# A-Level Chemistry

**Syllabus Checklist · 大纲自查表**

Tick one box per statement: ☐ not yet ☐ nearly ☐ confident. 每条打一个勾：尚未掌握 / 快会了 / 有把握。

## 1. Atomic structure 原子结构

### 1.1 Particles in the atom and atomic radius 原子中的粒子与原子半径

- ☐☐☐ understand that atoms are mostly empty space surrounding a very small, dense **nucleus** that contains **protons** and **neutrons**; **electrons** are found in **shells** in the empty space around the nucleus
- ☐☐☐ identify and describe protons, neutrons and electrons in terms of their relative charges and relative masses
- ☐☐☐ understand the terms **atomic and proton number**; **mass and nucleon number**
- ☐☐☐ describe the distribution of mass and charge within an atom
- ☐☐☐ describe the behaviour of beams of protons, neutrons and electrons moving at the same velocity in an electric field
- ☐☐☐ determine the numbers of protons, neutrons and electrons present in both atoms and ions given atomic or proton number, mass or nucleon number and charge
- ☐☐☐ state and explain qualitatively the variations in **atomic radius** and **ionic radius** across a period and down a group

### 1.2 Isotopes 同位素

- ☐☐☐ define the term **isotope** in terms of numbers of protons and neutrons
- ☐☐☐ understand the notation ${}^{x}_{y}\mathrm{A}$ for isotopes, where $x$ is the mass or nucleon number and $y$ is the atomic or proton number
- ☐☐☐ state that and explain why isotopes of the same element have the same chemical properties
- ☐☐☐ state that and explain why isotopes of the same element have different physical properties, limited to mass and density

### 1.3 Electrons, energy levels and atomic orbitals 电子、能级与原子轨道

- ☐☐☐ understand the terms: **shells**, **sub-shells** and **orbitals**; **principal quantum number** (n); **ground state**, limited to electronic configuration
- ☐☐☐ describe the number of orbitals making up s, p and d sub-shells, and the number of electrons that can fill s, p and d sub-shells
- ☐☐☐ describe the order of increasing energy of the sub-shells within the first three shells and the 4s and 4p sub-shells
- ☐☐☐ describe the **electronic configurations** to include the number of electrons in each shell, sub-shell and orbital
- ☐☐☐ explain the electronic configurations in terms of energy of the electrons and inter-electron repulsion
- ☐☐☐ determine the electronic configuration of atoms and ions given the atomic or proton number and charge, using either of the following conventions: e.g. for Fe: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$ (full electronic configuration) or [Ar] $3d^6 4s^2$ (shorthand electronic configuration)
- ☐☐☐ understand and use the electrons in boxes notation
- ☐☐☐ describe and sketch the shapes of s and p orbitals
- ☐☐☐ describe a **free radical** as a species with one or more unpaired electrons

### 1.4 Ionisation energy 电离能

- ☐☐☐ define and use the term **first ionisation energy**, IE
- ☐☐☐ construct equations to represent first, second and subsequent ionisation energies
- ☐☐☐ identify and explain the trends in ionisation energies across a period and down a group of the Periodic Table
- ☐☐☐ identify and explain the variation in successive ionisation energies of an element
- ☐☐☐ understand that ionisation energies are due to the attraction between the nucleus and the outer electron
- ☐☐☐ explain the factors influencing the ionisation energies of elements in terms of **nuclear charge**, atomic/ionic radius, **shielding** by inner shells and sub-shells and **spin-pair repulsion**
- ☐☐☐ deduce the electronic configurations of elements using successive ionisation energy data
- ☐☐☐ deduce the position of an element in the Periodic Table using successive ionisation energy data

## 2. Atoms, molecules and stoichiometry 原子、分子与化学计量

### 2.1 Relative masses of atoms and molecules 原子与分子的相对质量

- ☐☐☐ define the **unified atomic mass unit** as one twelfth of the mass of a **carbon-12** atom
- ☐☐☐ define **relative atomic mass**, $A_r$, **relative isotopic mass**, **relative molecular mass**, $M_r$, and **relative formula mass** in terms of the unified atomic mass unit

### 2.2 The mole and the Avogadro constant 摩尔与阿伏伽德罗常数

- ☐☐☐ define and use the term **mole** in terms of the **Avogadro constant**

### 2.3 Formulas 化学式

- ☐☐☐ write formulas of ionic compounds from ionic charges and oxidation numbers (shown by a Roman numeral), including: (a) the prediction of ionic charge from the position of an element in the Periodic Table (b) recall of the names and formulas for the following ions: $NO_3^-$, $CO_3^{2-}$, $SO_4^{2-}$, $OH^-$, $NH_4^+$, $Zn^{2+}$, $Ag^+$, $HCO_3^-$, $PO_4^{3-}$
- ☐☐☐ (a) write and construct equations (which should be balanced), including ionic equations (which should not include spectator ions) (b) use appropriate state symbols in equations
- ☐☐☐ define and use the terms **empirical and molecular formula**
- ☐☐☐ understand and use the terms **anhydrous**, **hydrated** and **water of crystallisation**
- ☐☐☐ calculate empirical and molecular formulas, using given data

### 2.4 Reacting masses and volumes (of solutions and gases) 反应的质量与体积（溶液与气体）

- ☐☐☐ perform calculations including use of the mole concept, involving: (a) reacting masses (from formulas and equations) including percentage yield calculations (b) volumes of gases (e.g. in the burning of hydrocarbons) (c) volumes and concentrations of solutions (d) **limiting reagent** and **excess reagent** (When performing calculations, candidates' answers should reflect the number of significant figures given or asked for in the question. When rounding up or down, candidates should ensure that significant figures are neither lost unnecessarily nor used beyond what is justified (see also Mathematical requirements section).) (e) deduce **stoichiometric** relationships from calculations such as those in 2.4.1(a)–(d)

# 3. Chemical bonding 化学键

### 3.1 Electronegativity and bonding 电负性与成键

- ☐☐☐ define **electronegativity** as the power of an atom to attract electrons to itself
- ☐☐☐ explain the factors influencing the electronegativities of the elements in terms of nuclear charge, atomic radius and shielding by inner shells and sub-shells
- ☐☐☐ state and explain the trends in electronegativity across a period and down a group of the Periodic Table
- ☐☐☐ use the differences in **Pauling electronegativity** values to predict the formation of **ionic** and **covalent bonds** (the presence of covalent character in some ionic compounds will not be assessed) (Pauling electronegativity values will be given where necessary)

### 3.2 Ionic bonding 离子键

- ☐☐☐ define **ionic bonding** as the electrostatic attraction between oppositely charged ions (positively charged **cations** and negatively charged **anions**)
- ☐☐☐ describe ionic bonding including the examples of sodium chloride, magnesium oxide and calcium fluoride

### 3.3 Metallic bonding 金属键

- ☐☐☐ define **metallic bonding** as the electrostatic attraction between positive metal ions and **delocalised electrons**

### 3.4 Covalent bonding and coordinate (dative covalent) bonding 共价键与配位（共价）键

- ☐☐☐ define **covalent bonding** as electrostatic attraction between the nuclei of two atoms and a shared pair of electrons (a) describe covalent bonding in molecules including: • hydrogen, $H_2$ • oxygen, $O_2$ • nitrogen, $N_2$ • chlorine, $Cl_2$ • hydrogen chloride, HCl • carbon dioxide, $CO_2$ • ammonia, $NH_3$ • methane, $CH_4$ • ethane, $C_2H_6$ • ethene, $C_2H_4$ (b) understand that elements in period 3 can expand their octet including in the compounds sulfur dioxide, $SO_2$, phosphorus pentachloride, $PCl_5$, and sulfur hexafluoride, $SF_6$ (c) describe coordinate (dative covalent) bonding, including in the reaction between ammonia and hydrogen chloride gases to form the ammonium ion, $NH_4^+$, and in the $Al_2Cl_6$ molecule
- ☐☐☐ (a) describe covalent bonds in terms of orbital overlap giving $\sigma$ and $\pi$ bonds: • $\sigma$ bonds are formed by direct overlap of orbitals between the bonding atoms • $\pi$ bonds are formed by the sideways overlap of adjacent p orbitals above and below the $\sigma$ bond (b) describe how the $\sigma$ and $\pi$ bonds form in molecules including $H_2$, $C_2H_6$, $C_2H_4$, HCN and $N_2$ (c) use the concept of **hybridisation** to describe sp, $sp^2$ and $sp^3$ orbitals
- ☐☐☐ (a) define the terms: • **bond energy** as the energy required to break one mole of a particular covalent bond in the gaseous state • **bond length** as the internuclear distance of two covalently bonded atoms (b) use bond energy values and the concept of bond length to compare the reactivity of covalent molecules

### 3.5 Shapes of molecules 分子的形状

- ☐☐☐ state and explain the shapes of, and bond angles in, molecules by using **VSEPR theory**, including as simple examples: • $BF_3$ (trigonal planar, 120°) • $CO_2$ (linear, 180°) • $CH_4$ (tetrahedral, 109.5°) • $NH_3$ (pyramidal, 107°) • $H_2O$ (non-linear, 104.5°) • $SF_6$ (octahedral, 90°) • $PF_5$ (trigonal bipyramidal, 120° and 90°)
- ☐☐☐ predict the shapes of, and bond angles in, molecules and ions analogous to those specified in 3.5.1

### 3.6 Intermolecular forces, electronegativity and bond properties 分子间作用力、电负性与键的性质

☐☐☐ (a) describe **hydrogen bonding**, limited to molecules containing N–H and O–H groups, including ammonia and water as simple examples (b) use the concept of hydrogen bonding to explain the anomalous properties of $H_2O$ (ice and water): • its relatively high melting and boiling points • its relatively high surface tension • the density of the solid ice compared with the liquid water

☐☐☐ use the concept of electronegativity to explain **bond polarity** and **dipole moments** of molecules

☐☐☐ (a) describe **van der Waals' forces** as the intermolecular forces between molecular entities other than those due to bond formation, and use the term van der Waals' forces as a generic term to describe all intermolecular forces (b) describe the types of van der Waals' forces: • instantaneous dipole–induced dipole (id-id) forces, also called **London dispersion forces** • permanent dipole–permanent dipole (pd-pd) forces, including hydrogen bonding (c) describe hydrogen bonding and understand that hydrogen bonding is a special case of permanent dipole–permanent dipole forces between molecules where hydrogen is bonded to a highly electronegative atom

☐☐☐ state that, in general, ionic, covalent and metallic bonding are stronger than intermolecular forces

### 3.7 Dot-and-cross diagrams 电子点叉图

☐☐☐ use **dot-and-cross diagrams** to illustrate ionic, covalent and coordinate bonding including the representation of any compounds stated in 3.4 and 3.5 (dot-and-cross diagrams may include species with atoms which have an expanded octet or species with an odd number of electrons)

## 4. States of matter 物质的状态

### 4.1 The gaseous state: ideal and real gases and pV = nRT 气态：理想气体与真实气体及 pV = nRT

☐☐☐ explain the origin of **pressure** in a gas in terms of collisions between gas molecules and the wall of the container

☐☐☐ understand that **ideal gases** have zero particle volume and no **intermolecular forces** of attraction

☐☐☐ state and use the **ideal gas equation** $pV = nRT$ in calculations, including in the determination of $M_r$

### 4.2 Bonding and structure 成键与结构

☐☐☐ describe, in simple terms, the **lattice structure** of a **crystalline solid** which is: (a) giant ionic, including sodium chloride and magnesium oxide (b) simple molecular, including iodine, buckminsterfullerene $C_{60}$ and ice (c) giant molecular, including silicon(IV) oxide, graphite and diamond (d) giant metallic, including copper

☐☐☐ describe, interpret and predict the effect of different types of structure and bonding on the physical properties of substances, including **melting point**, **boiling point**, **electrical conductivity** and **solubility**

☐☐☐ deduce the type of structure and bonding present in a substance from given information

## 5. Chemical energetics 化学能量学

### 5.1 Enthalpy change, ΔH 焓变 ΔH

☐☐☐ understand that chemical reactions are accompanied by **enthalpy changes** and these changes can be **exothermic** ($\Delta H$ is negative) or **endothermic** ($\Delta H$ is positive)

☐☐☐ construct and interpret a **reaction pathway diagram**, in terms of the enthalpy change of the reaction and of the **activation energy**

☐☐☐ define and use the terms: (a) **standard conditions** (this syllabus assumes that these are 298 K and 101 kPa) shown by $^{\ominus}$. (b) enthalpy change with particular reference to: reaction, $\Delta H_r$,

formation, $\Delta H_f$, combustion, $\Delta H_c$, neutralisation, $\Delta H_{\text{neut}}$

- ☐☐☐ understand that energy transfers occur during chemical reactions because of the breaking and making of chemical bonds
- ☐☐☐ use bond energies ($\Delta H$ positive, i.e. bond breaking) to calculate enthalpy change of reaction, $\Delta H_r$
- ☐☐☐ understand that some bond energies are exact and some bond energies are averages
- ☐☐☐ calculate enthalpy changes from appropriate experimental results, including the use of the relationships $q = mc\Delta T$ and $\Delta H = -mc\Delta T/n$

### 5.2 Hess's law 盖斯定律

- ☐☐☐ apply **Hess's law** to construct simple energy cycles
- ☐☐☐ carry out calculations using cycles and relevant energy terms, including: (a) determining enthalpy changes that cannot be found by direct experiment (b) use of bond energy data

## 6. Electrochemistry 电化学

### 6.1 Redox processes: electron transfer and changes in oxidation number (oxidation state) 氧化还原过程：电子转移与氧化数（氧化态）的变化

- ☐☐☐ calculate **oxidation numbers** of elements in compounds and ions
- ☐☐☐ use changes in oxidation numbers to help balance chemical equations
- ☐☐☐ explain and use the terms **redox**, **oxidation**, **reduction** and **disproportionation** in terms of electron transfer and changes in oxidation number
- ☐☐☐ explain and use the terms **oxidising agent** and **reducing agent**
- ☐☐☐ use a Roman numeral to indicate the magnitude of the oxidation number of an element

## 7. Equilibria 平衡

### 7.1 Chemical equilibria: reversible reactions, dynamic equilibrium 化学平衡：可逆反应与动态平衡

- ☐☐☐ (a) understand what is meant by a **reversible reaction** (b) understand what is meant by **dynamic equilibrium** in terms of the rate of forward and reverse reactions being equal and the concentration of reactants and products remaining constant (c) understand the need for a closed system in order to establish dynamic equilibrium
- ☐☐☐ define **Le Chatelier's principle** as: if a change is made to a system at dynamic equilibrium, the position of equilibrium moves to minimise this change
- ☐☐☐ use Le Chatelier's principle to deduce qualitatively (from appropriate information) the effects of changes in temperature, concentration, pressure or presence of a catalyst on a system at equilibrium
- ☐☐☐ deduce expressions for **equilibrium constants** in terms of concentrations, $K_c$
- ☐☐☐ use the terms **mole fraction** and **partial pressure**
- ☐☐☐ deduce expressions for equilibrium constants in terms of partial pressures, $K_p$ (use of the relationship between $K_p$ and $K_c$ is not required)
- ☐☐☐ use the $K_c$ and $K_p$ expressions to carry out calculations (such calculations will not require the solving of quadratic equations)
- ☐☐☐ calculate the quantities present at equilibrium, given appropriate data
- ☐☐☐ state whether changes in temperature, concentration or pressure or the presence of a catalyst affect the value of the equilibrium constant for a reaction
- ☐☐☐ describe and explain the conditions used in the **Haber process** and the **Contact process**, as

examples of the importance of an understanding of dynamic equilibrium in the chemical industry and the application of Le Chatelier's principle

### 7.2 Brønsted–Lowry theory of acids and bases 布朗斯特 – 劳里酸碱理论

- ☐☐☐ state the names and formulas of the common acids, limited to **hydrochloric acid**, HCl, **sulfuric acid**, $H_2SO_4$, **nitric acid**, $HNO_3$, **ethanoic acid**, $CH_3COOH$
- ☐☐☐ state the names and formulas of the common alkalis, limited to **sodium hydroxide**, NaOH, **potassium hydroxide**, KOH, **ammonia**, $NH_3$
- ☐☐☐ describe the **Brønsted–Lowry theory** of acids and bases
- ☐☐☐ describe **strong acids** and **strong bases** as **fully dissociated** in aqueous solution and **weak acids** and **weak bases** as **partially dissociated** in aqueous solution
- ☐☐☐ appreciate that water has pH of 7, acid solutions pH of below 7 and alkaline solutions pH of above 7
- ☐☐☐ explain qualitatively the differences in behaviour between strong and weak acids including the reaction with a reactive metal and difference in pH values by use of a pH meter, universal indicator or conductivity
- ☐☐☐ understand that neutralisation reactions occur when $H^+(aq)$ and $OH^-(aq)$ form $H_2O(l)$
- ☐☐☐ understand that salts are formed in neutralisation reactions
- ☐☐☐ sketch the **pH titration curves** of titrations using combinations of strong and weak acids with strong and weak alkalis
- ☐☐☐ select suitable indicators for acid-alkali titrations, given appropriate data ($pK_a$ values will not be used)

## 8. Reaction kinetics 反应动力学

### 8.1 Rate of reaction 反应速率

- ☐☐☐ explain and use the term **rate of reaction**, **frequency of collisions**, **effective collisions** and non-effective collisions
- ☐☐☐ explain qualitatively, in terms of frequency of effective collisions, the effect of concentration and pressure changes on the rate of a reaction
- ☐☐☐ use experimental data to calculate the rate of a reaction

### 8.2 Effect of temperature on reaction rates and the concept of activation energy 温度对反应速率的影响与活化能概念

- ☐☐☐ define **activation energy**, $E_A$, as the minimum energy required for a collision to be effective
- ☐☐☐ sketch and use the **Boltzmann distribution** to explain the significance of activation energy
- ☐☐☐ explain qualitatively, in terms both of the Boltzmann distribution and of frequency of effective collisions, the effect of temperature change on the rate of a reaction

### 8.3 Homogeneous and heterogeneous catalysts 均相与多相催化剂

- ☐☐☐ explain and use the terms **catalyst** and **catalysis**: (a) explain that, in the presence of a catalyst, a reaction has a different mechanism, i.e. one of lower activation energy (b) explain this catalytic effect in terms of the Boltzmann distribution (c) construct and interpret a reaction pathway diagram, for a reaction in the presence and absence of an effective catalyst

## 9. The Periodic Table: chemical periodicity 元素周期表：化学周期性

### 9.1 Periodicity of physical properties of the elements in Period 3 第三周期元素物理性质的周期性

- ☐☐☐ describe qualitatively (and indicate the periodicity in) the variations in **atomic radius**, **ionic radius**, **melting point** and **electrical conductivity** of the elements
- ☐☐☐ explain the variation in melting point and electrical conductivity in terms of the structure and bonding of the elements

### 9.2 Periodicity of chemical properties of the elements in Period 3 第三周期元素化学性质的周期性

- ☐☐☐ describe, and write equations for, the reactions of the elements with oxygen (to give $Na_2O$, MgO, $Al_2O_3$, $P_4O_{10}$, $SO_2$), chlorine (to give NaCl, $MgCl_2$, $AlCl_3$, $SiCl_4$, $PCl_5$) and water (Na and Mg only)
- ☐☐☐ state and explain the variation in the **oxidation number** of the oxides ($Na_2O$, MgO, $Al_2O_3$, $P_4O_{10}$, $SO_2$ and $SO_3$ only) and chlorides (NaCl, $MgCl_2$, $AlCl_3$, $SiCl_4$, $PCl_5$ only) in terms of their outer shell (valence shell) electrons
- ☐☐☐ describe, and write equations for, the reactions, if any, of the oxides $Na_2O$, MgO, $Al_2O_3$, $SiO_2$, $P_4O_{10}$, $SO_2$ and $SO_3$ with water including the likely pHs of the solutions obtained
- ☐☐☐ describe, explain, and write equations for, the acid/base behaviour of the oxides $Na_2O$, MgO, $Al_2O_3$, $P_4O_{10}$, $SO_2$ and $SO_3$ and the hydroxides NaOH, $Mg(OH)_2$ and $Al(OH)_3$ including, where relevant, amphoteric behaviour in reactions with acids and bases (sodium hydroxide only)
- ☐☐☐ describe, explain, and write equations for, the reactions of the chlorides NaCl, $MgCl_2$, $AlCl_3$, $SiCl_4$, $PCl_5$ with water including the likely pHs of the solutions obtained
- ☐☐☐ explain the variations and trends in 9.2.2, 9.2.3, 9.2.4 and 9.2.5 in terms of bonding and electronegativity
- ☐☐☐ suggest the types of chemical bonding present in the chlorides and oxides from observations of their chemical and physical properties

### 9.3 Chemical periodicity of other elements 其他元素的化学周期性

- ☐☐☐ predict the characteristic properties of an element in a given group by using knowledge of **chemical periodicity**
- ☐☐☐ deduce the nature, possible position in the Periodic Table and identity of unknown elements from given information about physical and chemical properties

## 10. Group 2 第 2 族

### 10.1 Similarities and trends in the properties of the Group 2 metals, magnesium to barium, and their compounds 第 2 族金属（镁到钡）及其化合物性质的相似性与变化趋势

- ☐☐☐ describe, and write equations for, the reactions of the elements with oxygen, water and dilute hydrochloric and sulfuric acids
- ☐☐☐ describe, and write equations for, the reactions of the oxides, hydroxides and carbonates with water and dilute hydrochloric and sulfuric acids
- ☐☐☐ describe, and write equations for, the **thermal decomposition** of the nitrates and carbonates, to include the trend in **thermal stabilities**
- ☐☐☐ describe, and make predictions from, the trends in physical and chemical properties of the elements involved in the reactions in 10.1.1 and the compounds involved in 10.1.2, 10.1.3 and 10.1.5
- ☐☐☐ state the variation in the **solubilities** of the hydroxides and sulfates

## 11. Group 17 第 17 族

### 11.1 Physical properties of the Group 17 elements 第 17 族元素的物理性质

- ☐☐☐ describe the colours and the trend in **volatility** of chlorine, bromine and iodine
- ☐☐☐ describe and explain the trend in the **bond strength** of the halogen molecules
- ☐☐☐ interpret the volatility of the elements in terms of instantaneous dipole–induced dipole forces

### 11.2 The chemical properties of the halogen elements and the hydrogen halides 卤素与卤化氢的化学性质

- ☐☐☐ describe the relative reactivity of the elements as **oxidising agents**
- ☐☐☐ describe the reactions of the elements with hydrogen and explain their relative reactivity in these reactions
- ☐☐☐ describe the relative **thermal stabilities** of the **hydrogen halides** and explain these in terms of bond strengths

### 11.3 Some reactions of the halide ions 卤离子的一些反应

- ☐☐☐ describe the relative reactivity of halide ions as **reducing agents**
- ☐☐☐ describe and explain the reactions of halide ions with: (a) aqueous silver ions followed by aqueous ammonia (the formation and formula of the $[Ag(NH_3)_2]^+$ complex is not required) (b) concentrated sulfuric acid, to include balanced chemical equations

### 11.4 The reactions of chlorine 氯的反应

- ☐☐☐ describe and interpret, in terms of changes in oxidation number, the reaction of chlorine with cold and with hot aqueous sodium hydroxide and recognise these as **disproportionation reactions**
- ☐☐☐ explain, including by use of an equation, the use of chlorine in **water purification** to include the production of the active species HOCl and $ClO^-$ which kill bacteria

## 12. Nitrogen and sulfur 氮与硫

### 12.1 Nitrogen and sulfur 氮与硫

- ☐☐☐ explain the lack of reactivity of nitrogen, with reference to **triple bond** strength and lack of polarity
- ☐☐☐ describe and explain: (a) the **basicity** of ammonia, using the **Brønsted–Lowry theory** (b) the structure of the ammonium ion and its formation by an acid–base reaction (c) the displacement of ammonia from ammonium salts by an acid–base reaction
- ☐☐☐ state and explain the natural and man-made occurrences of oxides of nitrogen and their catalytic removal from the exhaust gases of internal combustion engines
- ☐☐☐ understand that atmospheric oxides of nitrogen (NO and $NO_2$) can react with unburned hydrocarbons to form **peroxyacetyl nitrate**, PAN, which is a component of **photochemical smog**
- ☐☐☐ describe the role of NO and $NO_2$ in the formation of **acid rain** both directly and in their catalytic role in the oxidation of atmospheric sulfur dioxide

# 13. An introduction to AS Level organic chemistry AS Level 有机化学导论

### 13.1 Formulas, functional groups and the naming of organic compounds 有机化合物的化学式、官能团与命名

- ☐☐☐ define the term **hydrocarbon** as a compound made up of C and H atoms only
- ☐☐☐ understand that **alkanes** are simple hydrocarbons with no **functional group**
- ☐☐☐ understand that the compounds in the table on pages 29 and 30 contain a functional group which dictates their physical and chemical properties
- ☐☐☐ interpret and use the general, structural, displayed and skeletal formulas of the classes of compound stated in the table on pages 29 and 30
- ☐☐☐ understand and use **systematic nomenclature** of simple aliphatic organic molecules with functional groups detailed in the table on pages 29 and 30, up to six carbon atoms (six plus six for esters, straight chains only for esters and nitriles)
- ☐☐☐ deduce the molecular and/or empirical formula of a compound, given its structural, displayed or skeletal formula

### 13.2 Characteristic organic reactions 有机特征反应

- ☐☐☐ interpret and use the following terminology associated with types of organic compounds and reactions: (a) **homologous series** (b) **saturated and unsaturated** (c) **homolytic and heterolytic fission** (d) free radical, initiation, propagation, termination (e) **nucleophile**, **electrophile**, nucleophilic, electrophilic (f) **addition**, **substitution**, **elimination**, **hydrolysis**, **condensation** (g) oxidation and reduction (in equations for organic redox reactions, the symbol [O] can be used to represent one atom of oxygen from an oxidising agent and the symbol [H] to represent one atom of hydrogen from a reducing agent)
- ☐☐☐ understand and use the following terminology associated with types of organic mechanisms: (a) **free-radical substitution** (b) **electrophilic addition** (c) **nucleophilic substitution** (d) **nucleophilic addition** (in organic reaction mechanisms, the use of curly arrows to represent movement of electron pairs is expected; the arrow should begin at a bond or a lone pair of electrons)

### 13.3 Shapes of organic molecules; $\sigma$ and $\pi$ bonds 有机分子的形状；$\sigma$ 键与 $\pi$ 键

- ☐☐☐ describe organic molecules as either **straight-chained**, **branched** or **cyclic**
- ☐☐☐ describe and explain the shape of, and bond angles in, molecules containing sp, $sp^2$ and $sp^3$ hybridised atoms
- ☐☐☐ describe the arrangement of $\sigma$ and $\pi$ bonds in molecules containing sp, $sp^2$ and $sp^3$ hybridised atoms
- ☐☐☐ understand and use the term **planar** when describing the arrangement of atoms in organic molecules, for example ethene

### 13.4 Isomerism: structural isomerism and stereoisomerism 同分异构：结构异构与立体异构

- ☐☐☐ describe **structural isomerism** and its division into **chain**, **positional** and **functional group isomerism**
- ☐☐☐ describe **stereoisomerism** and its division into **geometrical (cis/trans)** and **optical isomerism** (use of E/Z nomenclature is acceptable but is not required)
- ☐☐☐ describe geometrical (cis/trans) isomerism in alkenes, and explain its origin in terms of restricted rotation due to the presence of $\pi$ bonds
- ☐☐☐ explain what is meant by a **chiral centre** and that such a centre gives rise to two optical isomers (**enantiomers**) (Candidates should appreciate that compounds can contain more than one chiral centre, but knowledge of meso compounds, or nomenclature such as diastereoisomers is not

required.)

- ☐☐☐ identify chiral centres and geometrical (cis/trans) isomerism in a molecule of given structural formula including cyclic compounds
- ☐☐☐ deduce the possible isomers for an organic molecule of known molecular formula

## 14. Hydrocarbons 烃

### 14.1 Alkanes 烷烃

- ☐☐☐ recall the reactions (reagents and conditions) by which alkanes can be produced: (a) addition of hydrogen to an alkene in a hydrogenation reaction, $H_2(g)$ and Pt/Ni catalyst and heat (b) cracking of a longer chain alkane, heat with $Al_2O_3$
- ☐☐☐ describe: (a) the complete and incomplete combustion of alkanes (b) the free-radical substitution of alkanes by $Cl_2$ or $Br_2$ in the presence of ultraviolet light, as exemplified by the reactions of ethane
- ☐☐☐ describe the mechanism of **free-radical substitution** with reference to the **initiation**, **propagation** and **termination** steps
- ☐☐☐ suggest how cracking can be used to obtain more useful alkanes and alkenes of lower $M_r$ from heavier crude oil fractions
- ☐☐☐ understand the general unreactivity of alkanes, including towards polar reagents in terms of the strength of the C–H bonds and their relative lack of polarity
- ☐☐☐ recognise the environmental consequences of **carbon monoxide**, oxides of nitrogen and unburnt hydrocarbons arising from the combustion of alkanes in the internal combustion engine and of their catalytic removal

### 14.2 Alkenes 烯烃

- ☐☐☐ recall the reactions (including reagents and conditions) by which alkenes can be produced: (a) elimination of HX from a halogenoalkane by ethanolic NaOH and heat (b) dehydration of an alcohol, by using a heated catalyst (e.g. $Al_2O_3$) or a concentrated acid (e.g. concentrated $H_2SO_4$) (c) cracking of a longer chain alkane
- ☐☐☐ describe the following reactions of alkenes: (a) the electrophilic addition of (i) hydrogen in a hydrogenation reaction, $H_2(g)$ and Pt/Ni catalyst and heat (ii) steam, $H_2O(g)$ and $H_3PO_4$ catalyst (iii) a hydrogen halide, HX(g), at room temperature (iv) a halogen, $X_2$ (b) the oxidation by cold dilute acidified $KMnO_4$ to form the diol (c) the oxidation by hot concentrated acidified $KMnO_4$ leading to the rupture of the carbon–carbon double bond and the identities of the subsequent products to determine the position of alkene linkages in larger molecules (d) addition polymerisation exemplified by the reactions of ethene and propene
- ☐☐☐ describe the use of aqueous bromine to show the presence of a C=C bond
- ☐☐☐ describe the mechanism of **electrophilic addition** in alkenes, using bromine/ethene and hydrogen bromide/propene as examples
- ☐☐☐ describe and explain the inductive effects of alkyl groups on the stability of **primary**, **secondary** and **tertiary cations** formed during electrophilic addition (this should be used to explain **Markovnikov addition**)

## 15. Halogen compounds 卤素化合物

### 15.1 Halogenoalkanes 卤代烷

- ☐☐☐ recall the reactions (reagents and conditions) by which halogenoalkanes can be produced: (a) the free-radical substitution of alkanes by $Cl_2$ or $Br_2$ in the presence of ultraviolet light, as exemplified by the reactions of ethane (b) electrophilic addition of an alkene with a halogen, $X_2$, or hydrogen halide, HX(g), at room temperature (c) substitution of an alcohol, e.g. by reaction

with HX(g); or with KCl and concentrated $H_2SO_4$ or concentrated $H_3PO_4$; or with $PCl_3$ and heat; or with $PCl_5$; or with $SOCl_2$

- ☐☐☐ classify halogenoalkanes into **primary**, **secondary** and **tertiary**
- ☐☐☐ describe the following **nucleophilic substitution** reactions: (a) the reaction with NaOH(aq) and heat to produce an alcohol (b) the reaction with KCN in ethanol and heat to produce a nitrile (c) the reaction with $NH_3$ in ethanol heated under pressure to produce an amine (d) the reaction with aqueous silver nitrate in ethanol as a method of identifying the halogen present as exemplified by bromoethane
- ☐☐☐ describe the **elimination reaction** with NaOH in ethanol and heat to produce an alkene as exemplified by bromoethane
- ☐☐☐ describe the $S_N1$ and $S_N2$ mechanisms of nucleophilic substitution in halogenoalkanes including the inductive effects of alkyl groups
- ☐☐☐ recall that primary halogenoalkanes tend to react via the $S_N2$ mechanism; tertiary halogenoalkanes via the $S_N1$ mechanism; and secondary halogenoalkanes by a mixture of the two, depending on structure
- ☐☐☐ describe and explain the different reactivities of halogenoalkanes (with particular reference to the relative strengths of the C–X bonds as exemplified by the reactions of halogenoalkanes with aqueous silver nitrates)

## 16. Hydroxy compounds 羟基化合物

### 16.1 Alcohols 醇

- ☐☐☐ recall the reactions (reagents and conditions) by which alcohols can be produced: (a) electrophilic addition of steam to an alkene, $H_2O(g)$ and $H_3PO_4$ catalyst (b) reaction of alkenes with cold dilute acidified potassium manganate(VII) to form a diol (c) substitution of a halogenoalkane using NaOH(aq) and heat (d) reduction of an aldehyde or ketone using $NaBH_4$ or $LiAlH_4$ (e) reduction of a carboxylic acid using $LiAlH_4$ (f) hydrolysis of an ester using dilute acid or dilute alkali and heat
- ☐☐☐ describe: (a) the reaction with oxygen (combustion) (b) substitution to form halogenoalkanes, e.g. by reaction with HX(g); or with KCl and concentrated $H_2SO_4$ or concentrated $H_3PO_4$; or with $PCl_3$ and heat; or with $PCl_5$; or with $SOCl_2$ (c) the reaction with Na(s) (d) oxidation with acidified $K_2Cr_2O_7$ or acidified $KMnO_4$ to: (i) carbonyl compounds by distillation (ii) carboxylic acids by refluxing (primary alcohols give aldehydes which can be further oxidised to carboxylic acids, secondary alcohols give ketones, tertiary alcohols cannot be oxidised) (e) dehydration to an alkene, by using a heated catalyst, e.g. $Al_2O_3$ or a concentrated acid (f) formation of esters by reaction with carboxylic acids and concentrated $H_2SO_4$ as catalyst as exemplified by ethanol
- ☐☐☐ (a) classify alcohols as **primary**, **secondary** and **tertiary alcohols**, to include examples with more than one alcohol group (b) state characteristic distinguishing reactions, e.g. mild oxidation with acidified $K_2Cr_2O_7$, colour change from orange to green
- ☐☐☐ deduce the presence of a $CH_3CH(OH)-$ group in an alcohol, $CH_3CH(OH)-R$, from its reaction with alkaline $I_2(aq)$ to form a yellow precipitate of tri-iodomethane and an ion, $RCO_2^-$
- ☐☐☐ explain the **acidity** of alcohols compared with water

## 17. Carbonyl compounds 羰基化合物

### 17.1 Aldehydes and ketones 醛与酮

- ☐☐☐ recall the reactions (reagents and conditions) by which aldehydes and ketones can be produced: (a) the oxidation of primary alcohols using acidified $K_2Cr_2O_7$ or acidified $KMnO_4$ and distillation to produce aldehydes (b) the oxidation of secondary alcohols using acidified $K_2Cr_2O_7$ or acidified $KMnO_4$ and distillation to produce ketones
- ☐☐☐ describe: (a) the reduction of aldehydes and ketones using $NaBH_4$ or $LiAlH_4$ to produce alcohols

(b) the reaction of aldehydes and ketones with HCN, KCN as catalyst, and heat to produce hydroxynitriles as exemplified by ethanal and propanone

- ☐☐☐ describe the mechanism of the **nucleophilic addition** reactions of hydrogen cyanide with aldehydes and ketones in 17.1.2(b)
- ☐☐☐ describe the use of **2,4-dinitrophenylhydrazine (2,4-DNPH reagent)** to detect the presence of carbonyl compounds
- ☐☐☐ deduce the nature (aldehyde or ketone) of an unknown carbonyl compound from the results of simple tests (Fehling's and Tollens' reagents; ease of oxidation)
- ☐☐☐ deduce the presence of a $CH_3CO-$ group in an aldehyde or ketone, $CH_3CO-R$, from its reaction with alkaline $I_2$(aq) to form a yellow precipitate of tri-iodomethane and an ion, $RCO_2^-$

## 18. Carboxylic acids and derivatives 羧酸及其衍生物

### 18.1 Carboxylic acids 羧酸

- ☐☐☐ recall the reactions by which carboxylic acids can be produced: (a) oxidation of primary alcohols and aldehydes with acidified $K_2Cr_2O_7$ or acidified $KMnO_4$ and refluxing (b) hydrolysis of nitriles with dilute acid or dilute alkali followed by acidification (c) hydrolysis of esters with dilute acid or dilute alkali and heat followed by acidification
- ☐☐☐ describe: (a) the **redox reaction** with reactive metals to produce a salt and $H_2$(g) (b) the **neutralisation reaction** with alkalis to produce a salt and $H_2O$(l) (c) the acid–base reaction with carbonates to produce a salt and $H_2O$(l) and $CO_2$(g) (d) **esterification** with alcohols with concentrated $H_2SO_4$ as catalyst (e) reduction by $LiAlH_4$ to form a primary alcohol

### 18.2 Esters 酯

- ☐☐☐ recall the reaction (reagents and conditions) by which esters can be produced: (a) the **condensation reaction** between an alcohol and a carboxylic acid with concentrated $H_2SO_4$ as catalyst
- ☐☐☐ describe the **hydrolysis** of esters by dilute acid and by dilute alkali and heat

## 19. Nitrogen compounds 含氮化合物

### 19.1 Primary amines 伯胺

- ☐☐☐ recall the reactions by which **amines** can be produced: (a) reaction of a halogenoalkane with $NH_3$ in ethanol heated under pressure Classification of amines will not be tested at AS Level.

### 19.2 Nitriles and hydroxynitriles 腈与羟基腈

- ☐☐☐ recall the reactions by which **nitriles** can be produced: (a) reaction of a halogenoalkane with KCN in ethanol and heat
- ☐☐☐ recall the reactions by which **hydroxynitriles** can be produced: (a) the reaction of aldehydes and ketones with HCN, KCN as catalyst, and heat
- ☐☐☐ describe the **hydrolysis** of nitriles with dilute acid or dilute alkali followed by acidification to produce a **carboxylic acid**

## 20. Polymerisation 聚合

### 20.1 Addition polymerisation 加成聚合

- ☐☐☐ describe **addition polymerisation** as exemplified by poly(ethene) and poly(chloroethene), PVC
- ☐☐☐ deduce the **repeat unit** of an addition polymer obtained from a given **monomer**

☐☐☐ identify the monomer(s) present in a given section of an addition polymer molecule

☐☐☐ recognise the difficulty of the disposal of poly(alkene)s, i.e. **non-biodegradability** and harmful combustion products

## 21. Organic synthesis 有机合成

### 21.1 Organic synthesis 有机合成

☐☐☐ for an organic molecule containing several **functional groups**: (a) identify organic functional groups using the reactions in the syllabus (b) predict properties and reactions

☐☐☐ devise **multi-step synthetic routes** for preparing organic molecules using the reactions in the syllabus

☐☐☐ analyse a given synthetic route in terms of type of reaction and reagents used for each step of it, and possible by-products

## 22. Analytical techniques 分析技术

### 22.1 Infrared spectroscopy 红外光谱

☐☐☐ analyse an **infrared spectrum** of a simple molecule to identify **functional groups** (see the Data section for the functional groups required)

### 22.2 Mass spectrometry 质谱

☐☐☐ analyse mass spectra in terms of $m/e$ values and **isotopic abundances** (knowledge of the working of the mass spectrometer is not required)

☐☐☐ calculate the **relative atomic mass** of an element given the relative abundances of its isotopes, or its mass spectrum

☐☐☐ deduce the molecular mass of an organic molecule from the **molecular ion peak** in a mass spectrum

☐☐☐ suggest the identity of molecules formed by simple fragmentation in a given mass spectrum

☐☐☐ deduce the number of carbon atoms, $n$, in a compound using the $[M+1]^+$ peak and the formula $n = \frac{100\times\text{abundance of } [M+1]^+ \text{ ion}}{1.1\times\text{abundance of } M^+ \text{ ion}}$

☐☐☐ deduce the presence of bromine and chlorine atoms in a compound using the $[M+2]^+$ peak

## 23. Chemical energetics 化学能量学

### 23.1 Lattice energy and Born-Haber cycles 晶格能与玻恩 – 哈伯循环

☐☐☐ define and use the terms: (a) **enthalpy change of atomisation**, $\Delta H_{\text{at}}$ (b) **lattice energy**, $\Delta H_{\text{latt}}$ (the change from gas phase ions to solid lattice)

☐☐☐ (a) define and use the term **first electron affinity**, EA (b) explain the factors affecting the electron affinities of elements (c) describe and explain the trends in the electron affinities of the Group 16 and Group 17 elements

☐☐☐ construct and use **Born–Haber cycles** for ionic solids (limited to +1 and +2 cations, –1 and –2 anions)

☐☐☐ carry out calculations involving Born–Haber cycles

☐☐☐ explain, in qualitative terms, the effect of ionic charge and of ionic radius on the numerical magnitude of a lattice energy

### 23.2 Enthalpies of solution and hydration 溶解焓与水合焓

- ☐☐☐ define and use the term enthalpy change with reference to **hydration**, $\Delta H_{\text{hyd}}$, and **solution**, $\Delta H_{\text{sol}}$
- ☐☐☐ construct and use an energy cycle involving **enthalpy change of solution**, **lattice energy** and **enthalpy change of hydration**
- ☐☐☐ carry out calculations involving the energy cycles in 23.2.2
- ☐☐☐ explain, in qualitative terms, the effect of ionic charge and of ionic radius on the numerical magnitude of an enthalpy change of hydration

### 23.3 Entropy change, ΔS 熵变 ΔS

- ☐☐☐ define the term **entropy**, $S$, as the number of possible arrangements of the particles and their energy in a given system
- ☐☐☐ predict and explain the sign of the entropy changes that occur: (a) during a change in state, e.g. melting, boiling and dissolving (and their reverse) (b) during a temperature change (c) during a reaction in which there is a change in the number of gaseous molecules
- ☐☐☐ calculate the entropy change for a reaction, $\Delta S$, given the standard entropies, $S^{\ominus}$, of the reactants and products, $\Delta S^{\ominus} = \Sigma S^{\ominus}(\text{products}) - \Sigma S^{\ominus}(\text{reactants})$ (use of $\Delta S^{\ominus} = \Delta S^{\ominus}_{\text{surr}} + \Delta S^{\ominus}_{\text{sys}}$ is not required)

### 23.4 Gibbs free energy change, ΔG 吉布斯自由能变 ΔG

- ☐☐☐ state and use the **Gibbs equation** $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$
- ☐☐☐ perform calculations using the equation $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$
- ☐☐☐ state whether a reaction or process will be **feasible** by using the sign of $\Delta G$
- ☐☐☐ predict the effect of temperature change on the feasibility of a reaction, given standard enthalpy and entropy changes

## 24. Electrochemistry 电化学

### 24.1 Electrolysis 电解

- ☐☐☐ predict the identities of substances liberated during **electrolysis** from the state of **electrolyte** (molten or aqueous), position in the redox series (electrode potential) and concentration
- ☐☐☐ state and apply the relationship $F = Le$ between the **Faraday constant**, $F$, the **Avogadro constant**, $L$, and the charge on the electron, $e$
- ☐☐☐ calculate: (a) the quantity of charge passed during electrolysis, using $Q = It$ (b) the mass and/or volume of substance liberated during electrolysis
- ☐☐☐ describe the determination of a value of the Avogadro constant by an electrolytic method

### 24.2 Standard electrode potentials E⊖, standard cell potentials E⊖cell and the Nernst equation 标准电极电势 E⊖、标准电池电动势 E⊖cell 与能斯特方程

- ☐☐☐ define the terms: (a) **standard electrode (reduction) potential** (b) **standard cell potential**
- ☐☐☐ describe the **standard hydrogen electrode**
- ☐☐☐ describe methods used to measure the standard electrode potentials of: (a) metals or non-metals in contact with their ions in aqueous solution (b) ions of the same element in different oxidation states
- ☐☐☐ calculate a standard cell potential by combining two standard electrode potentials
- ☐☐☐ use standard cell potentials to: (a) deduce the polarity of each electrode and hence explain/deduce the direction of electron flow in the external circuit of a simple cell (b) predict the feasibility of a reaction

☐☐☐ deduce from $E^{\ominus}$ values the relative reactivity of elements, compounds and ions as oxidising agents or as reducing agents

☐☐☐ construct redox equations using the relevant half-equations

☐☐☐ predict qualitatively how the value of an electrode potential, $E$, varies with the concentrations of the aqueous ions

☐☐☐ use the **Nernst equation**, e.g. $E = E^{\ominus} + (0.059/z) \log \frac{[\text{oxidised species}]}{[\text{reduced species}]}$, to predict quantitatively how the value of an electrode potential varies with the concentrations of the aqueous ions; examples include $Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$, $Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$

☐☐☐ understand and use the equation $\Delta G^{\ominus} = -nE^{\ominus}_{\text{cell}}F$

## 25. Equilibria 平衡

### 25.1 Acids and bases 酸与碱

☐☐☐ understand and use the terms **conjugate acid** and **conjugate base**

☐☐☐ define conjugate acid–base pairs, identifying such pairs in reactions

☐☐☐ define mathematically the terms pH, $K_a$, p$K_a$ and $K_w$ and use them in calculations ($K_b$ and the equation $K_w = K_a \times K_b$ will not be tested)

☐☐☐ calculate $[H^+(aq)]$ and pH values for: (a) strong acids (b) strong alkalis (c) weak acids

☐☐☐ (a) define a **buffer solution** (b) explain how a buffer solution can be made (c) explain how buffer solutions control pH; use chemical equations in these explanations (d) describe and explain the uses of buffer solutions, including the role of $HCO_3^-$ in controlling pH in blood

☐☐☐ calculate the pH of buffer solutions, given appropriate data

☐☐☐ understand and use the term **solubility product**, $K_{\text{sp}}$

☐☐☐ write an expression for $K_{\text{sp}}$

☐☐☐ calculate $K_{\text{sp}}$ from concentrations and vice versa

☐☐☐ (a) understand and use the **common ion effect** to explain the different solubility of a compound in a solution containing a common ion (b) perform calculations using $K_{\text{sp}}$ values and concentration of a common ion

### 25.2 Partition coefficients 分配系数

☐☐☐ state what is meant by the term **partition coefficient**, $K_{\text{pc}}$

☐☐☐ calculate and use a partition coefficient for a system in which the solute is in the same physical state in the two solvents

☐☐☐ understand the factors affecting the numerical value of a partition coefficient in terms of the polarities of the solute and the solvents used

## 26. Reaction kinetics 反应动力学

### 26.1 Simple rate equations, orders of reaction and rate constants 简单速率方程、反应级数与速率常数

☐☐☐ explain and use the terms **rate equation**, **order of reaction**, overall order of reaction, **rate constant**, **half-life**, **rate-determining step** and **intermediate**

☐☐☐ (a) understand and use rate equations of the form rate $= k[A]^m[B]^n$ (for which $m$ and $n$ are 0, 1 or 2) (b) deduce the order of a reaction from concentration–time graphs or from experimental data relating to the initial rates method and half-life method (c) interpret experimental data in graphical form, including concentration–time and rate–concentration graphs (d) calculate an initial rate using concentration data (e) construct a rate equation

☐☐☐ (a) show understanding that the half-life of a first-order reaction is independent of concentration

(b) use the half-life of a first-order reaction in calculations

☐☐☐ calculate the numerical value of a rate constant, for example by: (a) using the initial rates and the rate equation (b) using the half-life, $t_{\frac{1}{2}}$, and the equation $k = 0.693/t_{\frac{1}{2}}$

☐☐☐ for a multi-step reaction: (a) suggest a reaction mechanism that is consistent with the rate equation and the equation for the overall reaction (b) predict the order that would result from a given reaction mechanism and rate-determining step (c) deduce a rate equation using a given reaction mechanism and rate-determining step for a given reaction (d) identify an intermediate or catalyst from a given reaction mechanism (e) identify the rate determining step from a rate equation and a given reaction mechanism

☐☐☐ describe qualitatively the effect of temperature change on the rate constant and hence the rate of a reaction

### 26.2 Homogeneous and heterogeneous catalysts 均相与多相催化剂

☐☐☐ explain that catalysts can be **homogeneous** or **heterogeneous**

☐☐☐ describe the mode of action of a **heterogeneous catalyst** to include **adsorption** of reactants, bond weakening and **desorption** of products, for example: (a) iron in the Haber process (b) palladium, platinum and rhodium in the catalytic removal of oxides of nitrogen from the exhaust gases of car engines

☐☐☐ describe the mode of action of a homogeneous catalyst by being used in one step and reformed in a later step, for example: (a) atmospheric oxides of nitrogen in the oxidation of atmospheric sulfur dioxide (b) $Fe^{2+}$ or $Fe^{3+}$ in the $I^-/S_2O_8^{2-}$ reaction

## 27. Group 2 第 2 族

### 27.1 Similarities and trends in the properties of the Group 2 metals, magnesium to barium, and their compounds 第 2 族金属（镁到钡）及其化合物性质的相似性与变化趋势

☐☐☐ describe and explain qualitatively the trend in the **thermal stability** of the nitrates and carbonates including the effect of ionic radius on the polarisation of the large anion

☐☐☐ describe and explain qualitatively the variation in solubility and of enthalpy change of solution, $\Delta H_{\text{sol}}^{\ominus}$, of the hydroxides and sulfates in terms of relative magnitudes of the **enthalpy change of hydration** and the **lattice energy**

## 28. Chemistry of transition elements 过渡元素化学

### 28.1 General physical and chemical properties of the first row of transition elements, titanium to copper 第一行过渡元素（钛到铜）的一般物理与化学性质

☐☐☐ define a **transition element** as a **d-block** element which forms one or more stable ions with incomplete d orbitals

☐☐☐ sketch the shape of a $3d_{xy}$ orbital and $3d_{z^2}$ orbital

☐☐☐ understand that transition elements have the following properties: (a) they have **variable oxidation states** (b) they behave as **catalysts** (c) they form **complex ions** (d) they form **coloured compounds**

☐☐☐ explain why transition elements have variable oxidation states in terms of the similarity in energy of the 3d and the 4s sub-shells

☐☐☐ explain why transition elements behave as catalysts in terms of having more than one stable oxidation state, and vacant d orbitals that are energetically accessible and can form dative bonds with **ligands**

☐☐☐ explain why transition elements form complex ions in terms of vacant d orbitals that are energetically accessible

### 28.2 General characteristic chemical properties of the first set of transition elements, titanium to copper 第一行过渡元素（钛到铜）的一般特征化学性质

- ☐☐☐ describe and explain the reactions of transition elements with **ligands** to form **complexes**, including the complexes of copper(II) and cobalt(II) ions with water and ammonia molecules and hydroxide and chloride ions
- ☐☐☐ define the term **ligand** as a species that contains a lone pair of electrons that forms a dative covalent bond to a central metal atom/ion
- ☐☐☐ understand and use the terms: (a) **monodentate ligand** including as examples $H_2O$, $NH_3$, $Cl^-$ and $CN^-$ (b) **bidentate ligand** including as examples 1,2-diaminoethane, en, $H_2NCH_2CH_2NH_2$ and the ethanedioate ion, $C_2O_4^{2-}$ (c) **polydentate ligand** including as an example $EDTA^{4-}$
- ☐☐☐ define the term **complex** as a molecule or ion formed by a central metal atom/ion surrounded by one or more ligands
- ☐☐☐ describe the geometry (shape and bond angles) of transition element complexes which are **linear**, **square planar**, **tetrahedral** or **octahedral**
- ☐☐☐ (a) state what is meant by **coordination number** (b) predict the formula and charge of a complex ion, given the metal ion, its charge or oxidation state, the ligand and its coordination number or geometry
- ☐☐☐ explain qualitatively that **ligand exchange** can occur, including the complexes of copper(II) ions and cobalt(II) ions with water and ammonia molecules and hydroxide and chloride ions
- ☐☐☐ predict, using $E^{\ominus}$ values, the feasibility of redox reactions involving transition elements and their ions
- ☐☐☐ describe the reactions of, and perform calculations involving: (a) $MnO_4^-/C_2O_4^{2-}$ in acid solution given suitable data (b) $MnO_4^-/Fe^{2+}$ in acid solution given suitable data (c) $Cu^{2+}/I^-$ given suitable data
- ☐☐☐ perform calculations involving other redox systems given suitable data

### 28.3 Colour of complexes 配合物的颜色

- ☐☐☐ define and use the terms **degenerate** and **non-degenerate** d orbitals
- ☐☐☐ describe the splitting of degenerate d orbitals into two non-degenerate sets of d orbitals of higher energy, and use of $\Delta E$ in: (a) octahedral complexes, two higher and three lower d orbitals (b) tetrahedral complexes, three higher and two lower d orbitals
- ☐☐☐ explain why transition elements form **coloured compounds** in terms of the frequency of light absorbed as an electron is promoted between two non-degenerate d orbitals
- ☐☐☐ describe, in qualitative terms, the effects of different ligands on $\Delta E$, frequency of light absorbed, and hence the **complementary colour** that is observed
- ☐☐☐ use the complexes of copper(II) ions and cobalt(II) ions with water and ammonia molecules and hydroxide and chloride ions as examples of ligand exchange affecting the colour observed

### 28.4 Stereoisomerism in transition element complexes 过渡元素配合物中的立体异构

- ☐☐☐ describe the types of **stereoisomerism** shown by complexes, including those associated with bidentate ligands: (a) geometrical (cis/trans) isomerism, e.g. square planar such as $[Pt(NH_3)_2Cl_2]$ and octahedral such as $[Co(NH_3)_4(H_2O)_2]^{2+}$ and $[Ni(H_2NCH_2CH_2NH_2)_2(H_2O)_2]^{2+}$ (b) optical isomerism, e.g. $[Ni(H_2NCH_2CH_2NH_2)_3]^{2+}$ and $[Ni(H_2NCH_2CH_2NH_2)_2(H_2O)_2]^{2+}$
- ☐☐☐ deduce the overall polarity of complexes such as those described in 28.4.1(a) and 28.4.1(b)

### 28.5 Stability constants, Kstab 稳定常数 Kstab

- ☐☐☐ define the **stability constant**, $K_{stab}$, of a complex as the equilibrium constant for the formation of the complex ion in a solvent (from its constituent ions or molecules)

☐☐☐ write an expression for a $K_{stab}$ of a complex ([$H_2O$] should not be included)

☐☐☐ use $K_{stab}$ expressions to perform calculations

☐☐☐ describe and explain ligand exchanges in terms of $K_{stab}$ values and understand that a large $K_{stab}$ is due to the formation of a stable complex ion

## 29. An introduction to A Level organic chemistry A Level 有机化学导论

### 29.1 Formulas, functional groups and the naming of organic compounds 有机化合物的化学式、官能团与命名

☐☐☐ understand that the compounds in the table on page 47 contain a **functional group** which dictates their physical and chemical properties

☐☐☐ interpret and use the general, structural, displayed and skeletal formulas of the classes of compound stated in the table on page 47

☐☐☐ understand and use **systematic nomenclature** of simple aliphatic organic molecules (including cyclic compounds containing a single ring of up to six carbon atoms) with functional groups detailed in the table on page 47, up to six carbon atoms (six plus six for esters and amides, straight chains only for esters and nitriles)

☐☐☐ understand and use systematic nomenclature of simple **aromatic** molecules with one **benzene ring** and one or more simple substituents, for example 3-nitrobenzoic acid or 2,4,6-tribromophenol

### 29.2 Characteristic organic reactions 有机特征反应

☐☐☐ understand and use the following terminology associated with types of organic mechanisms: (a) **electrophilic substitution** (b) **addition–elimination**

### 29.3 Shapes of aromatic organic molecules; $\sigma$ and $\pi$ bonds 芳香有机分子的形状；$\sigma$ 键与 $\pi$ 键

☐☐☐ describe and explain the shape of **benzene** and other aromatic molecules, including $sp^2$ hybridisation, in terms of $\sigma$ bonds and a **delocalised** $\pi$ system

### 29.4 Isomerism: optical 同分异构：旋光异构

☐☐☐ understand that **enantiomers** have identical physical and chemical properties apart from their ability to rotate **plane polarised light** and their potential biological activity

☐☐☐ understand and use the terms **optically active** and **racemic mixture**

☐☐☐ describe the effect on plane polarised light of the two optical isomers of a single substance

☐☐☐ explain the relevance of **chirality** to the synthetic preparation of drug molecules including: (a) the potential different biological activity of the two enantiomers (b) the need to separate a racemic mixture into two pure enantiomers (c) the use of chiral catalysts to produce a single pure optical isomer (Candidates should appreciate that compounds can contain more than one chiral centre, but knowledge of meso compounds and nomenclature such as diastereoisomers is not required.)

## 30. Hydrocarbons 烃

### 30.1 Arenes 芳烃

☐☐☐ describe the chemistry of **arenes** as exemplified by the following reactions of benzene and methylbenzene: (a) substitution reactions with $Cl_2$ and with $Br_2$ in the presence of a catalyst, $AlCl_3$ or $AlBr_3$, to form halogenoarenes (aryl halides) (b) **nitration** with a mixture of concentrated $HNO_3$ and concentrated $H_2SO_4$ at a temperature between 25 °C and 60 °C (c) **Friedel–Crafts alkylation** by $CH_3Cl$ and $AlCl_3$ and heat (d) **Friedel–Crafts acylation** by

$CH_3COCl$ and $AlCl_3$ and heat (e) complete oxidation of the side-chain using hot alkaline $KMnO_4$ and then dilute acid to give a benzoic acid (f) hydrogenation of the benzene ring using $H_2$ and Pt/Ni catalyst and heat to form a cyclohexane ring

- ☐☐☐ describe the mechanism of **electrophilic substitution** in arenes: (a) as exemplified by the formation of nitrobenzene and bromobenzene (b) with regards to the effect of delocalisation (aromatic stabilisation) of electrons in arenes to explain the predomination of substitution over addition
- ☐☐☐ predict whether halogenation will occur in the side-chain or in the aromatic ring in arenes depending on reaction conditions
- ☐☐☐ describe that in the electrophilic substitution of arenes, different substituents direct to different ring positions (limited to the directing effects of $-NH_2$, $-OH$, $-R$, $-NO_2$, $-COOH$ and $-COR$)

## 31. Halogen compounds 卤素化合物

### 31.1 Halogen compounds 卤素化合物

- ☐☐☐ recall the reactions by which **halogenoarenes** can be produced: substitution of an arene with $Cl_2$ or $Br_2$ in the presence of a catalyst, $AlCl_3$ or $AlBr_3$ to form a halogenoarene, exemplified by benzene to form chlorobenzene and methylbenzene to form 2-chloromethylbenzene and 4-chloromethylbenzene
- ☐☐☐ explain the difference in reactivity between a **halogenoalkane** and a **halogenoarene** as exemplified by chloroethane and chlorobenzene

## 32. Hydroxy compounds 羟基化合物

### 32.1 Alcohols 醇

- ☐☐☐ describe the reaction with **acyl chlorides** to form **esters** using ethyl ethanoate

### 32.2 Phenol 苯酚

- ☐☐☐ recall the reactions (reagents and conditions) by which phenol can be produced: (a) reaction of phenylamine with $HNO_2$ or $NaNO_2$ and dilute acid below 10 °C to produce the **diazonium salt**; further warming of the diazonium salt with $H_2O$ to give phenol
- ☐☐☐ recall the chemistry of phenol, as exemplified by the following reactions: (a) with bases, for example NaOH(aq) to produce sodium phenoxide (b) with Na(s) to produce sodium phenoxide and $H_2$(g) (c) in NaOH(aq) with diazonium salts, to give **azo compounds** (d) nitration of the aromatic ring with dilute $HNO_3$(aq) at room temperature to give a mixture of 2-nitrophenol and 4-nitrophenol (e) bromination of the aromatic ring with $Br_2$(aq) to form 2,4,6-tribromophenol
- ☐☐☐ explain the **acidity** of phenol
- ☐☐☐ describe and explain the relative acidities of water, phenol and ethanol
- ☐☐☐ explain why the reagents and conditions for the nitration and bromination of phenol are different from those for benzene
- ☐☐☐ recall that the hydroxyl group of a phenol directs to the 2-, 4- and 6-positions
- ☐☐☐ apply knowledge of the reactions of phenol to those of other phenolic compounds, e.g. naphthol

## 33. Carboxylic acids and derivatives 羧酸及其衍生物

### 33.1 Carboxylic acids 羧酸

- ☐☐☐ recall the reaction by which benzoic acid can be produced: (a) reaction of an alkylbenzene with hot alkaline $KMnO_4$ and then dilute acid, exemplified by methylbenzene
- ☐☐☐ describe the reaction of carboxylic acids with $PCl_3$ and heat, $PCl_5$ or $SOCl_2$ to form **acyl chlorides**
- ☐☐☐ recognise that some carboxylic acids can be further oxidised: (a) the oxidation of methanoic acid, HCOOH, with Fehling's reagent or Tollens' reagent or acidified $KMnO_4$ or acidified $K_2Cr_2O_7$ to carbon dioxide and water (b) the oxidation of ethanedioic acid, HOOCCOOH, with warm acidified $KMnO_4$ to carbon dioxide
- ☐☐☐ describe and explain the **relative acidities** of carboxylic acids, phenols and alcohols
- ☐☐☐ describe and explain the relative acidities of chlorine-substituted carboxylic acids

### 33.2 Esters 酯

- ☐☐☐ recall the reaction by which esters can be produced: (a) reaction of alcohols with **acyl chlorides** using the formation of ethyl ethanoate and phenyl benzoate as examples

### 33.3 Acyl chlorides 酰氯

- ☐☐☐ recall the reactions (reagents and conditions) by which **acyl chlorides** can be produced: (a) reaction of carboxylic acids with $PCl_3$ and heat, $PCl_5$ or $SOCl_2$
- ☐☐☐ describe the following reactions of acyl chlorides: (a) hydrolysis on addition of water at room temperature to give the carboxylic acid and HCl (b) reaction with an alcohol at room temperature to produce an ester and HCl (c) reaction with phenol at room temperature to produce an ester and HCl (d) reaction with ammonia at room temperature to produce an amide and HCl (e) reaction with a primary or secondary amine at room temperature to produce an amide and HCl
- ☐☐☐ describe the **addition–elimination mechanism** of acyl chlorides in reactions in 33.3.2(a)–(e)
- ☐☐☐ explain the relative ease of hydrolysis of acyl chlorides, alkyl chlorides and halogenoarenes (aryl chlorides)

## 34. Nitrogen compounds 含氮化合物

### 34.1 Primary and secondary amines 伯胺与仲胺

- ☐☐☐ recall the reactions (reagents and conditions) by which **primary and secondary amines** are produced: (a) reaction of halogenoalkanes with $NH_3$ in ethanol heated under pressure (b) reaction of halogenoalkanes with primary amines in ethanol, heated in a sealed tube/under pressure (c) the reduction of amides with $LiAlH_4$ (d) the reduction of nitriles with $LiAlH_4$ or $H_2$/Ni
- ☐☐☐ describe the **condensation reaction** of ammonia or an amine with an acyl chloride at room temperature to give an **amide**
- ☐☐☐ describe and explain the **basicity** of aqueous solutions of amines

### 34.2 Phenylamine and azo compounds 苯胺与偶氮化合物

- ☐☐☐ describe the preparation of **phenylamine** via the nitration of benzene to form nitrobenzene followed by reduction with hot Sn/concentrated HCl followed by NaOH(aq)
- ☐☐☐ describe: (a) the reaction of phenylamine with $Br_2$(aq) at room temperature (b) the reaction of phenylamine with $HNO_2$ or $NaNO_2$ and dilute acid below 10 °C to produce the diazonium salt; further warming of the diazonium salt with $H_2O$ to give phenol
- ☐☐☐ describe and explain the **relative basicities** of aqueous ammonia, ethylamine and phenylamine

☐☐☐ recall the following about **azo compounds**: (a) describe the coupling of benzenediazonium chloride with phenol in NaOH(aq) to form an azo compound (b) identify the azo group (c) state that azo compounds are often used as dyes (d) that other azo dyes can be formed via a similar route

### 34.3 Amides 酰胺

☐☐☐ recall the reactions (reagents and conditions) by which **amides** are produced: (a) the reaction between ammonia and an acyl chloride at room temperature (b) the reaction between a primary amine and an acyl chloride at room temperature

☐☐☐ describe the reactions of amides: (a) hydrolysis with aqueous alkali or aqueous acid (b) the reduction of the CO group in amides with $LiAlH_4$ to form an amine

☐☐☐ state and explain why amides are much **weaker bases** than amines

### 34.4 Amino acids 氨基酸

☐☐☐ describe the acid/base properties of **amino acids** and the formation of **zwitterions**, to include the **isoelectric point**

☐☐☐ describe the formation of **amide (peptide) bonds** between amino acids to give di- and tripeptides

☐☐☐ interpret and predict the results of **electrophoresis** on mixtures of amino acids and dipeptides at varying pHs (the assembling of the apparatus will not be tested)

## 35. Polymerisation 聚合

### 35.1 Condensation polymerisation 缩合聚合

☐☐☐ describe the formation of **polyesters**: (a) the reaction between a diol and a dicarboxylic acid or dioyl chloride (b) the reaction of a hydroxycarboxylic acid

☐☐☐ describe the formation of **polyamides**: (a) the reaction between a diamine and a dicarboxylic acid or dioyl chloride (b) the reaction of an aminocarboxylic acid (c) the reaction between amino acids

☐☐☐ deduce the **repeat unit** of a **condensation polymer** obtained from a given **monomer** or pair of monomers

☐☐☐ identify the monomer(s) present in a given section of a condensation polymer molecule

### 35.2 Predicting the type of polymerisation 预测聚合类型

☐☐☐ predict the type of **polymerisation** reaction for a given monomer or pair of monomers

☐☐☐ deduce the type of polymerisation reaction which produces a given section of a polymer molecule

### 35.3 Degradable polymers 可降解聚合物

☐☐☐ recognise that poly(alkenes) are chemically inert and can therefore be difficult to **biodegrade**

☐☐☐ recognise that some polymers can be degraded by the action of light

☐☐☐ recognise that polyesters and polyamides are **biodegradable** by acidic and alkaline **hydrolysis**

## 36. Organic synthesis 有机合成

### 36.1 Organic synthesis 有机合成

☐☐☐ for an organic molecule containing several **functional groups**: (a) identify organic functional groups using the reactions in the syllabus (b) predict properties and reactions

☐☐☐ devise **multi-step synthetic routes** for preparing organic molecules using the reactions in the syllabus

☐☐☐ analyse a given synthetic route in terms of type of reaction and reagents used for each step of it, and possible by-products

## 37. Analytical techniques 分析技术

### 37.1 Thin-layer chromatography 薄层色谱

☐☐☐ describe and understand the terms (a) **stationary phase**, for example aluminium oxide (on a solid support) (b) **mobile phase**; a polar or non-polar solvent (c) $R_f$ value (d) solvent front and baseline

☐☐☐ interpret $R_f$ values

☐☐☐ explain the differences in $R_f$ values in terms of interaction with the stationary phase and of relative solubility in the mobile phase

### 37.2 Gas/liquid chromatography 气相/液相色谱

☐☐☐ describe and understand the terms (a) **stationary phase**; a high boiling point non-polar liquid (on a solid support) (b) mobile phase; an unreactive gas (c) **retention time**

☐☐☐ interpret gas/liquid chromatograms in terms of the percentage composition of a mixture

☐☐☐ explain retention times in terms of interaction with the stationary phase

### 37.3 Carbon-13 NMR spectroscopy 碳-13 核磁共振谱

☐☐☐ analyse and interpret a **carbon-13 NMR** spectrum of a simple molecule to deduce: (a) the different environments of the carbon atoms present (b) the possible structures for the molecule

☐☐☐ predict or explain the number of peaks in a carbon-13 NMR spectrum for a given molecule

### 37.4 Proton (1H) NMR spectroscopy 质子（$^1$H）核磁共振谱

☐☐☐ analyse and interpret a proton ($^1$H) NMR spectrum of a simple molecule to deduce: (a) the different environments of proton present using **chemical shift** values (b) the relative numbers of each type of proton present from relative peak areas (c) the number of equivalent protons on the carbon atom adjacent to the one to which the given proton is attached from the **splitting pattern**, using the $n + 1$ rule (limited to singlet, doublet, triplet, quartet and multiplet) (d) the possible structures for the molecule

☐☐☐ predict the chemical shifts and splitting patterns of the protons in a given molecule

☐☐☐ describe the use of **tetramethylsilane**, TMS, as the standard for chemical shift measurements

☐☐☐ state the need for deuterated solvents, e.g. $CDCl_3$, when obtaining a proton NMR spectrum

☐☐☐ describe the identification of O–H and N–H protons by proton exchange using $D_2O$