1a Atomic structure and mass spectrometry

Sub-atomic particles

- Can you describe the structure of an atom in terms of electrons, protons and neutrons?
- Can you state the relative mass and relative charge of protons, neutrons and electrons?
- Can you define atomic (proton) number and mass number?
- Can you work out the number of protons, neutrons and electrons in atoms, molecules and ions from atomic and mass numbers?
- Can you explain what isotopes are?

Relative masses

- Can you define relative isotopic mass and relative atomic mass using the carbon-12 scale?
- Can you define relative molecular mass and relative formula mass, and know which to use for molecular and ionic compounds?

Mass spectrometry

- Can you use mass spectrometry data to work out relative atomic mass from the relative abundances of isotopes?
- Can you use relative atomic mass and isotope data to calculate relative abundances?
- Can you predict the mass spectrum of a diatomic element such as chlorine, including the m/z values and relative peak heights?
- Can you use mass spectrometry to find the relative molecular mass of a molecule from its molecular ion peak?

1b Ionisation energies and electronic configuration

Ionisation energies

- Can you define first ionisation energy and successive ionisation energies, and write equations for them with state symbols?
- Can you explain how nuclear charge, atomic radius and electron shielding affect ionisation energy?
- Can you explain the general increase in first ionisation energy across a period?
- Can you explain the decrease in first ionisation energy down a group?

- Can you explain how successive ionisation energies give evidence for quantum shells and the group number of an element?
- Can you explain how the pattern of first ionisation energies across a period gives evidence for electron sub-shells?

Shells, orbitals and sub-shells

- Can you state the number of electrons that can fill the first four quantum shells?
- Can you describe an orbital as a region holding up to two electrons with opposite spins?
- Can you draw the shapes of s-orbitals and p-orbitals?
- Can you state the number of electrons held in s, p and d sub-shells?
- Can you explain why electrons occupy orbitals in a sub-shell singly before pairing?
- Can you write electronic configurations of atoms and ions up to Z = 36 using s, p, d notation and electrons-in-boxes?

Blocks and periodicity

- Can you classify elements as s-, p- or d-block from their electronic configuration?
- Can you explain that the chemical properties of an element depend on its electronic configuration?
- Can you explain the term periodicity as the repeating pattern of properties across periods?
- Can you describe and explain the trends in melting and boiling temperatures and first ionisation energy across Periods 2 and 3 in terms of structure and bonding?
- Can you illustrate periodicity using data such as electronic configuration, atomic radius, melting temperature and ionisation energy?

2A Bonding

Ionic bonding

- Can you describe ionic bonding as strong electrostatic attraction between oppositely charged ions?
- Can you explain how ionic radius and ionic charge affect the strength of ionic bonding?
- Can you explain how ions form by electron loss or gain?
- Can you draw dot-and-cross diagrams to show electrons in ions?
- Can you describe and explain trends in ionic radius down a group and for isoelectronic ions such as N3- to Al^{3+}?
- Can you describe the physical evidence for ions, such as the migration of coloured ions in electrolysis?

Covalent bonding

- Can you describe covalent bonding as strong electrostatic attraction between two nuclei and a shared pair of electrons?
- Can you draw dot-and-cross diagrams for covalent molecules and ions, including multiple bonds and dative covalent bonds?
- Can you explain the relationship between bond length and bond strength for covalent bonds?

Shapes of molecules

- Can you explain that the shape of a molecule or ion depends on repulsion between electron pairs, with lone pairs repelling more than bonding pairs?
- Can you predict and explain the shapes and bond angles of molecules and ions with up to six electron pairs, such as $BeCl_2$, BCl_3, CH_4, NH_3, NH_4^+, H_2O, CO_2, gaseous PCl_5 and SF_6?
- Can you use electron-pair repulsion to predict the shapes and bond angles of unfamiliar analogous species?

Electronegativity and polarity

- Can you define electronegativity and describe the trends in it across a period and down a group?
- Can you explain the ionic-covalent bonding continuum in terms of electronegativity difference and bond polarity?
- Can you explain why a molecule with polar bonds may be non-polar overall because of its symmetry?

Intermolecular forces

Can you describe the origin of London forces, permanent dipole-dipole forces and hydrogen bonds?

Can you draw hydrogen bonding in H_2O, NH_3 and HF, showing the lone pair and the near-180° bond angle?

Can you explain the anomalous properties of water, such as its high melting and boiling temperatures and the low density of ice?

Can you predict whether a substance will form hydrogen bonds from its structure?

Can you explain trends in boiling temperatures of alkanes (including branching), alcohols and hydrogen halides in terms of intermolecular forces?

Can you explain the choice of solvent for a solute, including water for ionic compounds, alcohols dissolving in water and non-aqueous solvents for compounds without hydrogen bonding?

Metallic bonding

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

2B Structure

Lattice types

Can you describe the structures of giant ionic, giant covalent (giant molecular) and giant metallic lattices, with examples?

Can you describe simple molecular lattices, such as iodine and ice?

Can you describe the structures of the carbon allotropes graphite, diamond and graphene, and relate them to their properties?

Linking structure and properties

Can you predict the type of structure and bonding in a substance from data such as melting temperature, solubility and electrical conductivity?

Can you predict the physical properties of a substance, such as melting temperature and conductivity, from its structure and bonding?

3 Redox I

Oxidation numbers

- Can you explain the term oxidation number?
- Can you calculate oxidation numbers of elements in compounds and ions?
- Can you use Roman numerals to show oxidation numbers in names, such as iron(II) and chlorate(V)?
- Can you write formulae from names that include oxidation numbers?

Oxidation and reduction

- Can you describe oxidation and reduction in terms of electron transfer and changes in oxidation number for s- and p-block elements?
- Can you define oxidation as electron loss and reduction as electron gain?
- Can you explain that an oxidising agent gains electrons and is itself reduced?
- Can you explain that a reducing agent loses electrons and is itself oxidised?
- Can you explain disproportionation as simultaneous oxidation and reduction of the same element, with examples?
- Can you use oxidation numbers to classify reactions as redox or not?
- Can you explain why metals generally form positive ions by losing electrons?
- Can you explain why non-metals generally form negative ions by gaining electrons?

Equations

- Can you write ionic half-equations and combine them to give full ionic equations?

4A Groups 1 and 2

Group 2 trends and reactions

- Can you explain the trend in first ionisation energy down Group 2?
- Can you explain the increase in reactivity down Group 2 in terms of ionisation energy?
- Can you describe and write equations for the reactions of Mg to Ba with oxygen, chlorine and water?
- Can you describe the reactions of Group 2 oxides and hydroxides with water and dilute acid, and the trend in the alkalinity of the hydroxides?
- Can you describe the trends in solubility of Group 2 hydroxides and sulfates?

Thermal stability and flame tests

- Can you explain the trend in thermal stability of Group 1 and 2 nitrates and carbonates in terms of cation charge density and polarisation of the anion?
- Can you write equations for the thermal decomposition of Group 1 and 2 nitrates and carbonates, including the exceptions of lithium?
- Can you explain the formation of flame colours in terms of electron transitions, and state the flame colours of Group 1 and 2 ions?
- Can you describe experiments to compare the thermal decomposition of nitrates and carbonates and to carry out flame tests?

4B Group 7 (chlorine to iodine)

Trends

- Can you describe and explain the trends in melting and boiling temperatures, physical state at room temperature and electronegativity of the halogens?
- Can you explain the trend in reactivity of the halogens down Group 7 in terms of oxidising power?

Reactions of halogens

- Can you describe and write equations for displacement reactions between halogens and halide ions, including colours in aqueous and organic solvents?
- Can you describe the disproportionation of chlorine with water and with cold and hot aqueous alkali, using oxidation numbers?
- Can you analyse halogen reactions, such as those of chlorine with water and sodium hydroxide, in terms of redox?

Halides and hydrogen halides

- Can you describe the reactions of solid halides with concentrated sulfuric acid and explain the increasing reducing power from Cl^- to I^-?
- Can you describe the tests for halide ions using acidified silver nitrate, followed by dilute and concentrated ammonia?
- Can you describe the reactions of hydrogen halides with ammonia and with water?
- Can you predict properties and reactions of fluorine and astatine from Group 7 trends?

4C Analysis of inorganic compounds

Ion tests

- Can you identify Group 1 and 2 cations using flame tests?
- Can you test for ammonium ions using sodium hydroxide and damp red litmus?
- Can you test for carbonate and hydrogencarbonate ions using dilute acid and limewater?
- Can you test for sulfate ions using acidified barium chloride?
- Can you test for halide ions using acidified silver nitrate and ammonia?

5 Amounts of substance

The mole

- Can you explain that the mole is the unit for amount of substance?
- Can you use the Avogadro constant, L, in calculations involving numbers of particles?
- Can you define and use molar mass in g mol-1?

Formulae and equations

- Can you define empirical formula and molecular formula?
- Can you calculate empirical and molecular formulae from composition by mass, percentage composition or experimental data?
- Can you write balanced full and ionic equations, including state symbols?

Calculations

- Can you calculate amounts of substance in mol from given data?
- Can you calculate reacting masses using balanced equations?
- Can you calculate reacting volumes of gases from amounts of substance?
- Can you use molar volume (24 dm3 mol-1 at room temperature and pressure) in gas volume calculations, including determining molar volume experimentally?
- Can you carry out calculations involving solution concentrations in mol dm^{-3} and g dm^{-3}, including titration calculations and making standard solutions?
- Can you calculate percentage yield and atom economy, and explain why atom economy matters for sustainability?
- Can you relate ionic and full equations to the observations made in simple test-tube reactions?

Errors and safety

- Can you calculate measurement uncertainties and identify sources of error in experiments?
- Can you suggest ways of reducing percentage uncertainty and percentage error in experiments?
- Can you identify risks and hazards in practical procedures and suggest suitable precautions?

6A Introductory organic chemistry

Formulae and naming

- Can you explain that a hydrocarbon contains carbon and hydrogen only?
- Can you represent organic molecules using empirical, molecular, general, structural, displayed and skeletal formulae?
- Can you define homologous series and functional group?
- Can you name compounds using IUPAC rules for chains up to C10?
- Can you classify reactions as addition, elimination, substitution, oxidation, reduction, hydrolysis or polymerisation?

Isomerism

- Can you identify and draw structural isomers (chain, positional and functional group) for a given molecular formula?
- Can you explain E/Z isomerism as a type of stereoisomerism caused by restricted rotation about C=C?
- Can you explain cis-trans isomerism as a special case of E/Z isomerism where two substituents are the same?

6B Alkanes

Fuels and pollution

- Can you state the general formula of alkanes, C_nH_{2n+2}?
- Can you explain that alkanes and cycloalkanes are saturated hydrocarbons?
- Can you explain how fuels are obtained from crude oil by fractional distillation, cracking and reforming?
- Can you explain that reforming turns straight-chain alkanes into branched and cyclic hydrocarbons that burn more efficiently?
- Can you name the pollutants formed by burning fuels: CO, oxides of nitrogen and sulfur, carbon particulates and unburned hydrocarbons?
- Can you explain the problems caused by these pollutants, including the toxicity of CO and the acidity of nitrogen and sulfur oxides?
- Can you explain how a catalytic converter reduces the emission of pollutants?
- Can you compare the benefits and drawbacks of alternative fuels such as biodiesel and alcohols from plants with fossil fuels?

Reactions of alkanes

- Can you define a radical as a species with an unpaired electron and explain how radicals form by homolytic fission?
- Can you write equations for the complete and incomplete combustion of alkanes?
- Can you describe the radical substitution of alkanes with halogens in terms of initiation, propagation and termination steps?
- Can you explain the limitations of radical substitution, including further substitution giving a mixture of products?

6C Alkenes

Structure and bonding

- Can you state the general formula of alkenes, CnH2n?
- Can you explain that alkenes and cycloalkenes are unsaturated hydrocarbons?
- Can you describe the C=C double bond in terms of a σ bond and a π bond formed by overlap of orbitals?
- Can you define the term electrophile?
- Can you explain that heterolytic fission produces ions?

Addition reactions

- Can you describe the addition of hydrogen to alkenes with a nickel catalyst, and its use in making margarine from vegetable oils?
- Can you describe the addition of halogens to alkenes to form dihalogenoalkanes?
- Can you describe the addition of hydrogen halides to alkenes to form halogenoalkanes?
- Can you describe the addition of steam to alkenes with an acid catalyst to form alcohols?
- Can you describe the oxidation of alkenes by acidified potassium manganate(VII) to form diols?
- Can you draw the electrophilic addition mechanisms for alkenes with halogens, hydrogen halides and other binary compounds, using curly arrows?
- Can you explain the products of addition to unsymmetrical alkenes using the relative stabilities of primary, secondary and tertiary carbocations?
- Can you describe the test for C=C using bromine water, which is decolourised?

Polymers

- Can you describe addition polymerisation and draw the repeat unit from a monomer, and the monomer from a repeat unit?
- Can you describe how waste polymers can be dealt with by recycling, incineration for energy and use as a feedstock for cracking?
- Can you explain how chemists make polymer use more sustainable across a product's life cycle?
- Can you explain how chemists reduce polymer disposal problems by developing biodegradable polymers and removing toxic gases from incineration?

6D Halogenoalkanes

Classification and reactions

- Can you classify halogenoalkanes as primary, secondary or tertiary?
- Can you define the term nucleophile?
- Can you describe the reaction of halogenoalkanes with aqueous KOH to form alcohols, with OH^- as the nucleophile?
- Can you describe the reaction of halogenoalkanes with aqueous silver nitrate in ethanol, with water as the nucleophile?
- Can you describe the reaction of halogenoalkanes with potassium cyanide to form nitriles, and explain that it increases the carbon chain length?
- Can you describe the reaction of halogenoalkanes with ammonia to form primary amines?
- Can you describe the elimination reaction of halogenoalkanes with ethanolic KOH to form alkenes, with OH^- acting as a base?

Rates of hydrolysis

- Can you describe experiments using aqueous silver nitrate in ethanol to compare the hydrolysis rates of primary, secondary and tertiary halogenoalkanes?
- Can you describe experiments to compare the hydrolysis rates of chloro-, bromo- and iodoalkanes?
- Can you state that the reactivity of halogenoalkanes is tertiary > secondary > primary?
- Can you explain, using bond enthalpies, why reactivity increases from chloro- to bromo- to iodoalkanes?

Mechanisms

- Can you draw the SN_2 mechanism for a primary halogenoalkane with aqueous KOH?
- Can you draw the SN_2 mechanism for a primary halogenoalkane with ammonia?

6E Alcohols

Reactions of alcohols

- Can you classify alcohols as primary, secondary or tertiary?
- Can you write equations for the combustion of alcohols?
- Can you describe the halogenation of alcohols using PCl_5, 50% concentrated sulfuric acid with KBr, and red phosphorus with iodine?
- Can you describe the oxidation of primary alcohols to aldehydes and carboxylic acids, and secondary alcohols to ketones, using acidified potassium dichromate(VI)?
- Can you explain how distillation or reflux controls whether an aldehyde or a carboxylic acid is formed, and test for aldehydes with Benedict's or Fehling's solution?
- Can you describe the dehydration of alcohols to alkenes using concentrated phosphoric acid?

Preparation and purification

- Can you describe heating under reflux and explain why it is used?
- Can you describe solvent extraction using a separating funnel?
- Can you describe distillation to separate and purify a liquid product?
- Can you describe drying an organic liquid with an anhydrous salt?
- Can you describe how boiling temperature is measured to check purity?

7A Mass spectrometry

Mass spectra of organic compounds

- Can you find the relative molecular mass of an organic compound from the m/z value of its molecular ion peak?
- Can you suggest possible structures of a simple organic compound from its molecular ion peak and fragmentation pattern?
- Can you identify common fragment ions, such as CH_3+ and C_2H_5+, from m/z values?

7B Infrared spectroscopy

Identifying functional groups

- Can you use IR data to identify the C-H stretch in alkanes, alkenes and aldehydes?
- Can you use IR data to identify the C=C stretch in alkenes?
- Can you use IR data to identify the O-H stretch in alcohols?
- Can you use IR data to identify the C=O stretch in aldehydes and ketones?
- Can you use IR data to identify the C=O stretch and broad O-H stretch in carboxylic acids?
- Can you use IR data to identify the N-H stretch in amines?
- Can you predict the IR absorptions of a given molecule from data?

8 Energetics I

Enthalpy changes

- Can you state the standard conditions of 100 kPa and a stated temperature, usually 298 K?
- Can you explain that enthalpy change is the heat energy change at constant pressure?
- Can you draw and interpret enthalpy level diagrams for exothermic and endothermic reactions with correct signs, and show activation energy on reaction profiles?
- Can you define standard enthalpy changes of reaction, formation, combustion and neutralisation?

Measuring enthalpy changes

- Can you use $q = mc\Delta T$ to process results from calorimetry experiments?
- Can you evaluate sources of error and assumptions in enthalpy experiments, such as mixing in insulated containers and burning alcohols in spirit burners?
- Can you calculate enthalpy changes in kJ mol-1 from experimental results, with sign and units?

Hess's law

- Can you construct enthalpy cycles using Hess's law?
- Can you calculate enthalpy changes from data using Hess's law, including those that cannot be measured directly?

Bond enthalpies

- Can you define bond enthalpy and mean bond enthalpy?
- Can you calculate enthalpy changes of reaction from mean bond enthalpies and explain the limitations of this method?
- Can you calculate a mean bond enthalpy from enthalpy change data?

9 Kinetics I

Collision theory and rate

- Can you use collision theory to explain how concentration, temperature, pressure and surface area affect reaction rate?
- Can you explain that a reaction only occurs if colliding particles have at least the activation energy?
- Can you calculate a reaction rate from experimental time data?
- Can you calculate a rate from the gradient of a graph, drawing a tangent for the initial rate or the rate at time t?
- Can you use the Maxwell-Boltzmann distribution to explain qualitatively how temperature affects rate?

Catalysts

- Can you explain that a catalyst provides an alternative route with a lower activation energy?
- Can you draw reaction profiles for catalysed and uncatalysed reactions?
- Can you use the Maxwell-Boltzmann distribution to explain qualitatively how a catalyst increases rate?
- Can you explain that solid heterogeneous catalysts in industrial gas reactions provide a surface for the reaction?
- Can you explain the economic benefits of using catalysts in industry?

10 Equilibrium I

Dynamic equilibrium

- Can you explain that dynamic equilibrium is reached when forward and backward rates are equal?
- Can you explain that at equilibrium the concentrations of reactants and products stay constant?
- Can you predict and justify the effect of changing temperature, concentration or pressure on the position of a homogeneous equilibrium?
- Can you evaluate data to explain why industrial conditions are a compromise between yield and rate?

K_c

- Can you write K_c expressions for homogeneous systems using equilibrium concentrations?
- Can you write K_c expressions for heterogeneous systems, leaving out solids?
- Can you describe experiments on equilibria such as iron(III) with thiocyanate and the $[Co(H_2O)_6]2+/[CoCl_4]2-$ system?

11 Equilibrium II

K_p and calculations

- Can you calculate partial pressures from mole fractions?
- Can you write K_p expressions for homogeneous and heterogeneous systems using partial pressures in atm?
- Can you calculate values of K_c and K_p, including units, from experimental data?

Factors affecting K

- Can you describe how changing temperature affects K_c and K_p for exothermic and endothermic reactions?
- Can you explain that a change in temperature shifts the equilibrium position because it changes the value of K?
- Can you explain that changes in concentration, pressure or adding a catalyst do not change K?

12a Acids, bases and pH

Brønsted-Lowry theory

- Can you define Brønsted-Lowry acids as proton donors and bases as proton acceptors?
- Can you explain acid-base reactions as proton transfer?
- Can you identify Brønsted-Lowry conjugate acid-base pairs?

pH calculations

- Can you define pH as -log[H^+]?
- Can you calculate pH from [H^+]?
- Can you calculate [H^+] from pH using [H^+] = 10^(-pH)?
- Can you explain the difference between strong and weak acids in terms of degree of dissociation?
- Can you calculate the pH of a strong acid?
- Can you write the K_a expression for a weak acid and carry out calculations with it?
- Can you calculate the pH of a weak acid and state the assumptions made?
- Can you define the ionic product of water, K_w?
- Can you calculate the pH of a strong base from its concentration using K_w?
- Can you define pK_a and pKw and convert between K and pK values?
- Can you analyse data from pH measurements of equimolar strong and weak acids, strong and weak bases, and salts?
- Can you analyse the change in pH of strong and weak acids diluted 10, 100 and 1000 times?
- Can you calculate K_a for a weak acid from the pH of a solution made from a known mass of acid?

12b Titration curves and buffers

Titration curves and indicators

- Can you draw and interpret titration curves for all combinations of strong and weak monobasic acids and bases?
- Can you select a suitable indicator for a titration using its pH range and the titration curve?

Buffers

Can you define a buffer solution?	○ ○ ○
Can you explain how a buffer solution resists changes in pH when small amounts of acid or alkali are added?	○ ○ ○
Can you calculate the pH of a buffer solution from given data?	○ ○ ○
Can you calculate the concentrations of solutions needed to make a buffer of a given pH?	○ ○ ○
Can you use the titration curve of a weak acid with a strong base to show buffer action?	○ ○ ○
Can you find K_a from the pH at half-neutralisation on a titration curve?	○ ○ ○
Can you explain why the enthalpy of neutralisation of a weak acid differs from that of a strong acid?	○ ○ ○
Can you explain how carbonic acid and hydrogencarbonate ions control the pH of blood?	○ ○ ○

13A Lattice energy

Born-Haber cycles

- Can you define lattice energy as the energy change when one mole of an ionic solid forms from its gaseous ions?
- Can you define enthalpy change of atomisation, ΔatH?
- Can you define electron affinity, including first and second electron affinities?
- Can you construct Born-Haber cycles and use them to calculate lattice energy or other enthalpy changes?
- Can you explain that lattice energy is a measure of ionic bond strength?

Polarisation and covalent character

- Can you compare experimental (Born-Haber) and theoretical lattice energies to judge the degree of covalent character in an ionic compound?
- Can you explain the meaning of polarisation of ions?
- Can you explain how the radius and charge of a cation affect its polarising power?
- Can you explain how the radius and charge of an anion affect its polarisability?

Solution and hydration

- Can you define enthalpy change of solution and enthalpy change of hydration?
- Can you use energy cycles and level diagrams to calculate enthalpy changes of solution, hydration and lattice energy?
- Can you explain how ionic charge and radius affect lattice energy?
- Can you explain how ionic charge and radius affect enthalpy change of hydration?

13B Entropy

Entropy and disorder

- Can you explain why enthalpy change alone cannot predict whether a reaction occurs, using endothermic reactions that happen at room temperature?
- Can you explain entropy as a measure of disorder, and that the natural direction of change is towards increasing total entropy?
- Can you explain entropy changes for changes of state, dissolving an ionic lattice and reactions that change the number of moles of gas?

Can you discuss in terms of disorder and enthalpy the reactions of dissolving ammonium nitrate, ethanoic acid with ammonium carbonate, burning magnesium and solid $Ba(OH)_2.8H2O$ with solid NH_4Cl?

Calculating entropy changes

Can you use ΔStotal = ΔSsystem + ΔSsurroundings?

Can you calculate ΔSsystem from standard entropies of reactants and products?

Can you calculate ΔSsurroundings = -ΔH/T and hence ΔStotal?

Gibbs free energy

Can you explain that feasibility depends on the balance between ΔH and TΔSsystem, as in ΔG = ΔH − TΔSsystem?

Can you use ΔG = ΔH − TΔSsystem to predict whether a reaction is feasible?

Can you use ΔG = ΔH − TΔSsystem to calculate the temperature at which a reaction becomes feasible?

Can you use ΔG = -RT ln K to show that reactions with negative ΔG have large values of K?

Can you explain why a reaction with a negative ΔG may not happen in practice?

Can you explain that a thermodynamically feasible reaction may be too slow because of kinetic factors such as a high activation energy?

14a Electrode potentials

Redox in all blocks

- Can you explain oxidation and reduction as electron transfer for s-, p- and d-block elements?
- Can you explain oxidation and reduction as changes in oxidation number for s-, p- and d-block elements?

Standard electrode potentials

- Can you define standard electrode potential, E°?
- Can you state the standard conditions for E°: 298 K, 100 kPa for gases and 1.00 mol dm^{-3} for ions?
- Can you describe the standard hydrogen electrode and explain why a reference electrode is needed?
- Can you describe how to measure E° for a metal or non-metal in contact with its ions?
- Can you describe how to measure E° for ions of the same element in different oxidation states, using a platinum electrode?
- Can you calculate a standard cell emf, E°cell, from two standard electrode potentials?
- Can you write cell diagrams using the conventional notation?
- Can you explain why the conditions must be stated when measuring electrode potential, E?

Using E° values

- Can you use E° values to predict whether a reaction is thermodynamically feasible?
- Can you explain that E°cell is directly proportional to ΔStotal and to ln K?
- Can you explain the limitations of E° predictions, including kinetic inhibition and non-standard conditions?
- Can you use the electrochemical series of standard electrode potentials?
- Can you use E° values to explain disproportionation reactions?

14b Cells and redox titrations

Storage and fuel cells

- Can you apply electrode potentials to storage cells?

Can you explain that a fuel cell uses the energy from a fuel such as hydrogen or methanol reacting with oxygen to produce a voltage?	○ ○ ○
Can you write the electrode reactions in a hydrogen-oxygen fuel cell with an acidic electrolyte?	○ ○ ○
Can you write the electrode reactions in a hydrogen-oxygen fuel cell with an alkaline electrolyte?	○ ○ ○

Redox titrations

Can you carry out structured and unstructured calculations for Fe^{2+}/MnO_4^- titrations?	○ ○ ○
Can you carry out structured and unstructured calculations for $I2/S_2O_3$ 2- titrations, including the use of starch indicator?	○ ○ ○
Can you explain the procedures used in redox titrations, including why potassium manganate(VII) is self-indicating?	○ ○ ○

15A Principles of transition metal chemistry

Electronic structure

- Can you deduce the electronic configurations of atoms and ions of the d-block elements Sc to Zn from their atomic number and charge?
- Can you define a transition metal as a d-block element forming one or more stable ions with an incomplete d-subshell, and explain why Sc and Zn are not?
- Can you explain why transition metals show variable oxidation numbers?

Complexes and colour

- Can you define the term ligand?
- Can you explain that complex ions form through dative (coordinate) bonding?
- Can you describe a complex ion as a central metal ion surrounded by ligands?
- Can you explain that transition metal ions form coloured solutions?
- Can you explain colour in terms of the splitting of d-orbital energy levels by ligands and absorption of visible light?
- Can you explain why some aqueous ions and complexes, such as those of Sc_3+, Zn_2+ and Cu+, are colourless?
- Can you explain that colour changes can result from changes in oxidation number, ligand or coordination number?

Shapes and ligands

- Can you define coordination number?
- Can you explain why H_2O, OH^- and NH_3 act as monodentate ligands?
- Can you explain that six-coordinate complexes, such as those with H_2O, OH^- and NH_3, are octahedral?
- Can you explain that larger ligands such as Cl^- form tetrahedral complexes?
- Can you describe square planar complexes, using cisplatin as an example?
- Can you explain why cisplatin for cancer treatment is supplied as a single isomer rather than mixed with transplatin?
- Can you identify bidentate ligands such as 1,2-diaminoethane and multidentate ligands such as $EDTA^{4-}$?
- Can you describe haemoglobin as an iron(II) complex containing a multidentate ligand?
- Can you explain how carbon monoxide replaces oxygen bound to haemoglobin by ligand exchange?

15B Transition metal reactions

Vanadium and chromium

- Can you state the colours of vanadium in oxidation states +5, +4, +3 and +2?
- Can you use E° values to explain the redox interconversion of vanadium oxidation states, such as reduction by zinc in acid?
- Can you use E° values to explain the reduction of dichromate(VI) to Cr_3+ and Cr_2+ by zinc in acid?
- Can you explain the formation of dichromate(VI) by oxidising Cr_3+ with hydrogen peroxide in alkali followed by acidification?
- Can you describe the dichromate(VI)/chromate(VI) equilibrium involving H+ ions?

Reactions with hydroxide and ammonia

- Can you record observations and write equations for Cr_3+, Fe^{2+}, Fe^{3+}, Co_2+ and Cu^{2+} aqueous ions with NaOH and with NH_3, including in excess?
- Can you write ionic equations that distinguish ligand exchange from amphoteric behaviour in these reactions?

Ligand exchange

- Can you describe the formation of $[Cu(NH_3)_4(H_2O)_2]2+$ from $[Cu(H_2O)_6]2+$ via $Cu(OH)_2(H_2O)_4$, with colours?
- Can you describe the formation of $[CuCl_4]2-$ from $[Cu(H_2O)_6]2+$, with colours?
- Can you describe the formation of $[CoCl_4]2-$ from $[Co(H_2O)_6]2+$, with colours?
- Can you explain why replacing H_2O with Cl^- ligands can change the coordination number?
- Can you explain why replacing monodentate ligands with bidentate or multidentate ligands forms a more stable complex, in terms of ΔSsystem?

Catalysis

- Can you explain that transition metals and their compounds can act as heterogeneous and homogeneous catalysts?
- Can you explain that a heterogeneous catalyst is in a different phase from the reactants and the reaction occurs at its surface?
- Can you explain the action of V_2O_5 in the Contact process in terms of changing oxidation number?

- Can you explain how a catalytic converter removes CO and NO by adsorption, bond weakening and reaction, and desorption of CO_2 and N2?
- Can you explain that a homogeneous catalyst is in the same phase as the reactants and works via an intermediate species?
- Can you explain the role of Fe^{2+} ions in catalysing the reaction between I^- and $S_2O_8^{2-}$ ions?
- Can you explain the role of Mn^{2+} ions in autocatalysing the reaction between MnO_4^- and $C_2O_4^{2-}$ ions?

16 Kinetics II

Rate equations

Can you define rate of reaction, rate equation, order of reaction (for a reactant and overall), rate constant, half-life, rate-determining step, activation energy and heterogeneous and homogeneous catalysts? ○ ○ ○

Can you deduce and use rate equations of the form rate = k[A]^m[B]^n, where m and n are 0, 1 or 2? ○ ○ ○

Measuring rates

Can you select and justify a method to collect rate data, such as titration, colorimetry, mass change or volume of gas? ○ ○ ○

Can you use the initial rate method, including clock reactions, with separate experiments at different starting concentrations? ○ ○ ○

Can you use continuous monitoring to obtain concentration-time or volume-time graphs? ○ ○ ○

Can you calculate the rate and half-life of a first order reaction from a concentration-time or volume-time graph? ○ ○ ○

Can you deduce the order (0, 1 or 2) of a reaction from a concentration-time graph? ○ ○ ○

Can you deduce the order (0, 1 or 2) of a reaction from a rate-concentration graph? ○ ○ ○

Can you deduce the order (0, 1 or 2) of a reaction from initial rates data? ○ ○ ○

Mechanisms

Can you determine the orders of reaction with respect to propanone, iodine and H+ in the acid-catalysed iodination of propanone? ○ ○ ○

Can you use these orders to suggest the species in the rate-determining step and propose a mechanism for the iodination of propanone? ○ ○ ○

Can you deduce the rate-determining step from a rate equation, and a rate equation from a rate-determining step? ○ ○ ○

Can you propose a reaction mechanism from a rate equation and the overall equation? ○ ○ ○

Can you use rate equations to distinguish SN_1 (tertiary) and SN_2 (primary) mechanisms for halogenoalkane hydrolysis? ○ ○ ○

Activation energy

Can you determine activation energy graphically from experimental data using the Arrhenius equation, plotting ln k against 1/T? ○ ○ ○

17A Chirality

Optical isomerism

- Can you explain that optical isomerism arises from chirality in molecules with a single chiral centre?
- Can you identify a chiral centre (asymmetric carbon) and draw optical isomers as non-superimposable mirror images?
- Can you explain optical activity as the rotation of the plane of plane-polarised monochromatic light by a single optical isomer?
- Can you explain the nature of a racemic mixture and why it is optically inactive?
- Can you use the optical activity of reactants and products as evidence for SN_1 and SN_2 mechanisms?

17B Carbonyl compounds

Structure and properties

- Can you identify the aldehyde and ketone functional groups?
- Can you explain why aldehydes and ketones cannot form intermolecular hydrogen bonds and how this affects their physical properties?
- Can you explain how aldehydes and ketones form hydrogen bonds with water and how this affects solubility?

Reactions

- Can you describe the oxidation of aldehydes using Fehling's or Benedict's solution, Tollens' reagent and acidified dichromate(VI), and use these to distinguish aldehydes from ketones?
- Can you describe the reduction of aldehydes and ketones using $LiAlH_4$ in dry ether?
- Can you draw the nucleophilic addition mechanism for HCN with KCN, showing curly arrows, lone pairs and dipoles?
- Can you explain how the optical activity of the product gives evidence for the nucleophilic addition mechanism?
- Can you use 2,4-DNPH as a test for C=O and identify a carbonyl compound from the melting temperature of its derivative?
- Can you describe the reaction of carbonyl compounds with iodine in alkali (the iodoform test) and the structure it identifies?

17C Carboxylic acids and derivatives

Carboxylic acids

- Can you identify the carboxylic acid functional group?
- Can you explain the effect of hydrogen bonding on the boiling temperatures and solubility of carboxylic acids?
- Can you describe the preparation of carboxylic acids by oxidising alcohols or aldehydes and by hydrolysing nitriles?
- Can you describe the reduction of carboxylic acids with $LiAlH_4$ in dry ether?
- Can you describe the reactions of carboxylic acids with bases to form salts, including with carbonates?
- Can you describe the reaction of carboxylic acids with PCl_5 to form acyl chlorides?
- Can you describe the reaction of carboxylic acids with alcohols and an acid catalyst to form esters?

Acyl chlorides and esters

- Can you identify the acyl chloride and ester functional groups?
- Can you describe the reactions of acyl chlorides with water, alcohols, concentrated ammonia and amines?
- Can you describe the hydrolysis of esters in acidic and alkaline conditions?
- Can you describe the formation of polyesters by condensation polymerisation?

18A Arenes: benzene

Structure of benzene

- Can you describe the Kekulé and delocalised models of benzene, including overlap of p-orbitals to form π bonds?
- Can you use enthalpy of hydrogenation data and C-C bond lengths as evidence for delocalisation in benzene?
- Can you explain why benzene resists bromination compared with alkenes, in terms of delocalised and localised π electrons?

Reactions of benzene

- Can you describe the combustion of benzene with a smoky flame?
- Can you describe the reaction of benzene with bromine in the presence of a catalyst?
- Can you describe the nitration of benzene with concentrated nitric and sulfuric acids?
- Can you describe the Friedel-Crafts reactions of benzene with halogenoalkanes and acyl chlorides using $AlCl_3$?
- Can you draw the electrophilic substitution mechanisms for halogenation, nitration and Friedel-Crafts reactions, including formation of the electrophile?

Phenol

- Can you describe the reaction of phenol with bromine water?
- Can you explain why phenol is brominated more readily than benzene?

18B Amines, amides, amino acids and proteins

Amines and amides

- Can you identify amine and amide functional groups?
- Can you identify the structure of amino acids?
- Can you describe the reactions of butylamine with water to form an alkaline solution, and with acids to form salts?
- Can you describe the reactions of butylamine with ethanoyl chloride and with halogenoalkanes?
- Can you describe the reaction of butylamine with copper(II) ions to form a complex ion?

- Can you explain the difference in base strength between ammonia, primary aliphatic amines and primary aromatic amines?
- Can you describe the preparation of primary aliphatic amines from halogenoalkanes and by reduction of nitriles?
- Can you describe the reduction of aromatic nitro compounds to amines using tin and concentrated HCl?
- Can you describe the formation of amides from acyl chlorides?

Condensation polymers

- Can you explain that forming a polyamide is condensation polymerisation?
- Can you draw the repeat units of condensation polymers from dicarboxylic acids with diols, dicarboxylic acids with diamines, and amino acids?

Amino acids and proteins

- Can you explain the acid-base properties of 2-amino acids, including zwitterion formation?
- Can you explain the effect of 2-amino acids on plane-polarised light?
- Can you describe the formation of peptide bonds by condensation of amino acids?
- Can you describe the hydrolysis of peptides to amino acids and their separation by chromatography?

18C Organic synthesis

Structure determination

- Can you deduce empirical, molecular and structural formulae from combustion data, elemental composition, functional group tests, IR, mass spectra and NMR?

Planning syntheses

- Can you plan reaction schemes of up to four steps, with reagents and conditions, for familiar and unfamiliar compounds?
- Can you describe the use of Grignard reagents, made from magnesium in dry ether, to lengthen carbon chains by reaction with CO_2 and carbonyl compounds?
- Can you select suitable practical procedures for reactions of given functional groups and identify control measures using hazard data?

Practical techniques

Can you describe heating under reflux and washing of an organic product?	○ ○ ○
Can you describe solvent extraction of an organic product?	○ ○ ○
Can you describe recrystallisation to purify a solid organic product?	○ ○ ○
Can you describe drying of an organic product?	○ ○ ○
Can you describe distillation, including steam distillation?	○ ○ ○
Can you describe melting temperature and boiling temperature determination to check purity and identity?	○ ○ ○

19A Mass spectrometry

High resolution mass spectrometry

- Can you suggest possible structures for a simple organic compound given its relative molecular mass to four decimal places?
- Can you calculate an accurate relative molecular mass from precise atomic masses to four decimal places and use it to identify a compound?

19B Nuclear magnetic resonance

^{13}C NMR

- Can you explain that ^{13}C NMR gives information about the positions of carbon atoms in a molecule?
- Can you use ^{13}C NMR chemical shift values to predict the different carbon environments in a molecule?
- Can you explain the number of peaks in a ^{13}C NMR spectrum in terms of different carbon environments?

High resolution ^{1}H NMR

- Can you explain that high resolution proton NMR gives information about the positions of hydrogen atoms in a molecule?
- Can you use chemical shift values to predict the types of proton present?
- Can you relate relative peak areas or integration ratios to the number of hydrogen atoms in each environment?
- Can you use the n+1 rule to deduce splitting patterns from adjacent non-equivalent protons and suggest possible structures?
- Can you predict the chemical shifts and splitting patterns of the protons in a given molecule?

19C Chromatography

Principles of chromatography

- Can you explain that chromatography separates the components of a mixture between a mobile phase and a stationary phase?
- Can you calculate Rf values from one-way chromatograms?

Can you explain that HPLC and GC are both types of column chromatography?	○ ○ ○
Can you explain that HPLC and GC separate substances because of differences in retention time?	○ ○ ○
Can you explain how HPLC and GC can be combined with mass spectrometry to identify the components of a mixture?	○ ○ ○

CP Core Practicals

Core practical activities

1 Can you measure the molar volume of a gas?

2 Can you prepare a standard solution from a solid acid and use it to find the concentration of a sodium hydroxide solution?

3 Can you find the concentration of a solution of hydrochloric acid by titration?

4 Can you investigate the rates of hydrolysis of some halogenoalkanes?

5 Can you carry out the oxidation of ethanol?

6 Can you carry out the chlorination of 2-methylpropan-2-ol using concentrated hydrochloric acid?

7 Can you analyse some inorganic and organic unknowns?

8 Can you determine the enthalpy change of a reaction using Hess's law?

9 Can you find the K_a value for a weak acid?

10 Can you investigate some electrochemical cells?

11 Can you carry out a redox titration?

12 Can you prepare a transition metal complex?

13a Can you follow the rate of the iodine-propanone reaction by a titrimetric method?

13b Can you investigate a clock reaction such as the Harcourt-Esson iodine clock?

14 Can you find the activation energy of a reaction?

15 Can you analyse some inorganic and organic unknowns?

16 Can you prepare aspirin?