C1.1 Formulae and equations

Formulae and equations

- Can you recall the formulae of common compounds and ions?
- Can you write the formula of an ionic compound from the charges on its ions?
- Can you work out the oxidation number of an atom in a compound or ion?
- Can you use oxidation numbers to name compounds and ions, e.g. iron(III) or chlorate(V)?
- Can you write balanced full equations with state symbols?
- Can you write balanced ionic equations, leaving out spectator ions?

C1.2 Basic ideas about atoms

Radioactivity

- Can you describe how α decay, β- decay, positron emission and electron capture change the atomic number and mass number of a nucleus?
- Can you write nuclear equations for these types of decay?
- Can you describe how α, β and γ radiation behave in electric and magnetic fields?
- Can you compare the relative penetrating power of α, β and γ radiation?
- Can you explain the meaning of half-life and carry out simple half-life calculations?
- Can you describe the harmful effects of radiation on living cells?
- Can you describe uses of radioisotopes, e.g. in medicine, dating and as tracers?

Ionisation energies and electronic structure

- Can you define the first molar ionisation energy and write an equation for it?
- Can you explain how first ionisation energies vary across a period and down a group?
- Can you use successive ionisation energies to deduce the electronic structure and group of an element?
- Can you sketch the shapes of s and p orbitals?
- Can you write the electronic configuration of elements 1 to 36 in s, p and d orbital notation, including Cr and Cu?

Atomic spectra

- Can you explain the origin of emission and absorption spectra in terms of electron transitions between energy levels?
- Can you describe the atomic emission spectrum of hydrogen, including the Lyman and Balmer series?
- Can you use $E = hf$ and $f = c/\lambda$ in calculations?
- Can you state the order of increasing energy of infrared, visible and ultraviolet radiation?
- Can you explain the significance of the convergence limit of the Lyman series and use it to find the ionisation energy of hydrogen?

C1.3 Chemical calculations

Relative masses and mass spectrometry

- Can you define relative atomic mass, relative isotopic mass, relative formula mass and relative molecular mass?
- Can you describe the basic principles of a mass spectrometer?
- Can you calculate relative atomic mass from isotopic abundance data?
- Can you interpret simple mass spectra of elements, e.g. the molecular peaks of chlorine?

Moles, formulae and concentration

- Can you calculate empirical and molecular formulae from experimental data?
- Can you define the Avogadro constant, the mole and molar mass?
- Can you convert between mass in grams and amount in moles?
- Can you calculate concentration in g dm^{-3} and mol dm^{-3}, including solubility?
- Can you use the molar volume of a gas and correct gas volumes for changes in temperature and pressure?
- Can you use the ideal gas equation $pV = nRT$?
- Can you carry out reacting quantity calculations, including those from acid-base titrations?

Yield, atom economy and errors

- Can you calculate the atom economy of a reaction?

- Can you calculate the percentage yield of a reaction? ○ ○ ○
- Can you calculate percentage error in measurements? ○ ○ ○
- Can you give answers to an appropriate number of significant figures? ○ ○ ○

C1.4 Bonding

Ionic and covalent bonding

- Can you describe ionic bonding in terms of ion formation and the attraction between oppositely charged ions in a crystal lattice? ○ ○ ○
- Can you describe covalent bonding, including coordinate (dative) bonding, using dot-and-cross diagrams? ○ ○ ○
- Can you explain a covalent bond as a balance between attraction of nuclei for shared electrons and repulsion between nuclei? ○ ○ ○
- Can you explain how bonds can have intermediate character between ionic and covalent? ○ ○ ○
- Can you define electronegativity and use it to explain bond polarity? ○ ○ ○

Intermolecular forces

- Can you explain why intermolecular forces are much weaker than covalent and ionic bonds? ○ ○ ○
- Can you describe permanent dipole-dipole forces and temporary (induced) dipole forces? ○ ○ ○
- Can you explain the effect of dipole forces on boiling temperatures and solubility? ○ ○ ○
- Can you describe hydrogen bonding and explain its effect on physical properties, e.g. the boiling temperature of water and the density of ice? ○ ○ ○

Shapes of molecules

- Can you use VSEPR theory to predict the shapes of simple molecules and ions? ○ ○ ○
- Can you state the bond angles in linear, trigonal planar, tetrahedral and octahedral species, and explain how lone pairs reduce bond angles? ○ ○ ○

C1.5 Solid structures

Solid structures

- Can you describe the crystal structures of sodium chloride and caesium chloride, including coordination numbers?
- Can you describe the structures of diamond and graphite?
- Can you describe the structures of iodine and ice?
- Can you describe metallic bonding using the electron sea model?
- Can you explain the physical properties of ionic, giant covalent, simple molecular and metallic substances in terms of structure and bonding?

C1.6 The Periodic Table

Periodicity and redox

- Can you explain that the Periodic Table is arranged in order of atomic number?
- Can you relate an element's electronic structure to its position in the s-, p- and d-blocks?
- Can you describe oxidation and reduction in terms of electron transfer in reactions of s-, p- and d-block elements?
- Can you describe and explain trends in ionisation energy, melting temperature and electronegativity across periods and down groups?

Groups 1 and 2

- Can you describe the reactions of Group 2 elements with oxygen and with water or steam?
- Can you describe the reactions of Mg^{2+}, Ca^{2+} and Ba^{2+} ions with OH^-, CO_3^{2-} and SO_4^{2-} ions?
- Can you recall the flame colours of Li, Na, K, Ca, Sr and Ba compounds, and that Mg gives no colour?
- Can you explain the trend in reactivity of Group 1 and Group 2 metals?
- Can you describe and explain the trend in thermal stability of Group 2 carbonates and hydroxides?
- Can you describe the trends in solubility of Group 2 hydroxides and sulfates?
- Can you describe the basic character of Group 1 and Group 2 oxides and hydroxides?

Group 7

- Can you describe and explain the trend in volatility of the halogens?
- Can you describe the reactions of halogens with metals?
- Can you explain the trend in oxidising power of the halogens?
- Can you describe the reactions of aqueous Ag^+ with halide ions and the effect of adding dilute and concentrated NH_3?
- Can you explain halogen displacement reactions as redox reactions?
- Can you discuss the use of chlorine and fluoride in water treatment, including health and ethical issues?

Salts and gravimetric analysis

- Can you describe how to prepare a soluble salt?
- Can you describe how to prepare an insoluble salt by precipitation?
- Can you carry out and calculate the results of a simple gravimetric analysis?

C2.1 Simple equilibria and acid-base reactions

Equilibria

- Can you describe reversible reactions and dynamic equilibrium?
- Can you use Le Chatelier's principle to predict the effect of changing temperature, concentration and pressure on an equilibrium?
- Can you write an expression for K_c and calculate K_c from equilibrium concentrations?

Acids and bases

- Can you define acids as H^+ donors and bases as H^+ acceptors?
- Can you use $pH = -\log[H^+]$ to convert between pH and $[H^+]$?
- Can you carry out and calculate the results of acid-base titrations?
- Can you explain the difference between strong and weak acids in terms of dissociation?

C2.2 Thermochemistry

Thermochemistry

- Can you define standard enthalpy changes of reaction, combustion and formation?
- Can you state Hess's law and use it to construct energy cycles?
- Can you define average bond enthalpy and use bond enthalpies in simple calculations?
- Can you calculate enthalpy changes using $q = mc\Delta T$ and energy cycles?
- Can you describe simple procedures for determining enthalpy changes, including sources of error?

C2.3 Rates of reaction

Rates of reaction

- Can you use collision theory to explain the effect of changing concentration, pressure, surface area and temperature on rate?
- Can you calculate rates of reaction from experimental data and relate rate to reactant concentration?
- Can you draw and interpret energy profiles showing activation energy?
- Can you use the Boltzmann distribution to explain the large increase in rate with a small rise in temperature?
- Can you describe the characteristics of catalysts?
- Can you explain how a catalyst provides an alternative route of lower activation energy, using the Boltzmann distribution?
- Can you explain how colorimetry is used to follow the rate of a reaction?
- Can you describe measuring rate by gas collection, by precipitation and using an iodine clock reaction?

C2.4 The wider impact of chemistry

The wider impact of chemistry

- Can you discuss the social, economic and environmental impact of chemical synthesis?
- Can you discuss the social, economic and environmental impact of energy production?
- Can you explain the role of green chemistry in improving sustainability, e.g. atom economy, renewable feedstocks and catalysts?

C3.1 Organic compounds

Organic compounds

- Can you draw and interpret shortened (structural), displayed and skeletal formulae?
- Can you name alkanes, alkenes, halogenoalkanes, alcohols and carboxylic acids using systematic nomenclature?
- Can you explain the effect of chain length and functional groups on boiling temperature and solubility?
- Can you identify and draw structural isomers (chain, position and functional group)?
- Can you define electrophiles, nucleophiles and radicals?
- Can you distinguish between homolytic and heterolytic bond fission?

C3.2 Hydrocarbons

Alkanes

- Can you write equations for complete and incomplete combustion of alkanes?
- Can you discuss the benefits and drawbacks of using fossil fuels?
- Can you describe C-C and C-H bonds in alkanes as σ-bonds?
- Can you describe the radical substitution mechanism, e.g. photochlorination of methane, including initiation, propagation and termination?

Alkenes

- Can you explain why alkenes are more reactive than alkanes?
- Can you describe the C=C bond as a σ-bond and a π-bond?
- Can you explain E-Z isomerism in terms of restricted rotation about the C=C bond?
- Can you describe the electrophilic addition mechanism, e.g. bromine with ethene?
- Can you describe the bromine water and potassium manganate(VII) tests for alkenes?
- Can you explain the products of adding HBr to propene in terms of carbocation stability?
- Can you state the conditions for catalytic hydrogenation of ethene and its relevance, e.g. making margarine?
- Can you describe addition polymerisation and its economic importance?

C3.3 Halogenoalkanes

Halogenoalkanes

- Can you describe elimination reactions of halogenoalkanes to form alkenes, e.g. HBr from 1-bromopropane?
- Can you describe the nucleophilic substitution mechanism of OH^- with a primary halogenoalkane?
- Can you explain the effects of bond polarity and bond enthalpy on the ease of substitution?
- Can you describe the hydrolysis of halogenoalkanes and the use of aqueous Ag^+ to identify the halogen?
- Can you describe uses of halogenoalkanes as solvents, anaesthetics and refrigerants, and why their use is regulated?
- Can you explain the environmental effects of CFCs in terms of the relative strengths of C-H, C-F and C-Cl bonds?
- Can you describe how to carry out a reflux?

C3.4 Alcohols and carboxylic acids

Alcohols

- Can you describe the industrial preparation of ethanol from ethene?
- Can you describe the preparation of ethanol by fermentation and distillation?
- Can you discuss the issues involved in using biofuels?
- Can you describe the dehydration of alcohols to alkenes?
- Can you classify alcohols as primary, secondary or tertiary?
- Can you describe the oxidation of primary and secondary alcohols?
- Can you use acidified dichromate(VI) to distinguish between primary, secondary and tertiary alcohols?

Carboxylic acids

- Can you use the sodium hydrogencarbonate test to identify carboxylic acids?
- Can you describe the reactions of carboxylic acids with bases, carbonates and hydrogencarbonates?
- Can you describe esterification of carboxylic acids with alcohols?
- Can you describe separation of a product by distillation?

C3.5 Instrumental analysis

Instrumental analysis

Can you use mass spectra, including molecular ion and fragment peaks, to identify the structure of a compound?	○ ○ ○
Can you use IR spectra to identify functional groups in a compound?	○ ○ ○
Can you use ^{13}C NMR spectra to identify the structure of a compound?	○ ○ ○
Can you use low-resolution ^{1}H NMR spectra to identify the structure of a compound?	○ ○ ○

PI1.1 Redox and standard electrode potential

Redox and electrode potentials

- Can you describe redox reactions in terms of electron transfer?
- Can you write ion/electron half-equations and cell diagrams?
- Can you define standard electrode potential and describe the standard hydrogen electrode?
- Can you describe simple cells made from metal/metal-ion electrodes and from electrodes of different oxidation states of the same element?
- Can you calculate the EMF of a cell from standard electrode potentials?
- Can you use standard electrode potentials to predict the feasibility of a reaction?
- Can you describe the principles of the hydrogen fuel cell and its benefits and drawbacks?

PI1.2 Redox reactions

Redox reactions

- Can you write half-equations for acidified dichromate(VI), acidified manganate(VII) and thiosulfate to tetrathionate?
- Can you combine half-equations to give a balanced stoichiometric redox equation?
- Can you describe the reaction of Cu^{2+} with I^- and the titration of the liberated iodine with thiosulfate?
- Can you carry out and calculate the results of a redox titration?

PI2.1 Chemistry of the p-block

General p-block features

- Can you describe the amphoteric behaviour of aluminium and lead compounds?
- Can you explain the increasing stability of the inert pair cation down Groups 3, 4 and 5?
- Can you give examples of compounds with fewer or more than eight valence electrons, e.g. BF_3 and SF_6?
- Can you describe the structure and bonding in Al_2Cl_6 and in donor-acceptor compounds such as NH_3.BF3?

Can you describe the bonding and structure of hexagonal and cubic boron nitride and compare them with graphite and diamond?

Group 4

Can you describe the change in stability of the +2 and +4 oxidation states down Group 4?

Can you describe the nature and acid-base properties of CO_2 and PbO?

Can you describe the change in bonding down Group 4 using the chlorides and their reactions with water?

Can you describe the reactions of Pb_2+(aq) with NaOH, Cl^- and I^-?

Group 7

Can you describe the reactions of chlorine with cold and with warm NaOH as disproportionation reactions?

Can you explain the bleaching and bactericidal action of chlorine and chlorate(I)?

Can you describe and explain the reactions of NaCl, NaBr and NaI with concentrated sulfuric acid?

PI2.2 Chemistry of the d-block transition metals

Oxidation states, complexes and colour

Can you explain the range of oxidation states shown by d-block elements?

Can you recall the important oxidation states of Cr, Mn, Fe, Co and Cu and the colours of their ions in solution?

Can you describe the bonding in tetrahedral and octahedral complexes?

Can you explain the origin of colour in terms of the splitting of d-orbitals?

Can you describe ligand exchange reactions, including changes in coordination number, e.g. Cu^{2+} and Co^{2+} with concentrated HCl?

Can you recall the colours and formulae of named octahedral and tetrahedral complex ions?

Can you describe the reactions of Cr^{3+}, Fe^{2+}, Fe^{3+} and Cu^{2+} with OH^-, including with excess OH^-?

Catalysis

Can you explain heterogeneous catalysis in terms of surface adsorption?

Can you explain homogeneous catalysis in terms of variable oxidation states?	○ ○ ○
Can you describe the use of nickel in alkene hydrogenation and iron in the Haber process?	○ ○ ○
Can you describe the use of vanadium(V) oxide in the contact process and manganese(IV) oxide in the decomposition of hydrogen peroxide?	○ ○ ○

PI3 Chemical kinetics

Chemical kinetics

Can you describe measuring rate by sampling and quenching?	○ ○ ○
Can you deduce the order of a reaction from experimental results, including initial rates and graphs?	○ ○ ○
Can you write a general rate equation and use it to calculate the rate constant and its units?	○ ○ ○
Can you explain the meaning of the rate-determining step?	○ ○ ○
Can you link a rate equation to a possible reaction mechanism?	○ ○ ○
Can you use the Arrhenius equation to explain the effect of temperature and catalysts on the rate constant?	○ ○ ○
Can you use experimental data to find the activation energy and frequency factor from the Arrhenius equation?	○ ○ ○

PI4.1 Enthalpy changes for solids and solutions

Enthalpy changes for solids and solutions

Can you define enthalpy changes of atomisation, lattice formation, lattice breaking, hydration and solution?	○ ○ ○
Can you explain solubility as a balance between lattice enthalpy and the hydration enthalpies of the ions?	○ ○ ○
Can you construct Born-Haber cycles for simple ionic compounds and use them in calculations?	○ ○ ○
Can you use how exothermic the standard enthalpy change of formation is as a qualitative indicator of a compound's stability?	○ ○ ○

PI4.2 Entropy and feasibility of reactions

Entropy and feasibility

- Can you explain entropy as a measure of the freedom of particles, which increases in natural changes?
- Can you explain why S(gas) > S(liquid) > S(solid)?
- Can you calculate an entropy change from absolute entropy values?
- Can you use $\Delta G = \Delta H - T\Delta S$ to calculate the Gibbs free energy change?
- Can you use a negative ΔG to predict that a reaction is feasible and calculate the temperature at which a reaction becomes feasible?
- Can you use entropy to explain why some endothermic processes are spontaneous?

PI5.1 Equilibrium constants

Equilibrium constants

- Can you describe the effect of temperature on K_p and K_c for exothermic and endothermic reactions?
- Can you write expressions for K_c and K_p, including units?
- Can you calculate K_p and K_c and equilibrium quantities from given data, including using mole fractions and partial pressures?
- Can you relate the magnitude of an equilibrium constant to the position of equilibrium?

PI5.2 Acid-base equilibria

Acids, bases and pH

- Can you use the Brønsted-Lowry theory to identify acids, bases and conjugate acid-base pairs?
- Can you explain the difference between strong and weak acids and bases in terms of K_a?
- Can you explain the significance of the ionic product of water, K_w?
- Can you calculate pH for strong acids, strong bases and weak acids using K_w, K_a and pK_a?

Titration curves, buffers and indicators

Can you sketch and explain titration curves for strong acid-strong base, strong acid-weak base, weak acid-strong base and weak acid-weak base?	○ ○ ○
Can you explain how a buffer solution works?	○ ○ ○
Can you calculate the pH of a buffer solution?	○ ○ ○
Can you explain the importance of buffers in living systems and industry?	○ ○ ○
Can you explain why solutions of some salts are acidic or alkaline in terms of hydrolysis?	○ ○ ○
Can you select a suitable indicator for a titration from its pH range?	○ ○ ○

OA1.1 Stereoisomerism

Stereoisomerism

- Can you distinguish stereoisomerism from structural isomerism?
- Can you identify E-Z and optical isomerism as types of stereoisomerism?
- Can you define chiral centre, enantiomer, optical activity and racemic mixture?
- Can you identify an asymmetric carbon atom and draw the 3D structures of a pair of optical isomers?
- Can you describe the effect of enantiomers on plane-polarised light?

OA1.2 Aromaticity

Aromaticity

- Can you describe the structure and bonding in benzene, including delocalised π-electrons?
- Can you use evidence, e.g. bond lengths and enthalpies of hydrogenation, to support the delocalised model of benzene?
- Can you explain why aromatic compounds resist addition reactions?
- Can you describe the electrophilic substitution mechanism for nitration, halogenation and Friedel-Crafts alkylation of benzene?
- Can you explain the interaction between the benzene ring and substituents, e.g. the strength of the C-Cl bond in chlorobenzene?

OA2.1 Alcohols and phenols

Alcohols and phenols

- Can you describe the formation of primary and secondary alcohols from halogenoalkanes and from carbonyl compounds?
- Can you describe the reactions of alcohols with hydrogen halides, ethanoyl chloride and carboxylic acids?
- Can you explain the acidity of phenol?
- Can you describe the reactions of phenol with bromine and with ethanoyl chloride?
- Can you use aqueous iron(III) chloride as a test for phenols?

OA2.2 Aldehydes and ketones

Aldehydes and ketones

- Can you describe the formation of aldehydes and ketones by oxidation of alcohols?
- Can you use Tollens' reagent and Fehling's reagent to distinguish between aldehydes and ketones?
- Can you describe the reduction of aldehydes and ketones using $NaBH_4$?
- Can you describe the nucleophilic addition mechanism of HCN to aldehydes and ketones?
- Can you use 2,4-dinitrophenylhydrazine to test for carbonyl compounds and to identify specific compounds from derivative melting temperatures?
- Can you use the triiodomethane (iodoform) test to identify CH_3CO^- groups or their precursors?

OA2.3 Carboxylic acids and their derivatives

Carboxylic acids

- Can you explain the relative acidities of carboxylic acids, phenols, alcohols and water?
- Can you describe the formation of carboxylic acids by oxidation of alcohols and aldehydes?
- Can you describe the reduction of carboxylic acids using $LiAlH_4$?
- Can you describe the formation of aromatic carboxylic acids by oxidation of methyl side-chains?
- Can you describe the decarboxylation of carboxylic acids?

Derivatives and nitriles

- Can you describe the conversion of carboxylic acids into esters and acid chlorides, and their hydrolysis?
- Can you describe the conversion of carboxylic acids into amides and nitriles?
- Can you describe the formation of nitriles from halogenoalkanes and hydroxynitriles from aldehydes and ketones?
- Can you describe the hydrolysis of nitriles and amides?
- Can you describe the reduction of nitriles using $LiAlH_4$?

OA3.1 Amines

Amines

- Can you describe the formation of primary aliphatic amines from halogenoalkanes and from nitriles?
- Can you describe the formation of aromatic amines by reduction of nitrobenzenes?
- Can you explain the basicity of amines?
- Can you describe the ethanoylation of primary amines using ethanoyl chloride?
- Can you describe the reactions of primary aliphatic and aromatic amines with cold nitric(III) acid?
- Can you describe the coupling of benzenediazonium salts with phenols and aromatic amines?
- Can you explain the role of the -N=N$^-$ chromophore in azo dyes?
- Can you explain the origin of colour in terms of the absorption of particular wavelengths of visible light?

OA3.2 Amino acids, peptides and proteins

Amino acids, peptides and proteins

- Can you give the general formula of α-amino acids and classify them?
- Can you explain the amphoteric and zwitterionic nature of amino acids and its effect on melting temperature and solubility?
- Can you describe the formation of dipeptides from α-amino acids?
- Can you describe the formation of polypeptides and proteins?
- Can you describe the primary, secondary and tertiary structure of proteins?
- Can you describe the essential roles of proteins in living systems, e.g. as enzymes?

OA4 Organic synthesis and analysis

Synthesis and purification

- Can you plan the synthesis of an organic compound through a sequence of reactions?
- Can you describe techniques of manipulation, separation and purification, e.g. reflux, distillation, separating funnel and recrystallisation?

Can you use melting temperature to assess the purity of a compound?

Polymerisation

Can you distinguish between condensation and addition polymerisation?

Can you describe the formation of polyesters and polyamides and identify the repeat unit?

Analysis

Can you use high-resolution ^{1}H NMR spectra, including spin-spin splitting, together with mass, IR and ^{13}C NMR data, to deduce structures?

Can you use paper and thin-layer chromatography, including Rf values, to find the composition of mixtures?

Can you use gas chromatography and HPLC to find the composition of mixtures?

SP Specified Practicals

Specified practical work

SP1 Can you carry out a gravimetric analysis, e.g. precipitation of a Group 2 carbonate or a metal chloride?

SP2 Can you identify unknown solutions by qualitative analysis?

SP3 Can you prepare a soluble salt by titration?

SP4 Can you standardise an acid solution?

SP5 Can you carry out a back titration, e.g. to find the percentage of calcium carbonate in limestone?

SP6 Can you carry out a double titration, e.g. of a mixture of sodium hydroxide and sodium carbonate?

SP7 Can you determine an enthalpy change indirectly, e.g. for $MgO + CO_2 \rightarrow MgCO_3$?

SP8 Can you determine an enthalpy change of combustion?

SP9 Can you investigate a rate of reaction by a gas collection method?

SP10 Can you carry out and interpret an iodine clock reaction?

SP11 Can you carry out a nucleophilic substitution, e.g. 1-bromobutane with aqueous sodium hydroxide?

SP12 Can you prepare an ester and separate it by distillation?

SP13 Can you construct electrochemical cells and measure Ecell?

SP14 Can you carry out a simple redox titration?

SP15 Can you estimate the copper content of a copper(II) salt?

SP16 Can you determine the order of a reaction, e.g. oxidation of iodide ions by hydrogen peroxide in acid?

SP17 Can you determine an equilibrium constant, e.g. for ethanol and ethanoic acid?

SP18 Can you carry out a titration using a pH probe, e.g. a weak acid against a weak base?

SP19 Can you identify aldehydes and ketones using 2,4-dinitrophenylhydrazine?

SP20 Can you synthesise a liquid organic product, including separation using a separating funnel?

SP21 Can you synthesise a solid organic product, including recrystallisation and melting temperature determination?

SP22 Can you carry out a two-step synthesis, including purification and melting temperature determination?

SP23 Can you plan and carry out a sequence of tests to identify organic compounds from a given list?

SP24 Can you separate a mixture by paper chromatography, including two-way separation?