

1.1.1 Planning**Planning**

Can you design an experiment, selecting suitable apparatus and techniques and applying your chemistry knowledge to a practical problem?



Can you identify the variables that must be controlled in an experiment, and explain how to control them?



Can you evaluate whether an experimental method is appropriate for meeting the expected outcome?

**1.1.2 Implementing****Implementing**

Can you use a wide range of practical apparatus and techniques correctly?



Can you use appropriate SI units for measurements (e.g. g, cm³, dm³, mol dm⁻³, kJ mol⁻¹)?



Can you present observations and data in a suitable format, such as a results table with headings and units?

**1.1.3 Analysis****Analysis**

Can you process, analyse and interpret qualitative and quantitative experimental results and reach valid conclusions?



Can you apply appropriate mathematical skills to quantitative data?



Can you use significant figures appropriately when processing and reporting data?



Can you plot and interpret graphs, labelling axes with quantities and units?



Can you measure the gradient of a graph (including a tangent to a curve) and read off an intercept?

**1.1.4 Evaluation****Evaluation**

Can you evaluate results and draw conclusions from them?



Can you identify anomalies in experimental measurements and decide how to deal with them?



Can you identify the limitations in an experimental procedure?



Can you calculate the uncertainty and percentage error of a measurement from the resolution of the apparatus?



Can you assess the precision and accuracy of results, including margins of error?



Can you suggest refinements to an experimental design that would reduce errors or improve the results?



1.2.1

Practical skills

Practical skills assessed in the practical endorsement

Can you apply investigative approaches and methods to solve practical problems?



Can you use practical equipment and materials safely, identifying hazards and ways to minimise the risks?



Can you follow written procedures and instructions accurately?



Can you make and record observations and measurements accurately?



Can you keep appropriate records of your experimental activities?



Can you present information and data in a scientific way?



Can you use appropriate software and tools to process data, carry out research and report findings?



Can you use online and offline research sources to support your practical work?



Can you correctly cite sources of information?



Can you use a wide range of experimental and practical instruments, equipment and techniques appropriate to chemistry?



1.2.2

Use of apparatus and techniques

Measurement and heating

Can you use appropriate apparatus to record measurements of mass, time, volume of liquids and gases, and temperature?



Can you heat substances safely using a water bath, electric heater or sand bath?



Can you measure pH using pH charts, a pH meter or a pH probe on a data logger?



Chemical techniques

Can you use laboratory apparatus for titration, using a burette and pipette?	☐	☐	☐
Can you set up apparatus for distillation and heating under reflux, including Quickfit apparatus?	☐	☐	☐
Can you carry out qualitative tests for ions and organic functional groups?	☐	☐	☐
Can you filter mixtures, including filtration under reduced pressure?	☐	☐	☐
Can you make up a standard solution using a volumetric flask?	☐	☐	☐
Can you use acid-base indicators in titrations of weak and strong acids with weak and strong bases?	☐	☐	☐
Can you purify a solid product by recrystallisation?	☐	☐	☐
Can you purify a liquid product using a separating funnel?	☐	☐	☐
Can you use melting point apparatus to assess the purity of a solid?	☐	☐	☐
Can you use thin layer or paper chromatography?	☐	☐	☐
Can you set up electrochemical cells and measure their voltages?	☐	☐	☐
Can you safely handle and carry out reactions with corrosive, irritant, flammable and toxic substances?	☐	☐	☐
Can you measure rates of reaction by at least two different methods, such as an initial rate method and a continuous monitoring method?	☐	☐	☐

2.1.1

Atomic structure and isotopes

Atomic structure and isotopes

Can you define isotopes as atoms of the same element with different numbers of neutrons and different masses?



Can you use atomic number, mass number and ionic charge to work out the numbers of protons, neutrons and electrons in atoms and ions?



Can you explain the terms relative isotopic mass and relative atomic mass, based on the carbon-12 scale?



Can you use mass spectrometry data to determine the relative isotopic masses and abundances of isotopes?



Can you calculate the relative atomic mass of an element from the relative abundances of its isotopes?



Can you use the terms relative molecular mass, M_r , and relative formula mass, and calculate them from relative atomic masses?



2.1.2

Compounds, formulae and equations

Formulae and equations

Can you write formulae of ionic compounds from ionic charges, using prior knowledge of ions such as NO_3^- , CO_3^{2-} , SO_4^{2-} , OH^- , NH_4^+ , Zn^{2+} and Ag^+ ?



Can you construct balanced chemical equations, including ionic equations, with appropriate state symbols?



2.1.3

Amount of substance

The mole and formulae

Can you explain and use the terms amount of substance, mole (mol), Avogadro constant N_A ($6.02 \times 10^{23} \text{ mol}^{-1}$), molar mass (g mol^{-1}) and molar gas volume ($24.0 \text{ dm}^3 \text{ mol}^{-1}$ at RTP)?



Can you use the terms empirical formula and molecular formula?



Can you calculate empirical and molecular formulae from composition by mass or percentage composition, and from other experimental data?



Can you use the terms anhydrous, hydrated and water of crystallisation, and calculate the formula of a hydrated salt from experimental data?



Calculations

Can you calculate amounts of substance in mol from mass, gas volume, and solution volume and concentration?



Can you use the ideal gas equation, $pV = nRT$, including converting units?



Can you use stoichiometric relationships from balanced equations in calculations?



Can you calculate the percentage yield of a reaction?



Can you calculate atom economy, and explain the sustainability benefits (and economic advantages) of processes with high atom economy?



Can you describe the techniques and procedures used to measure mass, volumes of solutions and volumes of gases?



2.1.4 Acids

Acids, bases and neutralisation

Can you state the formulae of common acids (HCl , H_2SO_4 , HNO_3 , CH_3COOH) and alkalis (NaOH , KOH , NH_3), and explain that acids release H^+ and alkalis release OH^- in aqueous solution?



Can you explain the difference between strong and weak acids in terms of complete or partial dissociation?



Can you describe neutralisation as the reaction of H^+ with OH^- to form water, and of acids with carbonates, metal oxides and alkalis to form salts, including ionic equations?



Titration

Can you describe how to make up a standard solution and carry out an acid-base titration?



Can you carry out structured and non-structured titration calculations for familiar and unfamiliar acids and bases?



2.1.5 Redox

Oxidation number and redox

Can you apply the rules for assigning oxidation numbers to atoms in elements, compounds and ions?



Can you write formulae using oxidation numbers?



Can you use Roman numerals to show the magnitude of an oxidation number, e.g. iron(II), nitrate(III), nitrate(V)?



Can you define oxidation and reduction in terms of electron transfer and changes in oxidation number?



Can you describe redox reactions of metals with dilute acids to form salts, including full and ionic equations?



Can you interpret and make predictions from redox equations in terms of oxidation numbers and electron loss or gain?



2.2.1 Electron structure

Shells, sub-shells and orbitals

Can you state the number of electrons that can fill the first four shells?



Can you describe an atomic orbital as a region that can hold up to two electrons with opposite spins?



Can you describe the shapes of s- and p-orbitals?



Can you state the number of orbitals making up s-, p- and d-sub-shells, and the number of electrons each sub-shell can hold?



Can you apply the rules for filling orbitals in order of increasing energy, including that orbitals of the same energy are occupied singly before pairing (and 4s fills before 3d)?



Can you deduce the electron configurations of atoms up to $Z = 36$ and of ions of s- and p-block elements, using sub-shell notation and 'electrons in boxes'?



2.2.2 Bonding and structure

Ionic bonding

Can you describe ionic bonding as electrostatic attraction between positive and negative ions, and draw dot-and-cross diagrams for ionic compounds?



Can you explain the structure of a giant ionic lattice, e.g. NaCl?



Can you explain how ionic bonding affects melting and boiling points, solubility and electrical conductivity in solid, liquid and aqueous states?



Covalent bonding

Can you describe a covalent bond as the strong electrostatic attraction between a shared pair of electrons and the nuclei of the bonded atoms?



Can you draw dot-and-cross diagrams of molecules and ions with single, multiple and dative covalent (coordinate) bonds, including 'expansion of the octet' examples such as SF_6 ?



Can you use the term average bond enthalpy as a measure of covalent bond strength?



Shapes of molecules and ions

Can you use electron pair repulsion theory to predict the shapes of, and bond angles in, molecules and ions with up to six electron pairs (including lone pairs)?



Can you explain the shapes and bond angles of molecules such as CH_4 , NH_3 , H_2O , BF_3 , SF_6 and ions such as NH_4^+ , including that lone pairs repel more than bonding pairs?



Electronegativity and polarity

Can you define electronegativity and interpret Pauling electronegativity values?



Can you explain the difference between a non-polar bond and a polar bond with a permanent dipole?



Can you explain how molecular polarity depends on bond polarity and molecular shape, including symmetrical molecules where dipoles cancel?



Intermolecular forces

Can you explain induced dipole-dipole (London) forces and permanent dipole-dipole interactions between molecules?



Can you explain hydrogen bonding between molecules containing N, O or F bonded to H, including drawing hydrogen bonds with lone pairs and dipoles (e.g. in H_2O and NH_3)?



Can you explain the anomalous properties of water from hydrogen bonding, such as ice being less dense than liquid water and its relatively high melting and boiling points?



Can you explain the structure of a simple molecular lattice, e.g. I_2 or ice?



Can you explain the effect of structure and bonding on the melting and boiling points, solubility and electrical conductivity of simple molecular substances?



3.1.1

Periodicity

The periodic table

Can you describe how the periodic table is arranged by increasing proton number, in periods showing repeating trends in properties and in groups with similar chemical properties?



Can you describe the periodic trend in electron configurations across Periods 2 and 3?



Can you classify elements into s-, p- and d-blocks?



Ionisation energies

Can you define first ionisation energy and successive ionisation energies, and write equations for them?



Can you explain the trend in first ionisation energy across Periods 2 and 3 and down a group, in terms of nuclear charge, atomic radius and electron shielding, including the falls at sub-shell changes and electron pairing?



Can you use successive ionisation energies to predict the number of electrons in each shell and the group of an element?



Structure, bonding and properties

Can you describe metallic bonding as strong electrostatic attraction between cations and delocalised electrons?



Can you describe a giant metallic lattice structure, e.g. all metals?



Can you describe the giant covalent lattice structures of carbon (diamond, graphite and graphene) and silicon?



Can you explain the melting and boiling points, solubility and electrical conductivity of giant metallic and giant covalent lattices?



Can you explain the variation in melting points across Periods 2 and 3 in terms of structure and bonding?



3.1.2

Group 2

Group 2 elements

Can you explain that Group 2 elements are oxidised in redox reactions by losing their two outer s electrons to form 2+ ions?



Can you describe the relative reactivities of Group 2 elements Mg to Ba with oxygen, water and dilute acids, including equations?



Can you explain the increase in reactivity down Group 2 using first and second ionisation energies?



Can you describe the reactions of Group 2 oxides with water to form hydroxides, and the trend in alkalinity (pH) of the solutions down the group?



Can you describe the use of $\text{Ca}(\text{OH})_2$ in agriculture to neutralise acid soils?



Can you describe the use of $\text{Mg}(\text{OH})_2$ and CaCO_3 as antacids for treating indigestion?



3.1.3

The halogens

Properties and reactivity

Can you explain the existence of halogens as diatomic molecules and the trend in boiling points of Cl_2 , Br_2 and I_2 using induced dipole-dipole (London) forces?



Can you explain that halogens have an outer shell s^2p^5 configuration and are reduced by gaining one electron to form 1^- ions?



Can you describe the trend in reactivity of Cl_2 , Br_2 and I_2 using halide displacement reactions, including colours in aqueous and organic solutions?



Can you explain the trend in reactivity of the halogens in terms of the ease of forming 1^- ions, using atomic radius, shielding and nuclear attraction?



Disproportionation and uses of chlorine

Can you explain disproportionation as oxidation and reduction of the same element in a redox reaction?



Can you write the equation for the reaction of chlorine with water used in water purification?



Can you write the equation for the reaction of chlorine with cold, dilute aqueous NaOH used to make bleach?



Can you write equations for analogous disproportionation reactions of other halogens using oxidation numbers?



Can you evaluate the benefits of chlorine in water treatment (killing bacteria) against its risks, such as toxic chlorine gas and possible formation of chlorinated hydrocarbons?



Testing for halides

Can you describe the precipitation reactions of Cl^- , Br^- and I^- with aqueous silver ions, including precipitate colours and ionic equations?



Can you use the solubility of silver halide precipitates in dilute and concentrated aqueous ammonia to identify the halide ion?



3.1.4 Qualitative analysis

Test-tube tests for ions

Can you describe the test for carbonate ions, CO_3^{2-} , using dilute acid and identifying the CO_2 produced with limewater?



Can you describe the test for sulfate ions, SO_4^{2-} , using aqueous Ba^{2+} ions to form a white precipitate?



Can you describe the tests for halide ions, Cl^- , Br^- and I^- , using aqueous silver nitrate and aqueous ammonia?



Can you describe the test for ammonium ions, NH_4^+ , by warming with aqueous NaOH and testing the gas with moist red litmus paper?



Can you explain why the anion tests must be carried out in the sequence carbonate, then sulfate, then halide?



3.2.1 Enthalpy changes

Enthalpy and definitions

Can you explain that exothermic reactions have a negative ΔH and endothermic reactions a positive ΔH , in terms of heat transfer to or from the surroundings?



Can you construct enthalpy profile diagrams for exothermic and endothermic reactions?



Can you define activation energy as the minimum energy required to start a reaction by breaking bonds, and show it on an enthalpy profile diagram?



Can you state standard conditions (100 kPa and a stated temperature, usually 298 K) and standard states?



Can you define the standard enthalpy changes of reaction, formation, combustion and neutralisation?



Measuring enthalpy changes

Can you determine enthalpy changes from experimental results using $q = mc\Delta T$ and $\Delta H = -q/n$?



Can you describe techniques for measuring energy transferred in reactions, directly (e.g. neutralisation) and indirectly (e.g. via Hess's law), and evaluate sources of error?



Bond enthalpies and Hess's law

Can you define average bond enthalpy as the energy required to break one mole of a specified type of bond in gaseous molecules?



Can you explain exothermic and endothermic reactions in terms of the energy needed to break bonds and the energy released when bonds form?



Can you calculate enthalpy changes of reaction from average bond enthalpies, and explain why the result differs from the experimental value?



Can you state Hess's law and construct enthalpy cycles to calculate enthalpy changes from enthalpy changes of combustion?



Can you construct enthalpy cycles to calculate enthalpy changes from enthalpy changes of formation?



Can you construct and use unfamiliar enthalpy cycles from given data?



3.2.2 Reaction rates

Rates and collisions

Can you explain the effect of concentration, including pressure for gases, on the rate of reaction in terms of frequency of collisions?



Can you calculate reaction rates from the gradients of graphs of a changing quantity (e.g. mass, gas volume, concentration) against time, including drawing tangents?



Can you describe practical techniques for investigating reaction rates, such as measuring mass loss or gas volume against time?



Catalysts

Can you explain that a catalyst increases the rate of reaction without being used up overall?



Can you explain that a catalyst provides an alternative route with lower activation energy, and show this on an enthalpy profile diagram?



Can you distinguish homogeneous and heterogeneous catalysts?



Can you explain the economic and sustainability importance of catalysts, such as lower temperatures, reduced energy demand and reduced CO₂ from burning fossil fuels?



The Boltzmann distribution

Can you sketch and explain a Boltzmann distribution of molecular energies and its relationship to activation energy?



Can you use Boltzmann distributions to explain how increasing temperature increases the proportion of molecules with energy above E_a ?



Can you use a Boltzmann distribution to explain how a catalyst increases the proportion of molecules with energy above the (lowered) activation energy?



Dynamic equilibrium and Le Chatelier

Can you explain dynamic equilibrium in a closed system as forward and reverse reactions occurring at equal rates with constant concentrations?



Can you use le Chatelier's principle to predict qualitatively the effect of changes in temperature, pressure and concentration on the position of a homogeneous equilibrium?



Can you explain that a catalyst increases the rates of forward and reverse reactions equally and so does not change the position of equilibrium?



Can you describe techniques for investigating qualitatively how equilibrium position shifts with concentration and temperature changes?



Can you explain the compromise between equilibrium position and rate in industrial processes such as the Haber process (ammonia) and methanol production?

**The equilibrium constant K_c**

Can you write an expression for K_c for a homogeneous equilibrium?



Can you calculate K_c from given equilibrium concentrations?



Can you estimate the position of equilibrium qualitatively from the magnitude of K_c ?



4.1.1

Basic concepts of organic chemistry

Naming and formulae

Can you apply IUPAC rules to name organic compounds containing the functional groups in the specification, including the first ten alkanes and alkyl groups (e.g. 2-methylbutan-1-ol)?



Can you interpret and use general, structural, displayed and skeletal formulae?



Can you use the terms homologous series, functional group, alkyl group (C_nH_{2n+1}), aliphatic, alicyclic and aromatic?



Can you use the terms saturated and unsaturated, including $C=C$, $C\equiv C$ and aromatic rings?



Can you use the general formula of a homologous series to predict the formula of any member?



Can you explain structural isomerism and determine possible structural formulae for a given molecular formula?



Reaction mechanisms

Can you describe homolytic fission as forming two radicals, each atom taking one electron?



Can you describe heterolytic fission as one bonding atom taking both electrons?



Can you define a radical as a species with an unpaired electron and represent radicals with a dot (e.g. $Cl\cdot$ and $CH_3\cdot$)?



Can you use curly arrows to show the movement of an electron pair in heterolytic bond fission and bond formation?



Can you draw reaction mechanisms using curly arrows and relevant dipoles?



4.1.2

Alkanes

Properties of alkanes

Can you describe alkanes as saturated hydrocarbons with single C-C and C-H σ -bonds, with free rotation about the σ -bond?



Can you explain the tetrahedral shape and 109.5° bond angle around each carbon in an alkane using electron pair repulsion, and draw 3-D diagrams?



Can you explain the effect of chain length and branching on the boiling points of alkanes using induced dipole-dipole (London) forces?



Can you explain the low reactivity of alkanes in terms of the high bond enthalpy and very low polarity of σ -bonds?



Reactions of alkanes

Can you describe the complete combustion of alkanes as fuels, and incomplete combustion in limited oxygen, including the toxicity of carbon monoxide?



Can you explain the radical substitution of alkanes with chlorine and bromine in UV light, including initiation, propagation and termination equations?



Can you explain the limitations of radical substitution in synthesis, such as further substitution and substitution at different positions giving a mixture of products?



4.1.3

Alkenes

Structure and stereoisomerism

Can you describe alkenes as unsaturated hydrocarbons with a C=C bond made of a σ -bond and a π -bond, formed by sideways overlap of p-orbitals, and explain restricted rotation about the π -bond?



Can you explain the trigonal planar shape and 120° bond angle around each carbon of a C=C bond?



Can you explain stereoisomerism, E/Z isomerism and cis-trans isomerism?



Can you use Cahn-Ingold-Prelog (CIP) priority rules to identify E and Z isomers, e.g. E-but-2-ene and Z-but-2-ene, and explain when E/Z matches cis-trans?



Can you determine possible E/Z or cis-trans stereoisomers of an organic molecule from its structural formula?



Addition reactions

Can you explain the reactivity of alkenes in terms of the relatively low bond enthalpy of the π -bond?



Can you describe the addition of hydrogen to alkenes using a nickel catalyst to form alkanes?



Can you describe the addition of halogens to alkenes to form dihaloalkanes, including using bromine water to test for C=C?



Can you describe the addition of hydrogen halides to alkenes to form haloalkanes?



Can you describe the addition of steam to alkenes in the presence of an acid catalyst (e.g. H_3PO_4) to form alcohols?



Can you define an electrophile as an electron pair acceptor?



Can you describe the mechanism of electrophilic addition in alkenes, with curly arrows, carbocation intermediates and dipoles?



Can you use Markownikoff's rule to predict the major product of adding H-X to an unsymmetrical alkene (e.g. HBr to propene), in terms of primary, secondary and tertiary carbocation stability?



Polymers from alkenes

Can you describe addition polymerisation of alkenes and substituted alkenes, and deduce the repeat unit of a polymer from its monomer?



Can you identify the monomer that would produce a given section of an addition polymer?



Can you describe the benefits for sustainability of processing waste polymers by combustion for energy production?



Can you describe the use of waste polymers as an organic feedstock for making plastics and other chemicals?



Can you describe the removal of toxic waste products, such as HCl formed when PVC is burned?



Can you describe the environmental benefits of biodegradable and photodegradable polymers?

**4.2.1 Alcohols****Properties of alcohols**

Can you explain the polarity of alcohols and their water solubility in terms of hydrogen bonding, and their lower volatility compared with alkanes?



Can you classify alcohols as primary, secondary or tertiary?

**Reactions of alcohols**

Can you describe the combustion of alcohols?



Can you describe the oxidation of primary alcohols with acidified dichromate ($K_2Cr_2O_7/H_2SO_4$) to aldehydes (by distillation) and carboxylic acids (under reflux), including the colour change?



Can you describe the oxidation of secondary alcohols with acidified dichromate to form ketones?



Can you explain why tertiary alcohols resist oxidation?



Can you describe the elimination of H_2O from alcohols to form alkenes, using an acid catalyst (H_3PO_4 or H_2SO_4) and heat?



Can you describe the substitution of alcohols with halide ions in the presence of acid (e.g. $NaBr/H_2SO_4$) to form haloalkanes?



4.2.2 Haloalkanes**Substitution reactions**

Can you describe the hydrolysis of haloalkanes using hot aqueous alkali to form alcohols?



Can you describe the hydrolysis of haloalkanes using water in ethanolic silver nitrate to compare the rates of hydrolysis of different carbon-halogen bonds?



Can you define a nucleophile as an electron pair donor?



Can you describe the nucleophilic substitution mechanism for the hydrolysis of primary haloalkanes with aqueous alkali, using curly arrows and dipoles?



Can you explain the trend in hydrolysis rates of primary haloalkanes in terms of C-X bond enthalpies (C-F, C-Cl, C-Br, C-I)?

**Environmental concerns**

Can you explain the environmental concern over CFCs depleting the ozone layer, and write equations for the production of halogen radicals by UV light (e.g. $\text{CF}_2\text{Cl}_2 \rightarrow \text{CF}_2\text{Cl}\cdot + \text{Cl}\cdot$)?



Can you write equations for the catalysed breakdown of ozone by $\text{Cl}\cdot$ and by other radicals such as $\cdot\text{NO}$?

**4.2.3 Organic synthesis****Practical skills**

Can you describe the use of Quickfit apparatus for distillation and heating under reflux?



Can you describe how to prepare and purify an organic liquid, including using a separating funnel, drying with an anhydrous salt (e.g. MgSO_4 , CaCl_2) and redistillation?

**Synthetic routes**

Can you identify the individual functional groups in an organic molecule with more than one functional group?



Can you predict the properties and reactions of a molecule with more than one functional group?



Can you devise two-stage synthetic routes for preparing organic compounds using the functional group reactions in this specification?



4.2.4

Analytical techniques

Infrared spectroscopy

Can you explain that infrared radiation is absorbed by covalent bonds, causing them to vibrate more?



Can you explain the absorption of IR by atmospheric gases containing C=O, O-H and C-H bonds (e.g. CO₂, H₂O, CH₄) and the link to global warming?



Can you use an IR spectrum to identify an alcohol from its O-H absorption?



Can you use an IR spectrum to identify an aldehyde or ketone from its C=O absorption?



Can you use an IR spectrum to identify a carboxylic acid from its C=O absorption and broad O-H absorption?



Can you interpret and predict IR spectra of familiar or unfamiliar substances using supplied data?



Can you describe the use of IR spectroscopy to monitor air pollutants (e.g. CO and NO from car engines) and in breathalysers to measure ethanol in breath?



Mass spectrometry and combined techniques

Can you use a mass spectrum to identify the molecular ion peak and so the molecular mass of an organic compound?



Can you analyse fragmentation peaks in a mass spectrum to identify parts of a structure and suggest formulae of fragment ions?



Can you deduce the structure of an organic compound from combined elemental analysis, mass spectra and IR spectra?



Orders and rate equations

Can you explain and use the terms rate of reaction, order, overall order, rate constant, half-life and rate-determining step?



Can you deduce orders of reaction (0, 1 or 2) from experimental data?



Can you write a rate equation of the form $\text{rate} = k[\text{A}]^m[\text{B}]^n$?



Can you calculate the rate constant k from a rate equation, including its units?

**Concentration-time and rate-concentration graphs**

Can you deduce zero- and first-order reactions from the shape of a concentration-time graph?



Can you calculate reaction rates from the gradient of a concentration-time graph using tangents?



Can you measure the constant half-life of a first-order reaction from a concentration-time graph?



Can you determine k for a first-order reaction from its half-life using $k = \ln 2 / t_{1/2}$?



Can you deduce zero-, first- and second-order reactions from the shape of a rate-concentration graph?



Can you determine k for a first-order reaction from the gradient of a rate-concentration graph?



Can you describe techniques for investigating rates by the initial rates method (including clock reactions) and by continuous monitoring (including colorimetry)?

**Mechanisms and temperature**

Can you predict a rate equation consistent with a given rate-determining step of a multi-step reaction?



Can you propose possible steps in a reaction mechanism from the rate equation and the balanced equation?



Can you explain qualitatively the effect of temperature change on the rate and on the rate constant?



Can you use the Arrhenius equation, $k = Ae^{-E_a/RT}$?



Can you determine E_a and A graphically by plotting $\ln k$ against $1/T$, using $\ln k = -E_a/RT + \ln A$?



5.1.2

How far?

 K_c and K_p

Can you use the terms mole fraction and partial pressure?



Can you calculate the quantities present at equilibrium from given data?



Can you describe techniques for determining the quantities present at equilibrium?



Can you write expressions for K_c and K_p for homogeneous and heterogeneous equilibria, omitting solids and liquids for heterogeneous K_c ?



Can you calculate K_c and K_p , or related quantities, including determining units?

**Changing conditions**

Can you explain qualitatively how temperature changes affect the value of K for exothermic and endothermic reactions?



Can you explain that K is unaffected by changes in concentration, pressure or the presence of a catalyst?



Can you explain how the equilibrium constant controls the position of equilibrium when concentration, pressure or temperature change?



Can you apply these principles to other equilibrium constants, such as K_a ?



5.1.3

Acids, bases and buffers

Brønsted-Lowry acids and bases

Can you define a Brønsted-Lowry acid as a proton donor and a base as a proton acceptor?



Can you identify conjugate acid-base pairs?



Can you classify acids as monobasic, dibasic or tribasic?



Can you explain the role of H^+ in reactions of acids with metals and with bases (carbonates, metal oxides and alkalis), using ionic equations?

**pH and K_a**

Can you use the acid dissociation constant, K_a , for the extent of acid dissociation?



Can you convert between K_a and pK_a ?



Can you use $pH = -\log[H^+]$ and $[H^+] = 10^{-pH}$?



Can you use the ionic product of water, $K_w = [H^+][OH^-]$?



Can you calculate the pH of strong monobasic acids?



Can you calculate the pH of strong bases using K_w ?



Can you calculate pH, K_a or related quantities for weak monobasic acids using approximations?



Can you explain the limitations of these approximations for 'stronger' weak acids?



Buffers

Can you define a buffer solution as a system that minimises pH changes on addition of small amounts of acid or base?



Can you describe how a buffer is formed from a weak acid and a salt of the weak acid, e.g. CH_3COOH/CH_3COONa ?



Can you describe how a buffer is formed from excess weak acid and a strong alkali, e.g. excess $CH_3COOH/NaOH$?



Can you explain the role of the conjugate acid-base pair (e.g. CH_3COOH/CH_3COO^-) in an acid buffer when small amounts of H^+ or OH^- are added?



Can you calculate the pH of a buffer from K_a and the equilibrium concentrations of the conjugate acid-base pair?



Can you explain how the H_2CO_3/HCO_3^- buffer controls blood pH within 7.35 to 7.45?



Neutralisation and titration curves

Can you sketch and interpret pH titration curves for strong and weak acids with strong and weak bases?



Can you choose a suitable indicator for a titration from its pH range, and explain why none is suitable for weak acid-weak base titrations?



Can you explain indicator colour changes in terms of equilibrium shift between the HA and A^- forms?



Can you describe how to measure pH with a pH meter, including calibration?



5.2.1

Lattice enthalpy

Born-Haber cycles

Can you define lattice enthalpy as the enthalpy change for the formation of 1 mol of an ionic lattice from its gaseous ions, and use it as a measure of ionic bond strength?



Can you construct Born-Haber cycles for simple ionic solids (e.g. NaCl, MgCl₂) using enthalpy changes of formation and atomisation, ionisation energies and electron affinities?



Can you carry out calculations using Born-Haber cycles?



Solution and hydration

Can you explain and use the terms enthalpy change of solution and enthalpy change of hydration?



Can you construct enthalpy cycles linking enthalpy change of solution, hydration enthalpies and lattice enthalpy for simple ionic solids?



Can you carry out calculations using these enthalpy cycles?



Can you explain qualitatively the effect of ionic charge and ionic radius on the exothermic values of lattice enthalpy and hydration enthalpy?



5.2.2 Enthalpy and entropy

Entropy and free energy

Can you explain entropy as a measure of the dispersal of energy in a system, greater when a system is more disordered?



Can you explain the difference in entropy of solids, liquids and gases, and predict the sign of ΔS for changes of state and reactions that change the number of gaseous molecules?



Can you calculate the entropy change of a system, ΔS , from the entropies of reactants and products?



Can you explain that the feasibility of a process depends on the balance between ΔH and $T\Delta S$?



Can you use $\Delta G = \Delta H - T\Delta S$ to determine feasibility ($\Delta G < 0$) and to calculate the temperature at which a reaction becomes feasible?



Can you explain the limitations of ΔG predictions of feasibility in terms of kinetics (high activation energy)?



5.2.3 Redox and electrode potentials

Redox reactions and titrations

Can you explain and use the terms oxidising agent and reducing agent?



Can you construct redox equations using half-equations and oxidation numbers?



Can you interpret and predict reactions involving electron transfer?



Can you describe the techniques for redox titrations of Fe^{2+} with MnO_4^- and of I_2 with $\text{S}_2\text{O}_3^{2-}$?



Can you carry out structured and non-structured redox titration calculations, including for non-familiar redox systems?



Electrode potentials

Can you use the term standard electrode potential, E° , including its measurement using a standard hydrogen electrode under standard conditions?



Can you describe how to measure cell potentials for metals or non-metals in contact with their ions, and for ions of the same element in different oxidation states using a platinum electrode?



Can you calculate a standard cell potential by combining two standard electrode potentials?



Can you predict the feasibility of a reaction using standard cell potentials, and explain the limitations of such predictions in terms of kinetics and non-standard concentrations?



Storage and fuel cells

Can you apply electrode potential principles to modern storage cells, including lithium-based cells?



Can you explain that a fuel cell uses the energy from the reaction of a fuel (e.g. hydrogen) with oxygen to create a voltage, and write the electrode reactions?



5.3.1 Transition elements

Properties of transition elements

Can you deduce the electron configurations of atoms and ions of the d-block elements Sc to Zn, including Cr and Cu and the loss of 4s electrons before 3d?



Can you explain why the elements Ti to Cu are transition elements, forming at least one ion with a partially filled d-sub-shell?



Can you illustrate, using at least two transition elements, their variable oxidation states, coloured ions and catalytic behaviour (e.g. Cu^{2+} with Zn and acid; MnO_2 with H_2O_2)?



Complex ions

Can you explain the terms ligand, coordinate (dative covalent) bond, complex ion and coordination number?



Can you identify monodentate ligands (e.g. H_2O , Cl^- , NH_3) and bidentate ligands (e.g. $\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2$, 'en')?



Can you describe octahedral (e.g. $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$), tetrahedral (e.g. $[\text{CuCl}_4]^{2-}$, $[\text{CoCl}_4]^{2-}$) and square planar (e.g. Pt complexes) shapes of complex ions, with bond angles?



Can you describe cis-trans isomerism in square planar complexes such as $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$?



Can you describe optical isomerism in octahedral complexes with bidentate ligands, e.g. $[\text{Ni}(\text{en})_3]^{2+}$, and draw 3-D diagrams?



Can you describe the use of cisplatin as an anticancer drug that binds to DNA and prevents cell division, and its side effects?



Ligand substitution

Can you describe ligand substitution of $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ with concentrated HCl and with excess NH_3 , including colour changes and equations?



Can you describe ligand substitution of $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ with excess NH_3 to form $[\text{Cr}(\text{NH}_3)_6]^{3+}$, including colour changes?



Can you explain the biochemical importance of iron in haemoglobin, including ligand substitution of O_2 by CO ?



Precipitation and redox reactions

Can you describe the precipitation reactions, with colours and ionic equations, of Cu^{2+} , Fe^{2+} , Fe^{3+} , Mn^{2+} and Cr^{3+} with aqueous NaOH and aqueous NH_3 , including complex formation with excess?



Can you describe the interconversion of Fe^{2+} and Fe^{3+} by oxidation with $\text{H}^+/\text{MnO}_4^-$ and reduction with I^- , with colour changes?



Can you describe the reduction of $\text{Cr}_2\text{O}_7^{2-}$ to Cr^{3+} with Zn and acid, and the oxidation of Cr^{3+} to CrO_4^{2-} with H_2O_2 and OH^- , with colour changes?



Can you describe the reduction of Cu^{2+} to Cu^+ with I^- , and the disproportionation of Cu^+ to Cu^{2+} and Cu ?



Can you interpret and predict unfamiliar ligand substitution, precipitation and redox reactions of transition metal ions?



5.3.2

Qualitative analysis

Identifying ions

Can you describe the test-tube processes and techniques needed to identify the anions CO_3^{2-} , SO_4^{2-} , Cl^- , Br^- and I^- in an unknown compound?



Can you describe the test for the NH_4^+ cation in an unknown compound?



Can you identify the transition metal cations Cu^{2+} , Fe^{2+} , Fe^{3+} , Mn^{2+} and Cr^{3+} in an unknown compound using aqueous NaOH and NH_3 ?



Benzene and its structure

Can you compare the Kekulé model of benzene with the delocalised model, in terms of p-orbital overlap forming a delocalised π -system?



Can you review the experimental evidence for a delocalised rather than Kekulé structure, using bond lengths, enthalpy change of hydrogenation and resistance to reaction?



Can you use IUPAC rules to name substituted aromatic compounds?

**Electrophilic substitution**

Can you describe the nitration of benzene with concentrated nitric and sulfuric acids?



Can you describe the halogenation of benzene with a halogen in the presence of a halogen carrier (e.g. AlCl_3 , FeBr_3)?



Can you describe Friedel-Crafts alkylation and acylation of aromatic compounds using a haloalkane or acyl chloride with a halogen carrier, and its use in forming C-C bonds to an aromatic ring?



Can you outline the electrophilic substitution mechanisms for nitration and halogenation of arenes, including generation of the electrophile?



Can you explain why benzene is less reactive than alkenes towards bromine, in terms of delocalised π -electron density?



Can you interpret unfamiliar electrophilic substitution reactions of aromatic compounds, including predicting mechanisms?

**Phenols and directing effects**

Can you describe the weak acidity of phenols, shown by reaction with NaOH but not with carbonates?



Can you describe the electrophilic substitution of phenol with bromine to form 2,4,6-tribromophenol?



Can you describe the electrophilic substitution of phenol with dilute nitric acid to form 2-nitrophenol and 4-nitrophenol?



Can you explain the relative ease of electrophilic substitution of phenol compared with benzene, in terms of donation of an oxygen p-orbital lone pair into the π -system?



Can you explain the 2- and 4-directing effect of electron-donating groups (OH , NH_2) and the 3-directing effect of electron-withdrawing groups (NO_2)?



Can you predict substitution products of aromatic compounds using directing effects, and explain their importance in organic synthesis?



6.1.2 Carbonyl compounds**Reactions of carbonyls**

Can you describe the oxidation of aldehydes to carboxylic acids using $\text{Cr}_2\text{O}_7^{2-}/\text{H}^+$ ($\text{K}_2\text{Cr}_2\text{O}_7/\text{H}_2\text{SO}_4$)?



Can you describe the reduction of carbonyl compounds with NaBH_4 to form alcohols?



Can you describe the reaction of carbonyl compounds with HCN (from NaCN and H^+) to form hydroxynitriles?



Can you outline the nucleophilic addition mechanism for reactions of aldehydes and ketones with NaBH_4 and HCN ?

**Tests for carbonyls**

Can you describe the use of 2,4-dinitrophenylhydrazine (2,4-DNP) to detect a carbonyl group?



Can you describe how the melting point of a 2,4-DNP derivative is used to identify a carbonyl compound?



Can you describe the use of Tollens' reagent (ammoniacal silver nitrate) to detect an aldehyde group and distinguish aldehydes from ketones, explaining the silver mirror in terms of oxidation and reduction?

**6.1.3 Carboxylic acids and esters****Carboxylic acids**

Can you explain the water solubility of carboxylic acids in terms of hydrogen bonding?



Can you describe the reactions of carboxylic acids in aqueous conditions with metals?



Can you describe the reactions of carboxylic acids with bases, including carbonates, metal oxides and alkalis?

**Esters**

Can you describe the esterification of carboxylic acids with alcohols in the presence of an acid catalyst (e.g. concentrated H_2SO_4)?



Can you describe the esterification of acid anhydrides with alcohols?



Can you describe the hydrolysis of esters in hot aqueous acid to form carboxylic acids and alcohols?



Can you describe the hydrolysis of esters in hot aqueous alkali to form carboxylate salts and alcohols?



Acyl chlorides

Can you describe the formation of acyl chlorides from carboxylic acids using SOCl_2 ?



Can you describe the use of acyl chlorides in synthesis to form esters, carboxylic acids, and primary and secondary amides?

**6.2.1****Amines****Amines**

Can you explain the basicity of amines in terms of proton acceptance by the nitrogen lone pair, and their reactions with dilute acids (e.g. HCl) to form salts?



Can you describe the preparation of aliphatic amines by substitution of haloalkanes with excess ethanolic ammonia, and of secondary amines from amines?



Can you describe the preparation of aromatic amines by reduction of nitroarenes using tin and concentrated hydrochloric acid?

**6.2.2****Amino acids, amides and chirality****Amino acids and amides**

Can you write the general formula of an α -amino acid as $\text{RCH}(\text{NH}_2)\text{COOH}$?



Can you describe the reactions of the carboxylic acid group of amino acids with alkalis and in forming esters?



Can you describe the reaction of the amine group of amino acids with acids?



Can you draw the structures of primary and secondary amides?

**Chirality**

Can you describe optical isomerism as stereoisomerism with non-superimposable mirror images about a chiral centre?



Can you identify chiral centres in any organic molecule?



Can you draw 3-D diagrams of a pair of optical isomers (enantiomers)?



6.2.3 Polyesters and polyamides**Condensation polymers**

Can you describe condensation polymerisation to form polyesters, from a diol and dicarboxylic acid (or dioyl dichloride) or from a hydroxycarboxylic acid?	☐ ☐ ☐
Can you describe condensation polymerisation to form polyamides, from a diamine and dicarboxylic acid (or dioyl dichloride) or from amino acids?	☐ ☐ ☐
Can you describe the acid and base hydrolysis of the ester groups in polyesters?	☐ ☐ ☐
Can you describe the acid and base hydrolysis of the amide groups in polyamides?	☐ ☐ ☐
Can you predict the repeat unit of a polymer from given monomers, for addition and condensation polymerisation?	☐ ☐ ☐
Can you predict the monomers required to form a given section of a polymer?	☐ ☐ ☐
Can you identify whether a polymer was formed by addition or condensation polymerisation?	☐ ☐ ☐

6.2.4 Carbon-carbon bond formation**Forming C-C bonds**

Can you explain the use of C-C bond formation in synthesis to increase the length of a carbon chain?	☐ ☐ ☐
Can you describe the formation of nitriles by nucleophilic substitution of haloalkanes with cyanide ions in ethanol?	☐ ☐ ☐
Can you describe the formation of hydroxynitriles by nucleophilic addition of HCN to carbonyl compounds?	☐ ☐ ☐
Can you describe the reduction of nitriles (e.g. H_2/Ni) to form amines?	☐ ☐ ☐
Can you describe the acid hydrolysis of nitriles to form carboxylic acids?	☐ ☐ ☐
Can you describe the formation of substituted aromatic C-C bonds by Friedel-Crafts alkylation and acylation using a halogen carrier?	☐ ☐ ☐

6.2.5 Organic synthesis**Practical techniques**

Can you describe the use of Quickfit apparatus for distillation and heating under reflux?	☐ ☐ ☐
Can you describe the preparation and purification of an organic solid using filtration under reduced pressure, recrystallisation and melting point determination?	☐ ☐ ☐

Synthetic routes

Can you identify the individual functional groups in an organic molecule containing several functional groups?



Can you predict the properties and reactions of an organic molecule containing several functional groups?



Can you devise multi-stage synthetic routes for preparing organic compounds, giving reagents and conditions?

**6.3.1****Chromatography and qualitative analysis****Chromatography**

Can you interpret one-way TLC chromatograms in terms of R_f values?



Can you interpret gas chromatograms in terms of retention times?



Can you interpret gas chromatograms in terms of the amounts and proportions of components, using peak areas?

**Tests for functional groups**

Can you test for alkenes using bromine?



Can you test for haloalkanes using aqueous silver nitrate in ethanol?



Can you test for phenols by their weak acidity (reaction with NaOH but not with carbonate)?



Can you test for carbonyl compounds using 2,4-DNP?



Can you test for aldehydes using Tollens' reagent?



Can you test for primary and secondary alcohols and aldehydes using acidified dichromate?



Can you test for carboxylic acids using aqueous carbonate?

**6.3.2****Spectroscopy****NMR spectroscopy**

Can you analyse a carbon-13 NMR spectrum to predict the number and types of carbon environments (from chemical shifts) and possible structures?



Can you analyse a high resolution proton NMR spectrum to predict the number and types of proton environments from chemical shifts?



Can you use peak areas (integration traces or ratio numbers) to find the relative numbers of each type of proton?



Can you use spin-spin splitting patterns and the $n + 1$ rule to find the number of non-equivalent protons adjacent to a proton environment?



Can you suggest possible structures for a molecule from its proton NMR spectrum?



Can you predict the carbon-13 or proton NMR spectrum of a given molecule?



Can you explain the use of tetramethylsilane (TMS) as the standard for chemical shift measurements?



Can you explain the need for deuterated solvents, e.g. CDCl_3 , when running an NMR spectrum?



Can you identify O-H and N-H protons by proton exchange using D_2O ?



Combined techniques

Can you deduce the structure of an organic compound from combined elemental analysis, mass spectra, IR spectra and NMR spectra?



Practical activity groups

PAG1 Can you carry out a moles determination, e.g. finding the molar mass of a gas or the formula of a hydrated salt?	☐	☐	☐
PAG2 Can you carry out an acid-base titration, including making up a standard solution?	☐	☐	☐
PAG3 Can you determine an enthalpy change experimentally, directly and indirectly via Hess's law?	☐	☐	☐
PAG4 Can you carry out qualitative analysis to identify unknown ions?	☐	☐	☐
PAG5 Can you synthesise and purify an organic liquid using reflux, distillation and a separating funnel?	☐	☐	☐
PAG6 Can you synthesise and purify an organic solid by recrystallisation and check its purity by melting point?	☐	☐	☐
PAG7 Can you carry out qualitative analysis of organic functional groups?	☐	☐	☐
PAG8 Can you set up electrochemical cells and measure cell potentials?	☐	☐	☐
PAG9 Can you investigate a rate of reaction by a continuous monitoring method?	☐	☐	☐
PAG10 Can you investigate a rate of reaction by an initial rates method, e.g. a clock reaction?	☐	☐	☐
PAG11 Can you measure pH with a pH meter, e.g. to plot a titration curve or find K_a ?	☐	☐	☐
PAG12 Can you research a chemistry topic and plan an investigation, citing sources correctly?	☐	☐	☐