

# AQA AS and A GCE CHEMISTRY

Modules 1, 2 and 3 constitute the 'AS' course. Modules 1, 2, 3, 4, 5 and 6 constitute the 'A' course.

Syllabus reference	Syllabus content	Page reference in <i>Chemistry in Context 5th Edn</i>
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## AS Module 1 – Atomic Structure, Bonding and Periodicity

### 10.1 Atomic Structure

10.1.1	Fundamental particles	Be able to describe the properties of protons, neutrons and electrons in terms of relative charge and relative mass.	60
10.1.2	Protons, neutrons and electrons	Understand the importance of these particles in the structure of the atom.	55–60
10.1.3	Mass number and isotopes	Be able to recall the meaning of mass number ( $A$ ) and atomic (proton) number ( $Z$ ). Be able to explain the existence of isotopes. Understand the principles of a simple mass spectrometer, limited to ionisation, acceleration, deflection and detection. Be able to interpret simple mass spectra of elements and calculate relative atomic mass from isotopic abundance, limited to mononuclear ions. Know that mass spectrometry can be used to determine relative molecular mass.	57–62 62 2–4 62 383
10.1.4	Electron arrangement	Be able to describe the electronic structures of atoms and ions up to $Z=36$ in terms of levels and sub-levels s, p and d, considered as energy levels not quantum numbers. Understand how ionisation energies in Group II (Be–Ba) and in Period 3 (Na–Ar) give evidence for electron arrangement in levels and sub-levels.	70–74 68, 212

### 10.2 Amount of Substance

10.2.1	Relative atomic mass and relative molecular mass	Be able to define relative atomic mass ( $A_r$ ) and relative molecular mass ( $M_r$ ) in terms of $^{12}\text{C}$ .	4
10.2.2	The mole and the Avogadro constant ( $L$ )	Understand the concept of a mole as applied to electrons, atoms, molecules, ions, formulae and equations. Understand the concept of the Avogadro constant and be able to perform calculations involving its use. Understand the concept of molarity.	5 7
10.2.3	The ideal gas equation	Be able to recall the ideal gas equation $pV=nRT$ and be able to apply it to simple calculations in S.I. units, for ideal gases.	139
10.2.4	Empirical and molecular formulae	Be able to calculate empirical formulae from data giving percentage composition by mass.	6
10.2.5	Balanced equations and associated calculations	Be able to write balanced equations (full and ionic) for reactions studied. Be able to balance equations for unfamiliar reactions when reactants and products are specified. Be able to calculate reacting masses from balanced equations (full and ionic). Be able to calculate reacting volumes of gases. Be able to calculate molarities and volumes for reactions in solutions, limited to titrations of monoprotic acids and bases and examples for which the equations are given.	14, 17–18 14 15–17 12–14 11

### 10.3 Bonding

10.3.1	Nature of ionic, covalent and metallic bonds	Understand that ionic bonding involves attraction between oppositely charged ions formed by electron transfer. Know that a covalent bond involves a shared pair of electrons. Know that co-ordinate bonding is dative covalency. Understand that metallic bonding involves a lattice of positive ions surrounded by delocalised electrons.	84–85 86–90 88 45–46
10.3.2	Bond polarity and the polarisation of ions	Understand that electronegativity is the power of an atom to withdraw electron density from a covalent bond. Understand that the electron distribution in a covalent bond may not be symmetrical. Know that covalent bonds between different elements will be polar to different extents. Know that anions can be polarised by cations of high charge density, limited to chlorides of elements in Period 3 and those in Group II.	97–98 100 97–98 98–99
10.3.3	Forces acting between molecules	Understand qualitatively how molecules may interact by permanent dipole-dipole, induced dipole-dipole (van der Waals') forces and hydrogen bonding.	100, 102–112
10.3.4	States of matter	Understand the behaviour of gases, liquids and solids in terms of the particles, their motion and the forces acting between them. Be able to explain the energy changes associated with changes of state. Recognise the four types of crystal: ionic, metallic, molecular and giant covalent (macromolecular). Know the structures of NaCl, I <sub>2</sub> , diamond and graphite. Be able to relate the physical properties of materials to the type of structure and bonding present.	136–137 42, 103 132, 125, 130 123–124, 126–128 131–132
10.3.5	Shapes of simple molecules and ions in terms of electron pair repulsion	Understand the concept of bonding and lone (non-bonding) pairs of electrons as charge clouds. Be able to use this concept to predict the shapes of, and bond angles in, simple molecules and ions, limited to 2, 3, 4, 5 and 6 co-ordination. Know that lone pair/lone pair repulsion is greater than lone pair/bonding pair repulsion, which is greater than bonding pair/bonding pair repulsion, and understand the resulting effect on bond angles.	90–92 90–92 92

### 10.4 Periodicity

10.4.1	Classification of elements in s, p and d blocks	Be able to classify an element as s, p or d block according to its position in the Periodic Table.	39–41
10.4.2	Properties of the elements of Period 3 (Na–Ar) to illustrate periodic trends	Be able to describe the trends in atomic radius, first ionisation energy, electronegativity, electrical conductivity, melting and boiling points of the elements Na–Ar. Understand the reasons for the trends in these properties.	173–175, 42–43 169, 170–177
10.4.3	Group II	Understand the trends in atomic radius, first ionisation energy, electronegativity and melting point of the elements Be–Ba. Know the reactions of the elements Be–Ba with water and recognise the trend. Know the relative solubilities of the hydroxides of the elements Be–Ba and that Mg(OH) <sub>2</sub> is sparingly soluble. Know the relative solubilities of the sulphates of the elements Be–Ba, that BaSO <sub>4</sub> is insoluble and is formed in the test for sulphate ions. Know that beryllium is atypical, limited to covalent character (e.g. in BeCl <sub>2</sub> ), the amphoteric character of Be(OH) <sub>2</sub> and the limitation of maximum co-ordination number to four.	212–213 213 214–215 215 213, 181, 90

## AS Module 2 – Foundation Physical and Inorganic Chemistry

### 11.1 Energetics

11.1.1	Enthalpy change ( $\Delta H$ )	Know that reactions can be endothermic or exothermic. Understand that enthalpy change ( $\Delta H$ ) is the heat energy change measured under conditions of constant pressure. Know that standard enthalpy changes refer to standard conditions, i.e. 100 kPa and a stated temperature (e.g. $\Delta H_{298}$ ). Be able to recall the definition of standard enthalpy changes of combustion ( $\Delta H_c^\ominus$ ) and formation ( $\Delta H_f^\ominus$ ).	146–147 148 148 148, 150
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11.1.2	Calorimetry	Be able to calculate the enthalpy change from the heat change in a reaction using the equation $q = mc\Delta T$ .	147–148
11.1.3	Simple applications of Hess's Law	Know Hess's Law and be able to use it to perform simple calculations.	150–153
11.1.4	Bond enthalpies	Be able to determine mean bond enthalpies from given data. Be able to use mean bond enthalpies to calculate a value of $\Delta H$ for simple reactions.	157–158 158–159

## 11.2 Kinetics

11.2.1	Collision theory	Understand that reactions can only occur when collisions take place between particles having sufficient energy.	366
11.2.2	Maxwell-Boltzmann distribution	Have a qualitative understanding of the Maxwell-Boltzmann distribution of molecular energies in gases. Be able to draw and interpret distribution curves for different temperatures.	367, 369 369
11.2.3	Factors affecting reaction rate. Concentration and physical state. Temperature  Catalysts	Understand the qualitative effect of changes in concentration (or pressure for gases) or surface area on the rate of reaction. Understand the qualitative effect of temperature changes on the rate of reaction. Be able to define the term activation energy and understand its significance. Understand that most collisions do not lead to reaction. Understand how small temperature increases can lead to a large increase in rate. Know the meaning of the term catalyst. Understand that catalysts work by providing an alternative reaction route of lower activation energy.	354–356 365–369 366 366 365 369–373 371

## 11.3 Equilibria

11.3.1	The dynamic nature of equilibria	Know that many chemical reactions are reversible. Understand that for a reaction in equilibrium, although the concentrations of reactants and products remain constant, both forward and reverse reactions are still proceeding.	289–292 292
11.3.2	Qualitative effects of changes of pressure, temperature and concentration on a system in equilibrium.	Be able to use Le Chatelier's principle to predict the effects of changes in temperature, pressure and concentration on the position of equilibrium in homogeneous reactions. Know that a catalyst does not affect the position of equilibrium.	305–309 308
11.3.3	Importance of equilibria in industrial processes	Be able to apply these concepts to given chemical processes. Be able to predict qualitatively the effect of temperature on the position of equilibrium from the sign of $\Delta H$ for the forward reaction. Understand why a compromise temperature and pressure may be used.	310–315

## 11.4 Redox Reactions

11.4.1	Oxidation and reduction	Know that oxidation is the process of electron loss. Know that reduction is the process of electron gain.	} 20–21
11.4.2	Oxidation states	Know and be able to apply the rules for assigning oxidation states in order to work out the oxidation state of an element in a compound from its formula. Understand oxidation and reduction reactions of s and p block elements.	
11.4.3	Redox equations	Be able to write half-equations identifying the oxidation and reduction processes in redox reactions when the reactants and products are specified. Be able to combine half-equations to give an overall redox equation.	} 23–24

### 11.5 Group VII, The Halogens

11.5.1	Trends in physical properties	Understand the trends in electronegativity and boiling point of the halogens	102, 227, 175–176
11.5.2	Trends in chemical properties	Understand that the ability of the halogens to oxidise decreases down the group (e.g. the displacement reactions with halide ions in aqueous solution).	230–231
11.5.3	Trends in properties of the halides	Understand the trend in reducing ability of the halide ions. Know the different products formed by reaction of NaX and H <sub>2</sub> SO <sub>4</sub> . Be able to use silver nitrate solution as a test to distinguish between F <sup>-</sup> , Cl <sup>-</sup> , Br <sup>-</sup> and I <sup>-</sup> . Know the trend in solubility of the silver halides in ammonia.	233–234
11.5.4	Uses of chlorine and estimation of chlorate(I)	Know the reactions of chlorine with water and the use of chlorine in water treatment. Know the reaction of chlorine with cold, dilute, aqueous NaOH and the uses of the solutions formed. Know that solutions of NaClO (e.g. bleaches) react with KI to liberate I <sub>2</sub> . Know that I <sub>2</sub> can be estimated by titration with standard Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> using starch indicator. Know the equations for these reactions and be able to perform calculations involving their use.	231 231–232 235 208 208

### 11.6 Extraction of Metals

11.6.1	Reduction of metal oxides with carbon	Understand how Fe is extracted by carbon reduction at high temperature in a continuous process from Fe <sub>2</sub> O <sub>3</sub> ; know that both C and CO are reductants in this process. Understand the use of limestone in this extraction process and the use of slag in the construction industry. Understand that Fe from the Blast Furnace is purified by the removal of C and P in a basic oxygen converter, and that S is removed by using Mg. Know that pollution problems can arise from the use of carbon as a reductant and the use of sulphide ores. Understand the general limitation of carbon reduction because of carbide formation (e.g. Ti or W).	265–267 267 267–269
11.6.2	Reduction of metal oxides by electrolysis of melts	Understand how Al is manufactured from purified bauxite (energy considerations, electrode equations and conditions only).	274–276
11.6.3	Reduction of metal halides with metal	Understand how Ti is extracted from TiO <sub>2</sub> via TiCl <sub>4</sub> in a batch process (equations and conditions only: either Na or Mg as a reducing agent). Understand the cost implications and hence the limited use despite the unique properties and high natural abundance of Ti. Understand that the choice of the reduction method depends upon the cost of the reductant, the energy requirements and the required purity of the metal.	281, 219 281
11.6.4	Economic factors and recycling	Understand how and why Fe and Al are recycled. Know the problems associated with recycling and know the social and economic benefits.	286

## AS Module 3 – Introduction to Organic Chemistry

### 12.1 Nomenclature and Isomerism

12.1.1	Nomenclature	Know and understand the terms empirical formula, molecular formula, structural formula, homologous series and functional group. Be able to apply IUPAC rules for nomenclature to simple organic compounds, limited to chains with up to 6 carbon atoms and the functional groups listed in this module.	6, 380–381 400–402, 418, 453, 467–468
12.1.2	Isomerism	Know and understand the meaning of the term structural isomerism. Be able to draw the structures of chain, position and functional group isomers. Know that the alkenes can exhibit geometrical, <i>cis-trans</i> , isomerism. Be able to draw the structures of <i>cis</i> and <i>trans</i> isomers.	391–392 391–392 420 420

## 12.2 Petroleum and Alkanes

12.2.1	Petroleum: fractional distillation	<p>Know that petroleum is a mixture consisting mainly of alkane hydrocarbons.</p> <p>Understand that different components (fractions) of this mixture can be drawn off at different levels in a fractionating column because of the temperature gradient, and know the major fractions and their uses.</p>	} 397–400
12.2.2	Petroleum: cracking	<p>Understand that cracking involves the breaking of C—C bonds in alkanes.</p> <p>Know that thermal cracking occurs by a free-radical mechanism and takes place at high pressure and high temperature and produces a high percentage of alkenes (mechanism not required).</p> <p>Know that catalytic cracking occurs by a carbocation mechanism and takes place at a slight pressure, high temperature and in the presence of a zeolite catalyst and is used mainly to produce motor fuels and aromatic hydrocarbons (mechanism not required).</p> <p>Understand the economic reasons for the cracking of alkanes (e.g. ethene used for poly(ethene); conversion of heavy fractions into higher value products).</p>	
12.2.3	Petroleum: combustion	<p>Know that sulphur-containing impurities are found in petroleum fractions and that combustion of these impurities produces oxides of sulphur which are toxic and can cause acid rain.</p> <p>Know that alkanes are used as fuels and understand that their combustion can be complete or incomplete and that the internal combustion engine produces a number of pollutants (e.g. NO<sub>x</sub>, CO and unburned hydrocarbons).</p> <p>Know that these pollutants can be removed by catalytic converters (mechanism not required).</p>	<p>411–413</p> <p>411–413</p> <p>413</p>
12.2.4	Alkanes: chlorination	Understand the reaction mechanism of methane with chlorine as a free-radical substitution reaction in terms of initiation, propagation and termination steps.	407–408, 409

## 12.3 Alkenes and Epoxyethane

12.3.1	Alkenes: structure and bonding	<p>Know that bonding in alkenes involves a double covalent bond.</p> <p>Know that the arrangement &gt;C=C&lt; is planar.</p> <p>Understand that the double bond in an alkene is a centre of high electron density.</p>	<p>419</p> <p>419</p> <p>421</p>
12.3.2	Alkene reactions	<p>Know that alkenes can be hydrogenated catalytically and understand the use of this process in the manufacture of margarine.</p> <p>Know that alkenes decolourise bromine water.</p> <p>Understand the mechanism of electrophilic addition of alkenes with HBr, H<sub>2</sub>SO<sub>4</sub> and Br<sub>2</sub>.</p> <p>Be able to predict the products of addition to unsymmetrical alkenes by reference to the relative stabilities of primary, secondary and tertiary carbocation intermediates.</p> <p>Understand that alcohols are produced industrially by hydration of alkenes in the presence of an acid catalyst.</p> <p>Know the typical conditions for the industrial production of ethanol from ethene.</p> <p>Know that addition polymers may be formed from alkenes.</p>	<p>422–423</p> <p>422</p> <p>421, 423–424</p> <p>424</p> <p>425</p> <p>425</p> <p>425–431</p>
12.3.3	Epoxyethane	<p>Know that epoxyethane is produced by direct synthesis from ethene and air or oxygen in the presence of a silver catalyst; understand the hazards of this process (details of plant not required).</p> <p>Know that the 3-membered ring is strained, resulting in high reactivity.</p> <p>Know that hydrolysis produces diols which are of industrial importance in the production of antifreeze and polyesters.</p> <p>Know that reactions between epoxyethane and alcohols are used in the production of solvents, plasticisers and surfactants.</p>	<p>425</p> <p>425</p> <p>479</p>

## 12.4 Haloalkanes

12.4.1	Nucleophilic substitution	Understand that haloalkanes contain polar bonds. Understand that haloalkanes are susceptible to nucleophilic attack, limited to $\text{OH}^-$ , $\text{CN}^-$ and $\text{NH}_3$ . Understand the mechanism of nucleophilic substitution in primary haloalkanes. Understand that the carbon-halogen bond enthalpy influences the rate of hydrolysis. Know that the hydrolysis of nitriles produces carboxylic acids.	454–455 456–459 456–459 461, 456 531, 499
12.4.2	Elimination	Understand concurrent displacement and elimination (including mechanisms) in the reaction of a haloalkane (e.g. 2-bromopropane with potassium hydroxide) and the role of the reagent as both base and nucleophile.	462

## 12.5 Alcohols

12.5.1	Ethanol production	Know that ethanol is produced industrially by fermentation. Know the conditions for this reaction and understand the economic and environmental advantages and disadvantages of this process compared with the industrial production from ethene.	467 467, 425
12.5.2	Classification and reactions	Understand that alcohols can be classified as primary, secondary or tertiary. Understand that tertiary alcohols are not easily oxidised. Understand that primary alcohols can be oxidised to aldehydes and carboxylic acids and that secondary alcohols can be oxidised to ketones by a suitable oxidising agent such as acidified potassium dichromate(VI) (equations showing [O] as oxidant are acceptable). Be able to use a simple chemical test to distinguish between aldehydes and ketones (e.g. Fehling's solution or Tollen's reagent). Know that aldehydes can be reduced to primary alcohols and ketones to secondary alcohols using reducing agents such as $\text{NaBH}_4$ (equations showing [H] as reductant are acceptable).	467 475 475 488 486
12.5.3	Elimination	Know that alkenes can be formed from alcohols; understand the mechanism of this elimination reaction in terms of the loss of a proton from a carbocation generated from the protonated alcohol.	473–474

## A2 Module 4 – Further Physical and Organic Chemistry

### 13.1 Kinetics

13.1.1	Simple rate equations	Understand and be able to use rate equations of the form $\text{Rate} = k[\text{A}]^m[\text{B}]^n$ where $m$ and $n$ are the orders of reaction with respect to reactants A and B ( $m, n$ restricted to values 1, 2 or 0).	360–363
13.1.2	Determination of rate equation	Be able to derive the rate equation for a reaction from data relating initial rate to the concentrations of the different reactants. Be able to explain the qualitative effect of changes in temperature on the rate constant $k$ .	362 366–369

### 13.2 Equilibria

13.2.1	Equilibrium constants $K_c$ and $K_p$ for homogeneous systems	Know that $K_c$ is the equilibrium constant calculated from equilibrium concentrations for a system at constant temperature. Know that $K_p$ is the equilibrium constant calculated from partial pressures for a system at constant temperature (the relationship between $K_c$ and $K_p$ is not required). Be able to derive partial pressures from mole fractions and total pressure. Be able to construct an expression for $K_c$ or $K_p$ for an homogeneous system in equilibrium; be able to perform calculations involving such expressions.	296–297 301 299–300
13.2.2	Qualitative effects of changes of pressure, temperature and concentration	Be able to predict the effects of changes of temperature, pressure and concentration on the position of equilibrium and on the value of the equilibrium constant. Know that a catalyst does not affect the value of the equilibrium constant.	305–309 308

### 13.3 Acids and Bases

13.3.1	Bronsted-Lowry acid-base equilibria in aqueous solution	<p>Know that an acid is a proton donor.</p> <p>Know that a base is a proton acceptor.</p> <p>Know that acid-base equilibria involve the transfer of protons.</p>	} 199–201
13.3.2	Definition and determination of pH	<p>Know that <math>\text{pH} = -\log_{10}[\text{H}^+]</math>, where [ ] represents the concentration in <math>\text{mol dm}^{-3}</math>.</p> <p>Be able to convert concentration into pH and vice-versa.</p> <p>Be able to calculate the pH of a solution of a strong acid from its molar concentration</p>	} 325–326
13.3.3	The ionic product of water, $K_w$	<p>Know that water is weakly dissociated.</p> <p>Know that <math>K_w = [\text{H}^+][\text{OH}^-] = 10^{-14} \text{ mol}^2\text{dm}^{-6}</math> at <math>25^\circ\text{C}</math>.</p> <p>Be able to calculate the pH of a strong base from its molar concentration.</p>	326 326 327
13.3.4	Weak acids and bases	Know that weak acids and weak bases dissociate only partially in aqueous solution.	329
13.3.5	$K_a$ for weak acids	<p>Be able to construct an expression, with units, for the dissociation constant <math>K_a</math> for a weak acid.</p> <p>Know that <math>\text{p}K_a = -\log_{10}K_a</math>.</p> <p>Be able to calculate the pH of a weak acid from the dissociation constant, <math>K_a</math>, and the molar concentration.</p> <p>Be able to perform calculations relating pH to <math>\text{p}K_a</math> for weak acids.</p>	329–330  329–330 329–330
13.3.6	pH curves, titrations and indicators	<p>Understand the typical shape of pH curves for acid-base titrations in all combinations of weak and strong monoprotic acids and bases; be able to perform calculations for these titrations.</p> <p>Understand the shape of the pH curves for the titration of sodium carbonate with monoprotic acids, e.g. HCl, and of diprotic acids, e.g. ethanedioic acid, with NaOH and be able to perform calculations for these titrations.</p> <p>Know that indicators change colour over a narrow pH range; be able to select an appropriate indicator by consideration of the pH curve.</p>	333–334  331–332, 334
13.3.7	Buffer action	<p>Be able to explain the action of acidic and basic buffers both qualitatively and quantitatively.</p> <p>Be able to calculate the pH of buffer solutions.</p>	} 334–337

### 13.4 Nomenclature and Isomerism in Organic Chemistry

13.4.1	Naming organic compounds	Be able to apply IUPAC rules for nomenclature to simple organic compounds, limited to chains with up to 6 carbon atoms and the functional groups listed in this module and in AS3.	400–402, 418, 453, 467–468, 483, 498, 506–507, 438, 516
13.4.2	Isomerism	<p>Know and understand the meaning of the term structural isomerism.</p> <p>Know that geometrical isomerism and optical isomerism are forms of stereoisomerism.</p> <p>Understand that geometrical isomers exist in <i>cis</i> and <i>trans</i> forms due to restricted rotation about the C=C bond.</p> <p>Know that an asymmetric carbon atom is chiral and gives rise to optical isomers which exist as mirror images and differ only in their effect on plane-polarised light.</p> <p>Understand the meaning of the terms enantiomer and racemate.</p> <p>Understand why racemates are formed.</p> <p>Be able to draw the structures of isomers.</p>	391 420 420  } 392–393

### 13.5 Compounds Containing the Carbonyl Group

13.5.1	Aldehydes and ketones	Recall that aldehydes are readily oxidised to carboxylic acid and that this forms the basis of a simple chemical test to distinguish between aldehydes and ketones (e.g. Fehling's solution or Tollen's reagent).	487–488
		Recall that aldehydes can be reduced to primary alcohols and ketones to secondary alcohols using reducing agents such as NaBH <sub>4</sub> .	486
		Mechanisms showing H <sup>-</sup> are required; (equations showing [H] as reductant are acceptable).	486
		Understand the mechanism of the reaction of carbonyl compounds with HCN as a further example of nucleophilic addition producing hydroxynitriles.	484–485
13.5.2	Carboxylic acids and esters	Know that carboxylic acids are weak acids but will liberate CO <sub>2</sub> from carbonates.	500
		Know that carboxylic acids and alcohols react, in the presence of a strong acid catalyst, to give esters.	505–507
		Know that esters can have pleasant smells.	507
		Know the common uses of esters (e.g. as solvents, plasticisers and food flavourings).	507
		Know that esters can be hydrolysed, including the production of soap, glycerol and higher fatty acids from naturally-occurring esters.	508, 509–510
13.5.3	Acylation	Know the reactions of water, alcohols, ammonia and primary amines with acyl chlorides and acid anhydrides.	462–463
		Understand the mechanism of nucleophilic addition-elimination reactions of water, alcohols, ammonia and primary amines with acyl chlorides and acid anhydrides.	462–463
		Understand the industrial advantages of ethanoic anhydride over ethanoyl chloride in the manufacture of the drug aspirin.	511

### 13.6 Aromatic Chemistry

13.6.1	Bonding	Understand the nature of the bonding in a benzene ring, limited to planar structure and bond length intermediate between single and double.	436–438
13.6.2	Delocalisation stability	Understand that delocalisation confers stability to the molecule.	437–438
		Be able to use thermochemical evidence from enthalpies of hydrogenation to illustrate this principle.	159–160
13.6.3	Electrophilic substitution	Understand that electrophilic attack in arenes results in substitution; mechanisms limited to the monosubstitutions given below.	441–442
13.6.4	Nitration	Understand that nitration is an important step in synthesis (e.g. explosive manufacture and formation of amines from which dyestuffs are manufactured). Understand the mechanism of nitration, including the generation of the nitronium ion.	} 441–442
13.6.5	Friedel-Crafts reactions	Understand that Friedel-Crafts alkylation and acylation reactions are important steps in synthesis.	
		Understand that mechanism of alkylation and acylation using AlCl <sub>3</sub> as a catalyst.	444–445
		Know that, industrially, ethylbenzene is manufactured from benzene and ethene using HCl/AlCl <sub>3</sub> ; know that this is an important intermediate in the manufacture of polystyrene (details of processes not required).	444

### 13.7 Amines

13.7.1	Base properties (Brønsted-Lowry)	Be able to explain the difference in base strength between ammonia, primary aliphatic and primary aromatic amines in terms of the availability of a lone pair on the N atom.	519–520
13.7.2	Nucleophilic properties	Understand that the nucleophilic substitution reactions (including mechanism) of ammonia and amines with haloalkanes form primary, secondary, tertiary amines and quaternary ammonium salts; know the use of the latter as cationic surfactants.	518, 461, 504
13.7.3	Preparation	Know that primary aliphatic amines can be prepared from haloalkanes and by the reduction of nitriles.	518–519
		Know that aromatic amines are prepared by the reduction of nitro compounds.	518

### 13.8 Amino Acids

13.8.1	Acid and base properties	Understand that amino acids have both acidic and basic properties.	524
13.8.2	Proteins	Understand that proteins are sequences of amino acids joined by peptide links. Understand that hydrolysis of the peptide link produces the constituent amino acids. Understand the importance of hydrogen bonding in proteins (detailed structures are not required).	524–525 525 109

### 13.9 Polymers

13.9.1	Addition polymers	Know that addition polymers may be formed directly from compounds containing C=C bonds. Be able to draw polymer structures from monomer structures and vice versa. Understand that polyalkenes are chemically inert and therefore non-biodegradable.	428–432 428–432 426
13.9.2	Condensation polymers	Understand that condensation polymers may be formed by reactions between dibasic acids and diols, between dicarboxylic acids and diamines and between amino acids. Know the linkage of the repeating units of polyesters (e.g. Terylene) and polyamides (e.g. nylon 6, 6). Understand that polyesters and polyamides can be broken down by hydrolysis and are, therefore, biodegradable (mechanisms not required).	507, 524–527 507, 525–526

### 13.10 Organic Synthesis and Analysis

13.10.1	Applications	Be able to use the organic reactions described above in synthesis and analysis, using the characteristic reactions of functional groups in this module and in AS3 (Alkenes, haloalkanes and alcohols).	530–534
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### 13.11 Structure Determination

13.11.1	Data sources	Be able to use data from all the analytical techniques listed below to determine the structure of specified compounds.	See below
13.11.2	Mass spectrometry	Understand that mass spectrometry can be used to determine the molecular formula of a compound from the mass of the molecular ion. Understand that the fragmentation of a molecular ion $M^{+} \rightarrow X^{+} + Y^{\cdot}$ gives rise to a characteristic relative abundance spectrum (rearrangement processes not required). Know that the more stable $X^{+}$ species give higher peaks, limited to carbocation and acylium ( $RCO^{+}$ ) ions.	383 383
13.11.3	Infra-red spectroscopy	Understand that certain groups in a molecule absorb infra-red radiation at characteristic frequencies. Understand that 'fingerprinting' allows identification of a molecule by comparison of spectra. Be able to use spectra to identify particular functional groups and to identify impurities, limited to data presented in wave-number form.	} 384–387
13.11.4	Nuclear magnetic resonance spectroscopy	Understand that nuclear magnetic resonance gives information about the relative number and position of hydrogen atoms in a molecule. Understand that proton n.m.r. spectra are obtained using samples dissolved in proton-free solvents (e.g. deuterated solvents and $CCl_4$ ). Understand why tetramethylsilane (TMS) is used as a standard. Know the use of the $\delta$ scale for recording chemical shift. Understand that chemical shift depends on the molecular environment. Understand how integrated spectra indicate the relative numbers of protons in different environments. Be able to use the $n + 1$ rule to deduce the spin-spin splitting patterns of adjacent, non-equivalent protons, limited to doublet, triplet and quartet formation in simple aliphatic compounds.	} 387–390 } 388 389 389–390

## A2 Module 5 – Thermodynamics and Further Inorganic Chemistry

### 14.1 Thermodynamics

14.1.1	Enthalpy change ( $\Delta H$ )	<p>Be able to define and apply the terms enthalpy of formation, ionisation enthalpy, enthalpy of atomisation of an element and of a compound, bond dissociation enthalpy, electron affinity, lattice enthalpy (defined as either lattice dissociation or lattice formation), enthalpy of hydration and enthalpy of solution.</p> <p>Be able to construct a Born-Haber cycle for the formation of simple ionic compounds.</p> <p>Be able to calculate enthalpies of solution for ionic compounds from lattice enthalpies and enthalpies of hydration.</p> <p>Be able to use mean bond enthalpies to calculate an approximate value of <math>\Delta H</math> for other reactions.</p> <p>Be able to explain why values from mean bond enthalpy calculations differ from those determined from enthalpy cycles.</p>	<p>148, 64, 149, 86, 160–163</p> <p>161</p> <p>162–163</p> <p>158–160</p> <p>158</p>
14.1.2	Free energy change $\Delta G$ and entropy change $\Delta S$	<p>Understand that <math>\Delta H</math>, whilst important, is not sufficient to explain spontaneous change (e.g. spontaneous endothermic reactions).</p> <p>Understand that the concept of increasing disorder (entropy change <math>\Delta S</math>) accounts for the above deficiency, illustrated by physical change (e.g. melting, evaporation) and chemical change (e.g. dissolution, evolution of <math>\text{CO}_2</math> from hydrogencarbonates with acid).</p> <p>Understand that the balance between entropy and enthalpy determines the feasibility of a reaction; know that this is given by the relationship <math>\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus</math> (derivation not required).</p> <p>Be able to calculate entropy changes from absolute entropy values.</p>	<p>154–155</p> <p>340–345</p> <p>346</p> <p>344</p>

### 14.2 Periodicity

14.2.1	Study of the reactions of Period 3 elements Na–Ar to illustrate periodic trends	<p>Be able to describe trends in the reactions of the elements with water, limited to Na and Mg.</p> <p>Be able to describe the trends in the reactions of the elements Na, Mg, Al, Si, P and S with oxygen, limited to the formation of <math>\text{Na}_2\text{O}</math>, MgO, <math>\text{Al}_2\text{O}_3</math>, <math>\text{SiO}_2</math>, <math>\text{P}_4\text{O}_{10}</math> and <math>\text{SO}_2</math>.</p> <p>Be able to describe the trends in the reactions of the elements Na, Mg, Al, Si and P with chlorine, limited to the formation of NaCl, <math>\text{MgCl}_2</math>, <math>\text{AlCl}_3</math>, <math>\text{SiCl}_4</math> and <math>\text{PCl}_5</math>.</p>	<p>47–48, 213</p> <p>47–48</p> <p>47–48</p>
14.2.2	A survey of the acid-base properties of the oxides of Period 3 elements.	<p>Understand the link between the physical properties of the highest oxides of the elements Na–S and their structure and bonding.</p> <p>Be able to describe the reactions of the oxides of the elements Na–S with water, limited to <math>\text{Na}_2\text{O}</math>, MgO; <math>\text{Al}_2\text{O}_3</math>, <math>\text{SiO}_2</math>, <math>\text{P}_4\text{O}_{10}</math>, <math>\text{SO}_2</math> and <math>\text{SO}_3</math>.</p> <p>Know the change in pH of the resulting solutions across the Period.</p> <p>Be able to explain the trends in these properties in terms of the type of bonding present.</p> <p>Be able to write equations for the reactions which occur between these oxides and given simple acids and bases.</p>	<p>180–181</p> <p>182–184</p>
14.2.3	A survey of the reactions of the chlorides of Period 3 elements with water	<p>Understand the link between the physical properties of the chlorides of the elements Na–P and their structure and bonding.</p> <p>Be able to describe the reactions of the chlorides of the elements Na–P with water, limited to NaCl, <math>\text{MgCl}_2</math>, <math>\text{AlCl}_3</math>, <math>\text{SiCl}_4</math>, and <math>\text{PCl}_5</math>.</p> <p>Know the change in pH of the resulting solutions across the Period.</p> <p>Be able to explain the trends in these properties in terms of the type of bonding present.</p>	<p>48–49</p> <p>179–180</p>

### 14.3 Redox Equilibria

14.3.1	Variable oxidation state	<p>Understand oxidation and reduction as electron transfer reactions applied to reactions of d block elements.</p> <p>Know and be able to apply the rules for assigning oxidation states in order to work out the oxidation state of an element in a compound from its formula.</p> <p>Understand that changes in oxidation state involve redox processes.</p> <p>Be able to write half-equations identifying the oxidation and reduction processes in redox reactions when the reactants and products are specified.</p> <p>Be able to combine half-equations to give an overall redox equation.</p>	<p>253–255</p> <p>29–32</p> <p>31</p> <p>23–24</p> <p>23–24</p>
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14.3.2	Electrode potentials	<p>Know the IUPAC convention for writing half-equations for electrode reactions.</p> <p>Know and be able to use the conventional representation of cells.</p> <p>Understand how cells are used to measure electrode potentials by reference to the standard hydrogen electrode and know that secondary standards are normally used.</p> <p>Know the importance of the conditions when measuring the electrode potential, <math>E</math> (Nernst equation not required).</p> <p>Know that standard electrode potential <math>E^\ominus</math>, refers to conditions of 298 K, 100 kPa and 1 M solution of ions.</p>	<p>190–192</p> <p>191</p> <p>191</p>
14.3.3	Electrochemical series	<p>Know that standard electrode potentials can be listed as an electrochemical series.</p> <p>Be able to use <math>E^\ominus</math> values to predict the direction of simple redox reactions and to calculate the e.m.f. of a cell.</p>	<p>193</p> <p>193–195</p>

#### 14.4 Transition Metals

14.4.1	General properties of transition metals	<p>Know that transition metal characteristics of elements Sc — Cu arise from an incomplete d sub-shell in atoms or ions.</p> <p>Know that these characteristics include complex formation, formation of coloured ions, variable oxidation state and catalytic activity.</p>	<p>249–251</p> <p>263</p>
14.4.2	Complex formation	<p>Be able to define the term ligand.</p> <p>Know that co-ordinate bonding is involved in complex formation.</p> <p>Understand that a complex is a central metal ion surrounded by ligands.</p> <p>Know the meaning of co-ordination number.</p> <p>Understand that ligands can be unidentate (e.g. <math>\text{H}_2\text{O}</math>, <math>\text{NH}_3</math> and <math>\text{Cl}^-</math>) or bidentate (e.g. <math>\text{NH}_2\text{CH}_2\text{NH}_2</math> and <math>\text{C}_2\text{O}_4^{2-}</math>) or multidentate (e.g. <math>\text{EDTA}^{4-}</math>).</p> <p>Know that haem is an iron (II) complex with a multidentate ligand.</p>	<p>201–202</p> <p>201–202</p> <p>257–258</p> <p>257</p> <p>202–203</p> <p>205</p>
14.4.3	Shape of complex ions	<p>Know that transition metal ions commonly form octahedral complexes with small ligands (e.g. <math>\text{H}_2\text{O}</math> and <math>\text{NH}_3</math>).</p> <p>Know that transition metal ions commonly form tetrahedral complexes with large ligands (e.g. <math>\text{Cl}^-</math>).</p> <p>Know that <math>\text{Ag}^+</math> commonly forms linear complexes, (e.g. <math>[\text{Ag}(\text{NH}_3)_2]^+</math>, <math>[\text{Ag}(\text{S}_2\text{O}_3)_2]^{3-}</math> and <math>[\text{Ag}(\text{CN})_2]</math>).</p>	<p>257</p> <p>258</p> <p>257</p>
14.4.4	Formation of coloured ions	<p>Know that transition metal ions can be identified by their colour, limited to the complexes in this module.</p> <p>Know that colour changes arise from changes in oxidation state, co-ordination number and ligand.</p> <p>Know that colour arises from electronic transitions from the ground state to excited states: <math>\Delta E = h\nu</math>.</p> <p>Know the use of ultraviolet and visible spectrophotometry in determining the concentration of metal ions in solution after the addition of a suitable ligand to intensify the colour.</p>	<p>259–261</p> <p>259–261</p> <p>259</p>
14.4.5	Variable oxidation states	<p>Know that transition elements show variable oxidation states.</p> <p>Know that <math>\text{VO}^{2+}</math>, <math>\text{V}^{3+}</math> and <math>\text{V}^{2+}</math> are formed by reduction of <math>\text{VO}_2^+</math> by zinc in acid solution.</p> <p>Know that <math>\text{Cr}^{3+}</math> and <math>\text{Cr}^{2+}</math> are formed by reduction of <math>\text{Cr}_2\text{O}_7^{2-}</math> by zinc in acid solution.</p>	<p>254–256</p> <p>255</p>
14.4.5		<p>Know the redox titration of <math>\text{Fe}^{2+}</math> with <math>\text{MnO}_4^-</math> and <math>\text{Cr}_2\text{O}_7^{2-}</math> in acid solution.</p> <p>Be able to perform calculation for these titrations and for others when the reductant and its oxidation product are given.</p> <p>Know the oxidation of <math>\text{Co}^{2+}</math> by air in ammoniacal solution.</p> <p>Know the oxidations in alkaline solution of <math>\text{Co}^{2+}</math> and <math>\text{Cr}^{3+}</math> by <math>\text{H}_2\text{O}_2</math>.</p>	<p>207–208</p> <p>207–208</p>

14.4.6	Catalysis	Know that transition metals and their compounds can act as heterogeneous and homogeneous catalysts.	261–262
	Heterogeneous	Know that a heterogeneous catalyst is in a different phase from the reactants and that the reaction occurs at the surface. Understand that adsorption of reactants at active sites on the surface may lead to catalytic action. Know that the strength of adsorption helps to determine the activity (e.g. W too strong adsorption, Ag too weak adsorption, and hence the unity of Ni and Pt.) Understand the use of a support medium to maximise the surface area and minimise the cost (e.g. Rh on a ceramic support in catalytic converters). Know that V <sub>2</sub> O <sub>5</sub> is used as a catalyst in the Contact Process. Know that Fe is used as a catalyst in the Haber Process.	371 413 262 315
	Homogeneous	Know that catalysts can become poisoned by impurities and consequently have reduced efficiency; know that this has a cost implication (e.g. poisoning by sulphur in the Haber Process and by lead in catalytic converters in cars.) Know that when catalysts and reactants are in the same phase, the reaction proceeds through an intermediate species (e.g. the reaction between I <sup>-</sup> and S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> catalysed by Fe <sup>2+</sup> and auto catalysis by Mn <sup>2+</sup> in titrations of C <sub>2</sub> O <sub>4</sub> <sup>2-</sup> with MnO <sub>4</sub> <sup>-</sup> ).	413 371
14.4.7	Other applications of transition metal complexes	Understand the importance of variable oxidation states in catalysis; both heterogeneous and homogeneous catalysts (e.g. V <sub>2</sub> O <sub>5</sub> in the Contact process and autocatalysis by Mn <sup>2+</sup> in MnO <sub>4</sub> <sup>-</sup> titrations). Understand that Fe(II) in haemoglobin enables oxygen to be transported into blood, and why CO is toxic. Know that the Pt(II) complex cisplatin is used as an anticancer drug. Understand that [Ag(NH <sub>3</sub> ) <sub>2</sub> ] <sup>+</sup> is used in Tollen's reagent and that [Ag(S <sub>2</sub> O <sub>3</sub> ) <sub>2</sub> ] <sup>3-</sup> is formed in photography. Know that [Ag(CN) <sub>2</sub> ] <sup>-</sup> is used in electroplating.	262 205–206

### 14.5 Reactions of Inorganic Compounds in Aqueous Solution

14.5.1	Lewis acids and bases	Know the definitions of a Lewis acid and Lewis base; understand the importance of lone pair electrons in co-ordinate bond formation.	
14.5.2	Metal-aqua ions	Know that metal-aqua ions are formed in aqueous solution: [M(H <sub>2</sub> O) <sub>6</sub> ] <sup>2+</sup> , limited to M=Fe,Co and Cu; [M(H <sub>2</sub> O) <sub>6</sub> ] <sup>3+</sup> , limited to M=Al, V, Cr and Fe. Know that these aqua ions can be present in the solid state (e.g. FeSO <sub>4</sub> ·7H <sub>2</sub> O and CoCl <sub>2</sub> ·6H <sub>2</sub> O).	201
14.5.3	Acidity or hydrolysis reactions	Understand the equilibria [M(H <sub>2</sub> O) <sub>6</sub> ] <sup>2+</sup> + H <sub>2</sub> O ⇌ [M(H <sub>2</sub> O) <sub>5</sub> (OH)] <sup>+</sup> + H <sub>3</sub> O <sup>+</sup> and [M(H <sub>2</sub> O) <sub>6</sub> ] <sup>3+</sup> + H <sub>2</sub> O ⇌ [M(H <sub>2</sub> O) <sub>5</sub> (OH)] <sup>2+</sup> + H <sub>3</sub> O <sup>+</sup> to show generation of acidic solutions with M <sup>3+</sup> , and very weakly acidic solutions with M <sup>2+</sup> .	257
		Understand that the acidity of [M(H <sub>2</sub> O) <sub>6</sub> ] <sup>3+</sup> is greater than that of [M(H <sub>2</sub> O) <sub>6</sub> ] <sup>2+</sup> in terms of the polarising power (charge/ size ratio) of the metal ion. Be able to describe and explain the simple test-tube reactions of M <sup>2+</sup> (aq) ions, limited to M=Fe, Co and Cu and of M <sup>3+</sup> (aq) ions, limited to M=Al, Cr and Fe, with the bases OH <sup>-</sup> , NH <sub>3</sub> and CO <sub>3</sub> <sup>2-</sup> . Know that MCO <sub>3</sub> is formed but that M <sub>2</sub> (CO <sub>3</sub> ) <sub>3</sub> is not formed.	257 283–285
		Know that some metal hydroxides show amphoteric character by dissolving in both acids and bases (e.g. hydroxides of Al <sup>3+</sup> and Cr <sup>3+</sup> ). Know the equilibrium reaction 2CrO <sub>4</sub> <sup>2-</sup> + 2H <sup>+</sup> ⇌ Cr <sub>2</sub> O <sub>7</sub> <sup>2-</sup> + H <sub>2</sub> O.	284
14.5.4	Substitution reactions	Understand that the ligands NH <sub>3</sub> and H <sub>2</sub> O are similar in size and are uncharged, and that ligand exchange occurs without change of co-ordination number (e.g. Co <sup>2+</sup> and Cr <sup>3+</sup> ).	201–204
		Know that substitution may be incomplete (e.g. the formation of [Cu(NH <sub>3</sub> ) <sub>4</sub> (H <sub>2</sub> O) <sub>2</sub> ] <sup>2+</sup> ). Understand that the Cl <sup>-</sup> ligand is larger than these uncharged ligands and that ligand exchange can involve a change of co-ordination number (e.g. Co <sup>2+</sup> and Cu <sup>2+</sup> ). Know that a substitution with a bidentate or a multidentate ligand leads to a more stable complex. Understand this chelate effect in terms of positive entropy change in these reactions.	257–258