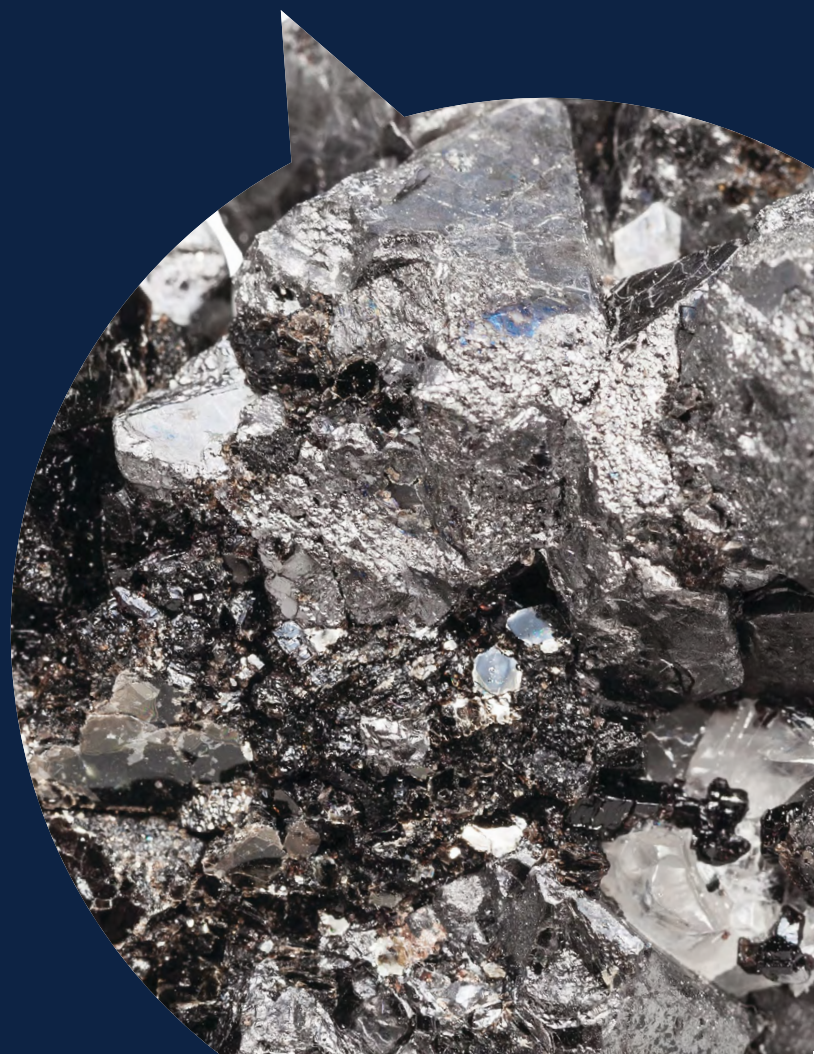
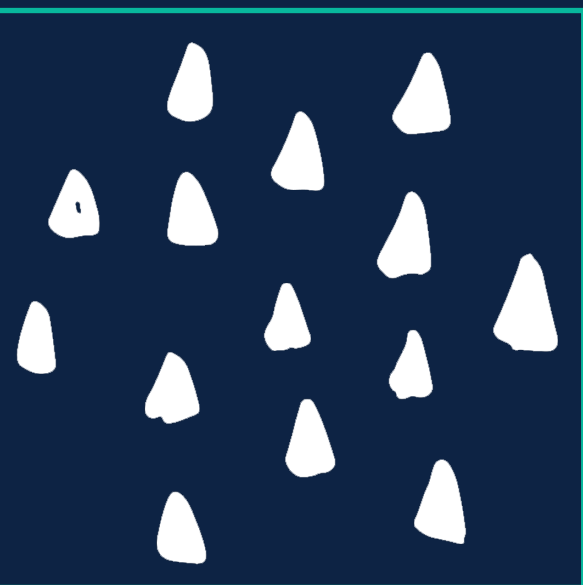


International AS and A-level **Chemistry**

(9620) Specification



For teaching from September 2019 onwards

For International AS exams

May/June 2020 onwards

For International A-level exams

May/June 2020 onwards

For teaching and examination outside
the United Kingdom

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Are you using the latest version of this specification?

- You will always find the most up-to-date version of this specification on our website at [oxfordaqa.com/9620](https://www.oxfordaqa.com/9620)
- We will write to you if there are significant changes to the specification.

1 Introduction

1.1 Why choose OxfordAQA International AS and A-levels?

Our international qualifications enable schools that follow a British curriculum to benefit from the best education expertise in the United Kingdom (UK).

Our International AS and A-levels offer the same rigour and high quality as AS and A-levels in the UK and are relevant and appealing to students worldwide. They reflect a deep understanding of the needs of teachers and schools around the globe and are brought to you by Oxford University Press and AQA, the UK's leading awarding body.

Providing valid and reliable assessments, these qualifications are based on over 100 years of experience, academic research and international best practice. They have been independently validated as being to the same standard as the qualifications accredited by the UK examinations regulator, Ofqual. They reflect the latest changes to the British system, enabling students to progress to higher education with up-to-date qualifications.

You can find out about OxfordAQA at oxfordaqa.com

1.2 Why choose our International AS and A-level Chemistry?

In developing our specifications, we consulted widely with teachers, learned societies and professionals from universities and industry. Our content is designed to stimulate student's interest in, and enthusiasm for, chemistry and provides an excellent grounding for further study.

Our assessments reward students' knowledge, understanding and application of a wide range of chemistry topics. These include all of those topics that universities expect students to understand in order to progress to higher education.

Our exams include a range of question styles, allowing students to demonstrate a range of skills. Our extensive experience allows us to write exams which are challenging but do not put unhelpful barriers to students. For example, we have a reduced word count in questions, eliminating any information that is not required for students to answer the question. This will particularly help students who speak English as a second language. Multiple choice questions are given at the end of papers allowing students to manage their time better.

Practical work is at the heart of science. Our specification includes ten required practicals that have been designed to give students a broad range of practical experiences. These will be assessed via the written papers, giving more flexibility to schools allowing them to choose how to deliver practical work through their teaching. The required practicals have also been chosen to minimise the use of resources or equipment that could potentially present difficulties in resourcing. This method of assessing practical work ensures all students are given the opportunity to gain key skills without the pressures of coursework or practical exams.

Our clear modular structure allows teachers to plan delivery of the content, and for students to be able to prepare for each exam appropriately. The knowledge and understanding from each module builds on the previous ones, and the skills required for each exam build to allow students to gain confidence in their practical, mathematical and communications skills as they learn.

Helpful resources support this specification. These include schemes of work and a Practical handbook which harmonises the rules for International A-level Biology, Chemistry and Physics. This allows your students to be confident in the knowledge that they are using the same rule in each of their OxfordAQA. The Practical handbook also includes example methods for each of the required practicals, allowing you to plan your practical work with confidence.

You can find out about all our International AS and A-level Chemistry qualifications at oxfordaqa.com/science

1.3 Recognition

OxfordAQA meet the needs of international students. Please refer to the published timetables on the exams administration page of our website ([oxfordaqa.com/exams-administration](https://www.oxfordaqa.com/exams-administration)) for up to date exam timetabling information. They are an international alternative and comparable in standard to the Ofqual regulated qualifications offered in the UK.

Our qualifications have been independently benchmarked by UK NARIC, the UK national agency for providing expert opinion on qualifications worldwide. They have confirmed they can be considered 'comparable to the overall GCE A-level and GCSE standard offered in the UK'. Read their report at [oxfordaqa.com/recognition](https://www.oxfordaqa.com/recognition)

To see the latest list of universities who have stated they accept these international qualifications visit [oxfordaqa.com/recognition](https://www.oxfordaqa.com/recognition)

1.4 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. That's why we've worked with experienced teachers to provide you with resources that will help you confidently plan, teach and prepare for exams.

Teaching resources

You will have access to:

- sample schemes of work to help you plan your course with confidence
- teacher guidance notes to give you the essential information you need to deliver the specification
- training courses to help you deliver our qualifications
- student textbooks that have been checked and approved by us
- engaging worksheets and activities developed by teachers, for teachers.

Preparing for exams

You will have access to the support you need to prepare for our exams, including:

- specimen papers and mark schemes
- exemplar student answers with examiner commentaries
- a searchable bank of past AQA exam questions mapped to these new International qualifications.

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

After the first examination series, you can use this tool to see 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.

Information about results, including maintaining standards over time, grade boundaries and our post-results services, will be available on our website in preparation for the first examination series.

Help and support

Visit our website for information, guidance, support and resources at oxfordaqa.com/9620

You can contact the subject team directly at science@oxfordaqa.com or call us on +44 (0)161 696 5995 (option 1 and then 1 again).

Please note: We aim to respond to all email enquiries within two working days.

Our UK office hours are Monday to Friday, 8am – 5pm.

2 Specification at a glance

The titles of the qualifications are:

- OxfordAQA International Advanced Subsidiary Chemistry
- OxfordAQA International Advanced Level Chemistry.

These qualifications are modular. The full International A-level is intended to be taken over two years. The specification content for the International AS is half that of an International A-level. The International AS can be taken as a stand-alone qualification or can be used to count towards the International A-level. Students can take the International AS in the first year and then take the International A2 in the second year to complete the International A-level or they can take all the units together in the same examination series at the end of the course.

The International AS content will be 50 % of the International A-level content but International AS assessments will contribute 40 % of the total marks for the full International A-level qualification with the remaining 60 % coming from the International A2 assessments.

Candidates may resit a unit any number of times within the shelf-life of the specification. The best result for each unit will count towards the final qualification. Exams will be available in January and May/June.

The guided learning hours (GLH) for an OxfordAQA International Advanced Subsidiary is 180.

The guided learning hours (GLH) for an OxfordAQA International Advanced Level is 360.

These figures are for guidance only and may vary according to local practice and the learner's prior experience of the subject.

2.1 Subject content

3.1 Physical chemistry

3.1.1 – 3.1.7 International AS Physical chemistry

3.1.8 – 3.1.12 International A2 Physical chemistry

3.2 Inorganic chemistry

3.2.1 – 3.2.3 International AS Inorganic chemistry

3.2.4 – 3.2.6 International A2 Inorganic chemistry

3.3 Organic chemistry

3.3.1 – 3.3.6 International AS Organic chemistry

3.3.7 – 3.3.16 International A2 Organic chemistry

2.2 International AS

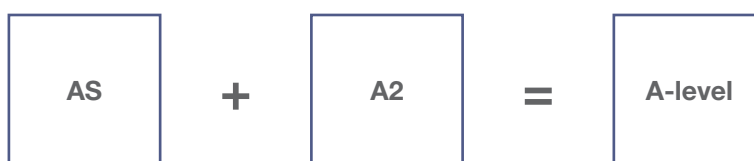
Assessments

Unit 1: Inorganic 1 and Physical 1	+	Unit 2: Organic 1 and Physical 1
What's assessed Content: 3.1.1 – 3.1.5 International AS Physical chemistry 3.2.1 – 3.2.3 International AS Inorganic chemistry		What's assessed Content: 3.1.6 – 3.1.7 International AS Physical chemistry 3.3.1 – 3.3.6 International AS Organic chemistry Although questions will not be set on topics from Unit 1, questions may draw on amount of substance in 3.1.2 and bonding principles in 3.1.3.
How it's assessed Written exam: 1 hour 30 minutes 70 marks 50 % of the International AS assessment 20 % of the International A-level assessment		How it's assessed Written exam: 1 hour 30 minutes 70 marks 50 % of the International AS assessment 20 % of the International A-level assessment
Questions A mixture of short and longer answer questions.		Questions A mixture of short and longer answer questions.

2.3 International A2

Assessments

Unit 3: Inorganic 2 and Physical 2	+	Unit 4: Organic 2 and Physical 2	+	Unit 5: Practical and synoptic
<p>What's assessed</p> <p>Content:</p> <p>3.1.8 – 3.1.10 International A2 Physical chemistry</p> <p>3.2.4 – 3.2.6 International A2 Inorganic chemistry</p> <p>Knowledge of chemistry from Units 1 and 2 is assumed.</p>		<p>What's assessed</p> <p>Content:</p> <p>3.1.11 – 3.1.12 International A2 Physical chemistry</p> <p>3.3.7 – 3.3.16 International A2 Organic chemistry</p> <p>Knowledge of chemistry from Units 1 and 2 is assumed.</p>		<p>What's assessed</p> <p>All content.</p>
<p>How it's assessed</p> <p>Written exam: 1 hour 30 minutes</p> <p>80 marks</p> <p>21 % of International A-level</p>		<p>How it's assessed</p> <p>Written exam: 1 hour 30 minutes</p> <p>80 marks</p> <p>21 % of International A-level</p>		<p>How it's assessed</p> <p>Written exam: 1 hour 25 minutes</p> <p>60 marks</p> <p>18 % of International A-level</p>
<p>Questions</p> <p>A mixture of short and longer answer questions.</p>		<p>Questions</p> <p>A mixture of short and longer answer questions.</p>		<p>Questions</p> <p>30 marks on practical work.</p> <p>30 marks of multiple choice questions.</p>



3 Subject content

This specification is divided into Physical chemistry, Inorganic chemistry and Organic chemistry. 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 taught in the first year of the course and will be assessed in the International AS assessments. The rest of each section is designed to be taught in the second year of the course and will be assessed in the International A2 assessments.

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 encourage an overarching approach to the teaching and learning of topic areas. They will not be directly assessed.

3.1 Physical chemistry

3.1.1 Atomic structure (International AS)

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 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

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

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.

3.1.1.3 Electron configuration

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 (International AS)

When chemists measure 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

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

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.

3.1.2.3 The ideal gas equation

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 .

3.1.2.4 Empirical and molecular formula

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.

3.1.2.5 Balanced equations and associated calculations

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.

Required practical 1:

Make up a volumetric solution and carry out a simple acid–base titration.

3.1.3 Bonding (International AS)

The physical and chemical properties of compounds depend on the ways in which the compounds are held together by chemical bonds and 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

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

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

Metallic bonding involves attraction between delocalised electrons and positive ions arranged in a lattice.

3.1.3.4 Bonding and physical properties

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.

3.1.3.5 Shapes of simple molecules and ions

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:

- name and 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.

3.1.3.6 Bond polarity

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

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.

3.1.4 Energetics (International AS)

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

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 ΔH_{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

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.

Required practical 2:

Measure an enthalpy change.

3.1.4.3 Applications of Hess's law

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.

3.1.4.4 Bond enthalpies

Mean bond enthalpy.

Students should be able to:

- define the term mean bond enthalpy
- use mean bond enthalpies to calculate an approximate value of ΔH for reactions in the gaseous phase
- explain why values from mean bond enthalpy calculations differ from those determined using Hess's law.

3.1.5 Oxidation, reduction and redox equations (International AS)

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.

3.1.5.1 Oxidation, reduction and redox equations

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.

3.1.6 Kinetics (International AS)

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.

3.1.6.1 Collision theory

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.

3.1.6.2 Maxwell–Boltzmann distribution

Maxwell–Boltzmann distribution of molecular energies in gases.

Students should be able to:

- draw and interpret distribution curves for different temperatures.

3.1.6.3 Effect of temperature on reaction rate

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.

3.1.6.4 Effect of concentration and pressure

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.

3.1.6.5 Catalysts

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.

3.1.7 Chemical equilibria, Le Chatelier's principle and K_c (International AS)

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.

3.1.7.1 Chemical equilibria and Le Chatelier's principle

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.

3.1.7.2 Equilibrium constant K_c for homogeneous systems

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 .

3.1.8 Thermodynamics (International A2)

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

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 can be 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

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.

3.1.9 Electrode potentials and electrochemical cells (International A2)

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.

3.1.9.1 Electrode potentials and cells

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.

Required practical 6:

Measure the EMF of an electrochemical cell.

3.1.9.2 Commercial applications of electrochemical cells

Electrochemical cells can be used as a commercial source of electrical energy.

The simplified electrode reactions in a lithium cell:

Positive electrode: $\text{Li}^+ + \text{CoO}_2 + \text{e}^- \rightarrow \text{Li}^+[\text{CoO}_2]^-$

Negative electrode: $\text{Li} \rightarrow \text{Li}^+ + \text{e}^-$

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.

3.1.10 Acids and bases (International A2)

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.

3.1.10.1 Brønsted–Lowry acid–base equilibria in aqueous solution

An acid is a proton donor.

A base is a proton acceptor.

Acid–base equilibria involve the transfer of protons.

3.1.10.2 Definition and determination of pH

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.

$$\text{pH} = -\log_{10}[\text{H}^+]$$

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.

3.1.10.3 The ionic product of water, K_w

Water is slightly dissociated.

K_w is derived from the equilibrium constant for this dissociation.

$$K_w = [\text{H}^+][\text{OH}^-]$$

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.

3.1.10.4 Weak acids and bases; K_a for weak acids

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.

3.1.10.5 pH curves, titrations and indicators

Titration 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.

Required practical 7:

Investigate how pH changes when a weak acid reacts with a strong base and when a strong acid reacts with a weak base.

3.1.10.6 Buffer action

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.

3.1.11 Rate equations (International A2)

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.

3.1.11.1 Rate equations

The rate of a chemical reaction is related to the concentration of reactants by a rate equation of the form:

$$\text{Rate} = k[\text{A}]^m [\text{B}]^n$$

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.

3.1.11.2 Determination of rate equation

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.

Required practical 8:

Measure the rate of reaction by an initial rate method and a continuous monitoring method.

3.1.12 Equilibrium constant K_p for homogeneous systems (International A2)

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.

3.1.12.1 Equilibrium constant K_p for homogeneous systems

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.

3.2 Inorganic chemistry

3.2.1 Periodicity (International AS)

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

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

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 (International AS)

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.

3.2.2.1 Group 2, the alkaline earth metals

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.

3.2.3 Group 7(17), the halogens (International AS)

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

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.

3.2.3.2 Uses of chlorine and chlorate(I)

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 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.

Required practical 3:

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 and chlorides (International A2)

The reactions of the Period 3 elements with oxygen and chlorine are considered. The pH of the solutions formed when the oxides and chlorides of Period 3 elements 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.

3.2.4.1 Properties of Period 3 elements and their oxides and chlorides

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 trends in the reactions of the elements Na, Mg, Al, Si, P and S with chlorine, limited to the formation of NaCl , MgCl_2 , Al_2Cl_6 , SiCl_4 and PCl_5

The reactions of the oxides Na_2O , MgO , Al_2O_3 , SiO_2 , P_4O_{10} , SO_2 and SO_3 and the chlorides NaCl , MgCl_2 , AlCl_3 , SiCl_4 and PCl_5 with water and the pH of the solutions formed.

The structures of the acids and the anions formed when the oxides P_4O_{10} , SO_2 and SO_3 and the chlorides SiCl_4 and PCl_5 react with water.

Students should be able to:

- explain the trend in the melting point of the specified oxides and chlorides in terms of their structure and bonding
- explain the trends in the reactions of the oxides and chlorides with water in terms of the type of bonding present in each specified oxide and chloride and write equations for these reactions
- write equations for the reactions that occur between the specified oxides and chlorides, and given acids and bases.

3.2.5 Transition metals (International A2)

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

Transition metal characteristics of elements Ti–Cu arise from an incomplete 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 ion 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

H₂O, NH₃ and Cl⁻ can act as monodentate ligands.

The ligands NH₃ and H₂O are similar in size and are uncharged.

Exchange of the ligands NH₃ and H₂O occurs without change of co-ordination number (eg Co²⁺ and Cu²⁺).

Substitution may be incomplete (eg the formation of [Cu(NH₃)₄(H₂O)₂]²⁺).

The Cl⁻ ligand is larger than the uncharged ligands NH₃ and H₂O

Exchange of the ligand H₂O by Cl⁻ can involve a change of co-ordination number (eg Co²⁺, Cu²⁺ and Fe³⁺).

Ligands can be bidentate (eg H₂NCH₂CH₂NH₂ and C₂O₄²⁻).

Ligands can be multidentate (eg EDTA⁴⁻).

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.

3.2.5.3 Shapes of complex ions

Transition metal ions commonly form octahedral complexes with small ligands (eg H₂O and NH₃).

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(NH₃)₂]⁺ as used in Tollens' reagent.

3.2.5.4 Formation of coloured ions

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.

3.2.5.5 Variable oxidation states

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(NH₃)₂]⁺ (Tollens' reagent) to metallic silver is used to distinguish between aldehydes and ketones.

The redox titrations of Fe²⁺ and C₂O₄²⁻ with MnO₄⁻

Students should be able to:

- perform calculations for these titrations and similar redox reactions.

3.2.5.6 Catalysts

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^-

3.2.6 Reactions of ions in aqueous solution (International A2)

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.

3.2.6.1 Reactions of ions in aqueous solution

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-}

Required practical 9:

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 (International AS)

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

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

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

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.

3.3.2 Alkanes (International AS)

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

Alkanes are saturated hydrocarbons.

Petroleum is a mixture consisting mainly of alkane hydrocarbons that can be separated by fractional distillation.

3.3.2.2 Modification of alkanes by cracking

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

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

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 (International AS)

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

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.

3.3.3.2 Elimination

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.

3.3.4 Alkenes (International AS)

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

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

Electrophilic addition reactions of alkenes with HBr, H₂SO₄ and Br₂

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.

3.3.4.3 Addition polymers

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.

3.3.4.4 Epoxyethane

The production of epoxyethane by the partial oxidation of ethene and understand the hazards of this process.

The reactions with water and alcohols and the uses of the products formed.

Students should be able to:

- explain the high reactivity of epoxyethane
- write equations for the reactions of epoxyethane with water and with alcohols and outline the mechanism for these reactions
- explain the economic and environmental importance of products including, surfactants and antifreeze, formed in these reactions.

3.3.5 Alcohols (International AS)

Alcohols have many scientific, medicinal and industrial uses.

3.3.5.1 Oxidation of alcohols

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.

3.3.5.2 Elimination

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.

Required practical 4:

Distil a product from a reaction.

3.3.6 Organic analysis (International AS)

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

The reactions of functional groups listed in the specification.

Students should be able to:

- identify the functional groups using reactions in the specification.

Required practical 5:

Carry out tests for alcohols, aldehydes, alkenes and carboxylic acids.

3.3.6.2 Mass spectrometry

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

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 booklet to identify particular bonds, and therefore functional groups, and also to identify impurities.

The link between absorption of infrared radiation by bonds in CO₂, methane and water vapour and global warming.

3.3.7 Optical isomerism (International A2)

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.

3.3.7.1 Optical isomerism

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.

3.3.8 Aldehydes and ketones (International A2)

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.

3.3.8.1 Aldehydes and ketones

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 NaBH₄ 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 NaBH₄ (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.

3.3.9 Carboxylic acids and derivatives (International A2)

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

The structures of:

- carboxylic acids
- esters.

Carboxylic acids are weak acids but will liberate CO₂ 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.

3.3.9.2 Acylation

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.

Required practical 10:

Prepare a pure organic solid and test its purity.

3.3.10 Aromatic chemistry (International A2)

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

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

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.

Sulfonation is an important step in synthesis including the manufacture of surfactant and sulfonamides.

Friedel–Crafts acylation reactions are also important steps in synthesis.

Free-radical attack by chlorine results in ring addition to benzene and side chain substitution in methylbenzene.

Students should be able to:

- outline the electrophilic substitution mechanisms of nitration and sulfonation on benzene and methylbenzene; identity of the products formed in these reactions
- outline the electrophilic substitution mechanisms of acylation and alkylation using AlCl_3 as a catalyst; identity of the products formed in these reactions
- outline the free-radical attack of chlorine on benzene and methylbenzene; identity of the products formed in these reactions
- explain the relative reactivities of chlorine substituted in the ring and in the side chain.

3.3.11 Amines (International A2)

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

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

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

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 (International A2)

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

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.

3.3.12.2 Biodegradability and disposal of polymers

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.

3.3.13 Amino acids and proteins (International A2)

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

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

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 Action of anticancer drugs

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 a protein.

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 (International A2)

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

3.3.14 Organic synthesis

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 (International A2)

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.

3.3.15.1 Nuclear magnetic resonance spectroscopy

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 ^1H atoms in a molecule.

^{13}C NMR gives simpler spectra than ^1H 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 ^1H atoms in different environments.

^1H 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 ^1H 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 ^1H 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.

3.3.16 Chromatography (International A2)

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.

3.3.16.1 Chromatography

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.

4 Scheme of assessment

Find mark schemes, and specimen papers for new courses, on our website at oxfordaqa.com/9620

These qualifications are modular. The full International A-level is intended to be taken over two years. The specification content for the International AS is half that of an International A-level.

The International AS can be taken as a stand-alone qualification or it can count towards the International A-level. To complete the International A-level, students can take the International AS in their first year and the International A2 in their second year or they can take all the units together in the same examination series at the end of the two year course.

The International AS content will be 50 % of the International A-level content. International AS assessments contribute 40 % of the total marks for the full International A-level qualification. The remaining 60 % comes from the International A2 assessments.

The specification provides an opportunity for students to produce extended responses either in words or using open-ended calculations.

The specification content will be split across units and will include some synoptic assessment. This allows students to draw together different areas of knowledge from across the full course of study.

All materials are available in English only.

Our International AS and A-level exams in Chemistry include questions that allow students to demonstrate their ability to:

- demonstrate knowledge and understanding of scientific, mathematical and practical techniques, principles and concepts
- apply their knowledge and understanding of scientific, mathematical and practical techniques, principles and concepts.

4.1 Availability of assessment units and certification

Examinations and certification for this specification are available as follows:

	Availability of units		Availability of certification	
	International AS	International A2	International AS	International A-level
June 2017	✓		✓	
January 2018	✓		✓	
June 2018	✓	✓	✓	✓
January 2019 onwards	✓	✓	✓	✓
June 2019 onwards	✓	✓	✓	✓

4.2 Aims

Science is more than facts and information. It is stimulating and helps us to make sense of the world around us in a way that no other subject allows.

Courses based on this specification should encourage students to:

- develop a deep appreciation, enjoyment and enthusiasm for science
- appreciate the breadth of the subject
- allow a depth of treatment that prepares students for further study in chemistry
- understand the tentative nature of science and understand the importance of critical thinking
- apply scientific knowledge and understanding in novel contexts
- develop practical, mathematical and communication skills.

4.3 Assessment Objectives

The exams will measure how students have achieved the following Assessment Objectives.

- AO1: Knowledge and understanding of scientific principles and concepts.
- AO2: Application of knowledge and understanding of scientific principles and concepts in both familiar and novel contexts.
- AO3: The ability to describe, analyse, interpret and evaluate scientific information presented in different forms.
- AO4: The ability to select, describe and evaluate scientific procedures.

Quality of Written Communication (QWC)

Students must:

- ensure that text is legible and that spelling, punctuation and grammar are accurate so that meaning is clear
- select and use a form and style of writing appropriate to purpose and to complex subject matter
- organise information clearly and coherently, using specialist vocabulary when appropriate.

Questions in the papers for this specification do not include specific marks for QWC. However, poor written communication may lead to lower marks due to lack of clarity in answers.

4.3.1 Assessment Objective weightings for International AS Chemistry

Assessment Objectives (AOs)	Unit weightings (approx %)		Overall weighting of AOs (approx %)
	Unit 1	Unit 2	
AO1	12	18	30
AO2	19	17	36
AO3	12	10	22
AO4	7	5	12
Overall weighting of units (%)	50	50	100

4.3.2 Assessment Objective weightings for International A-level Chemistry

Assessment Objectives (AOs)	Unit weightings (approx %)					Overall weighting of AOs (approx %)
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	
AO1	4.8	7.2	4.6	4.6	2.2	23
AO2	7.6	6.8	4.8	9.2	6.7	35
AO3	4.8	4.0	8.4	4.4	3.2	25
AO4	2.8	2.0	3.2	2.8	5.9	17
Overall weighting of units (%)	20	20	21	21	18	100

4.4 Assessment weightings

The raw marks awarded on each unit will be transferred to a uniform mark scale (UMS) to meet the weighting of the units and to ensure comparability between units sat in different exam series. Students' final grades will be calculated by adding together the uniform marks for all units. The maximum raw and uniform marks are shown in the table below.

Unit	Maximum raw mark	Percentage weighting International A-level (AS)	Maximum uniform mark
1	70	20 (50)	100
2	70	20 (50)	100
3	80	21	105
4	80	21	105
5	60	18	90
Qualification			
International AS (Unit 1 + Unit 2)	–	40 (100)	200
International A-level (Unit 1 + Unit 2 + Unit 3 + Unit 4 + Unit 5)	–	100	500

For more detail on UMS, see Section 5.3.

5 General administration

We are committed to delivering assessments of the highest quality and have developed practices and procedures to support this aim. To ensure all students have a fair experience, we have worked with other awarding bodies in England to develop best practice for maintaining the integrity of exams. This is published through the Joint Council for Qualifications (JCQ). We will maintain the same high standard through their use for OxfordAQA Exams.

More information on all aspects of administration is available at oxfordaqa.com/exams-administration

For any immediate enquiries please contact info@oxfordaqa.com

Please note: We aim to respond to all email enquiries within two working days.

Our UK office hours are Monday to Friday, 8am – 5pm local time.

5.1 Entries and codes

You should use the following subject award entry codes:

Qualification title	OxfordAQA Exams entry code
OxfordAQA International Advanced Subsidiary Chemistry	9621
OxfordAQA International Advanced Level Chemistry	9622

Please check the current version of the Entry Codes book and the latest information about making entries on oxfordaqa.com/exams-administration

You should use the following unit entry codes:

Unit 1 – CH01

Unit 2 – CH02

Unit 3 – CH03

Unit 4 – CH04

Unit 5 – CH05

A unit entry will not trigger certification. You will also need to make an entry for the overall subject award in the series that certification is required.

Exams will be available May/June and in January.

5.2 Overlaps with other qualifications

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

5.3 Awarding grades and reporting results

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

The International A-level qualification will be graded on a six-point scale: A*, A, B, C, D and E. To be awarded an A*, students will need to achieve a grade A on the full A-level qualification and 90% of the maximum uniform mark on the aggregate of the A2 units. Students who fail to reach the minimum standard for grade E will be recorded as U (unclassified) and will not receive a qualification certificate.

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

We will publish the minimum raw mark needed for each grade in each unit when we issue students' results. We will report a student's unit results to schools in terms of uniform marks and unit grades and we will report qualification results in terms of uniform marks and grades.

The relationship between uniform marks and grades is shown in the table below.

Grade	Uniform mark range per unit and per qualification						
	Unit 1	Unit 2	International AS Chemistry	Unit 3	Unit 4	Unit 5	International A-level Chemistry
Maximum uniform mark	100	100	200	105	105	90	500
A*							* See note below
A	80–100	80–100	160–200	84–105	84–105	72–90	400–500
B	70–79	70–79	140–159	74–83	74–83	63–71	350–399
C	60–69	60–69	120–139	63–73	63–73	54–62	300–349
D	50–59	50–59	100–119	53–62	53–62	45–53	250–299
E	40–49	40–49	80–99	42–52	42–52	36–44	200–249

* For the award of grade A*, a student must achieve grade A in the full International A-level qualification and a minimum of 270 uniform marks in the aggregate of Units 3, 4 and 5.

5.4 Resits

Unit results remain available to count towards certification, whether or not they have already been used, provided the specification remains valid. Students can resit units as many times as they like, as long as they're within the shelf-life of the specification. The best result from each unit will count towards the final qualification grade. Students who wish to repeat a qualification may do so by resitting one or more units.

To be awarded a new subject grade, the appropriate subject award entry, as well as the unit entry/entries, must be submitted.

5.5 Previous learning and prerequisites

There are no previous learning requirements. Any requirements for entry to a course based on this specification are at the discretion of schools.

5.6 Access to assessment: equality and inclusion

Our general qualifications are designed to prepare students for a wide range of occupations and further study whilst assessing a wide range of competences.

The subject criteria have been assessed to ensure they test specific competences. The skills or knowledge required do not disadvantage particular groups of students.

Exam access arrangements are available for students with disabilities and special educational needs.

We comply with the *UK Equality Act 2010* to make reasonable adjustments to remove or lessen any disadvantage that affects a disabled student. Information about access arrangements is issued to schools when they become OxfordAQA centres.

5.7 Working with OxfordAQA for the first time

You will need to apply to become an OxfordAQA centre to offer our specifications to your students. Find out how at oxfordaqa.com/centreapprovals

5.8 Private candidates

Centres may accept private candidates for examined units/components only with the prior agreement of OxfordAQA. If you are an approved OxfordAQA centre and wish to accept private candidates, please contact OxfordAQA at: info@oxfordaqa.com

As some of the marks in the AS and A-level papers will relate to practical work, students undertaking this specification must carry out the required practical activities in section 6.1 of the specification.

Centres accepting private candidates must ensure they have carried out this minimum requirement. Private candidates may also enter for examined only units via the British Council; please contact your local British Council office for details.

6 Practical assessment

Practical work is at the heart of science and we expect students taking this course to have a rich diet of practical work. This will allow them to fully appreciate the practical nature of science and understand the methods scientists use to investigate the world around us.

As schools around the world have very different circumstances, particularly around access to practical equipment, there is no direct assessment of practical work for this qualification. This allows teachers to choose the best ways to introduce practical work to their students. It also allows meaningful discussion of practical work in a way that is separated from the artificial rigors of coursework or other exam board set assessments.

To answer the questions on the papers for this specification, students must have had hands-on experience of the following required practicals. Questions may be set on these practicals directly, or on the skills contained within the practicals.

These skills could include, but are not limited to:

- planning experiments, including identifying and understanding how to control variables
- choosing equipment, or evaluating the use of specified pieces of equipment
- skills required for carrying out experiments such as taking readings or recording data
- choosing, constructing and interpreting appropriate graphical displays for data
- analysing and interpreting data, including carrying out calculations on data
- evaluating experimental procedures.

6.1 Required practical activities

International AS practical activities	International A2 practical activities
<p>Students must carry out the practical activities listed below. The International AS written papers test knowledge and understanding of the procedures involved and require an evaluation of the techniques adopted. Students may be required to interpret specimen results.</p> <p>Practical activity</p> <ol style="list-style-type: none">1. Make a volumetric solution and carry out a simple acid-base titration.2. Measure an enthalpy change.3. Carry out simple test-tube reactions to identify:<ul style="list-style-type: none">• cations – Group 2, NH_4^+• anions – Group 7 (halide ions), OH^-, CO_3^{2-}, SO_4^{2-}4. Distil a product from a reaction.5. Carry out tests for alcohols, aldehydes, alkenes and carboxylic acids.	<p>Students must complete the practical activities listed below. The International A2 written papers test knowledge and understanding of the procedures involved and require an evaluation of the techniques adopted. Students may be required to interpret specimen results.</p> <p>Practical activity</p> <ol style="list-style-type: none">6. Measure the electromotive force (EMF) of an electrochemical cell.7. Investigate how pH changes when a weak acid reacts with a strong base and when a strong acid reacts with a weak base.8. Measure the rate of reaction by an initial rate method and a continuous monitoring method.9. Carry out simple test-tube reactions to identify transition metal ions in aqueous solution.10. Prepare a pure organic solid and test its purity.

Schools entering students for this specification will be required to submit confirmation that students have had opportunities to complete all of the above required practical activities.

7 Mathematical requirements

Bold statements will be assessed in International A2 units only.

1. Carry out calculations in decimal and standard form, using an appropriate number of significant figures.
2. Recognise and use appropriate units in calculations.
3. Use fractions, ratios and percentages.
4. Use power functions.
5. Calculate arithmetic means.
6. Make estimates and order of magnitude calculations.
7. Identify and determine uncertainties in measurements, including calculating uncertainties in derived measurements and data (limited to data combined by addition, subtraction, multiplication, division and raising to powers).
8. Understand the symbols =, <, <<, >>, >, α , \approx , \neq , Δ , \rightleftharpoons
9. Change the subject of, substitute numbers into, or solve, algebraic equations.
10. Translate information between graphical, numerical and algebraic forms.
11. Plot graphs, draw lines of best fit on linear and non-linear graphs and extrapolate lines.
12. Determine the slope and intercept of a linear graph.
13. Calculate rate of change from linear and non-linear graphs, using tangents as required.
14. Distinguish between instantaneous rate of change and average rate of change.
15. **Use logarithmic and exponential functions.**
16. Visualise, represent and use angles in 2D and 3D structures and 2D representations of 3D structures.
17. Calculate areas, perimeters and volumes of simple shapes.

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