Singapore Examinations and Assessment Board

CAMBRIDGE
International Education

Singapore–Cambridge General Certificate of Education Advanced Level Higher 2 (2026)

Chemistry (Syllabus 9476)

(First year of examination in 2026)

CONTENTS

INTRODUCTION

Candidates will be assumed to have knowledge and understanding of Chemistry at O-Level, as a single subject or as part of a balanced science course.

This syllabus is designed to place less emphasis on factual material and greater emphasis on the understanding and application of scientific concepts and principles. This approach has been adopted in recognition of the need for students to develop skills that will be of long term value in an increasingly technological world rather than focusing on large quantities of factual material which may have only short term relevance.

Experimental work is an important component and should underpin the teaching and learning of Chemistry.

AIMS

The *Aims* of a course based on this syllabus should be to:

1 provide students with an experience that develops interest in Chemistry and builds the knowledge, skills and attitudes necessary for further studies in related fields

2 enable students to become scientifically literate citizens who are well-prepared for the challenges of the 21st century

3 develop in students the understanding, skills, ethics and attitudes relevant to the *Practices of Science*, including the following:

    3.1 demonstrating the ways of thinking and doing in science
    3.2 understanding the nature of scientific knowledge
    3.3 relating science, technology, society and environment

4 develop the way of thinking to explain phenomena, approach and solve problems in chemical systems which involves students in:

    4.1 understanding the structure, properties and transformation of matter at the atomic/molecular level and how they are related to each other
    4.2 connecting between the submicroscopic, macroscopic and symbolic levels of representations in explaining and making predictions about chemical systems, structures and properties.

PRACTICES OF SCIENCE

Science as a discipline is more than the acquisition of a body of knowledge (e.g. scientific facts, concepts, laws, and theories); it is a way of knowing and doing. It includes an understanding of the nature of scientific knowledge and how this knowledge is generated, established and communicated. Scientists rely on a set of established procedures and practices associated with scientific inquiry to gather evidence and test their ideas on how the natural world works. However, there is no single method and the real process of science is often complex and iterative, following many different paths. While science is powerful, generating knowledge that forms the basis for many technological feats and innovations, it has limitations.

The *Practices of Science* are explicitly articulated in this syllabus to allow teachers to embed them as learning objectives in their lessons. Students' understanding of the nature and limitations of science and scientific inquiry are developed effectively when the practices are taught in the context of relevant science content. Attitudes relevant to science such as inquisitiveness, concern for accuracy and precision, objectivity, integrity and perseverance should be emphasised in the teaching of these practices where appropriate. For example, students learning science should be introduced to the use of technology as an aid in practical work or as a tool for the interpretation of experimental and theoretical results.

The *Practices of Science* comprise three components:

1 Demonstrating Ways of Thinking and Doing in Science (WOTD)

The Ways of Thinking and Doing in Science illustrate a set of established procedures and practices associated with scientific inquiry to gather evidence and test ideas on how the natural world works. There are three broad, iterative domains of scientific activity: investigating, evaluating and reasoning, and developing explanations and solutions.

Investigating

1.1 Posing questions and defining problems

1.2 Designing investigations

1.3 Conducting experiments and testing solutions

1.4 Analysing and interpreting data

Evaluating and Reasoning

1.5 Communicating, evaluating and defending ideas with evidence

1.6 Making informed decisions and taking responsible actions

Developing explanations and solutions

1.7 Using and developing models[1]

1.8 Constructing explanations and designing solutions

2 Understanding the Nature of Scientific Knowledge (NOS)

Science is an epistemic endeavour to build a better understanding of reality.

2.1 Science is an evidence-based, model-building enterprise to understand the real world.

2.2 Science assumes natural causes, order and consistency in natural systems.

2.3 Scientific knowledge is generated through established procedures and critical debate.

2.4 Scientific knowledge is reliable, durable, open to change in light of new evidence.

3 Relating Science-Technology-Society-Environment (STSE)

Science is not done completely independently of the other spheres of human activity. The relationships and connections to these areas are important as students learn science in context.

3.1 There are risks and benefits associated with the applications of science in society.

3.2 Applications of science often have ethical, social, economic, and environmental implications.

3.3 Applications of new scientific discoveries often drive technological advancements while advances in technology enable scientists to make new or deeper inquiry.

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[1] *A model is a representation of an idea, an object, a process or a system that is used to describe and explain phenomena that cannot be experienced directly. Models exist in different forms ranging from the concrete, such as physical, scale models to abstract representations, such as diagrams or mathematical expressions. The use of models involves the understanding that all models contain approximations and assumptions limiting their validity and predictive power.*

CURRICULUM FRAMEWORK

The A-Level Chemistry curriculum framework (see **Figure 1**) encapsulates the disciplinary ideas that are enduring and central in Chemistry and includes the *Practices of Science* (POS) as well as Values, Ethics and Attitudes[2] that are brought to life through Learning Experiences[3] (LEs).

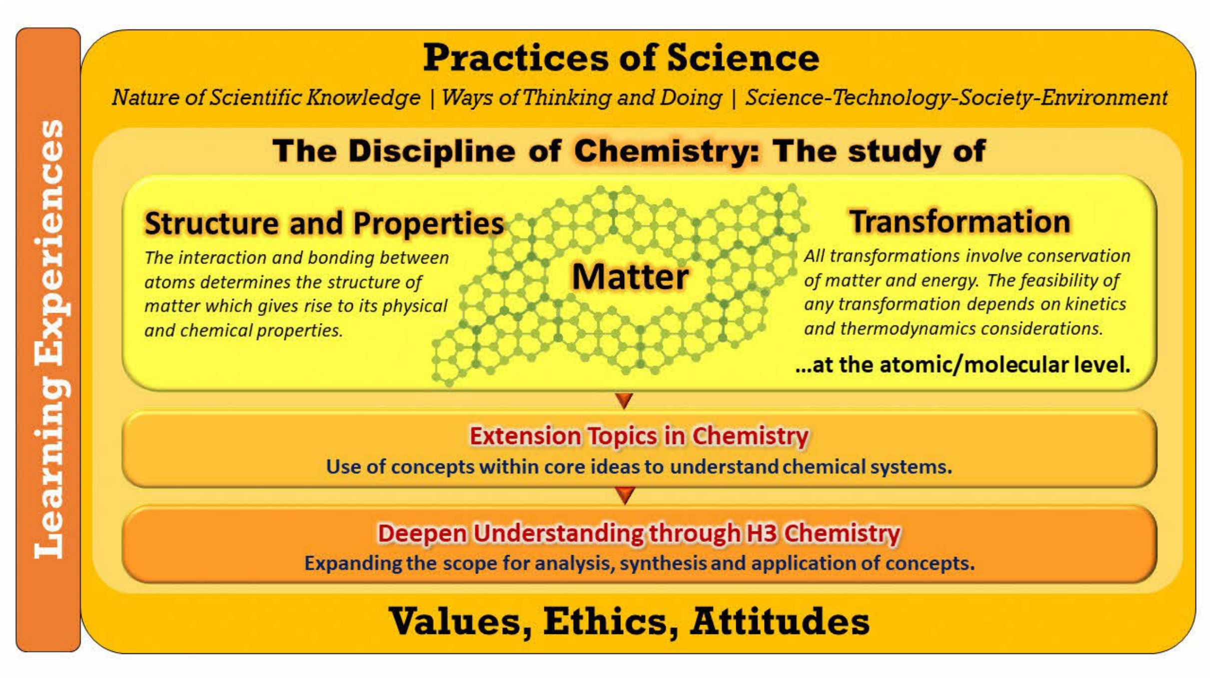

Figure 1: A-Level Chemistry Curriculum Framework

The Values, Ethics, Attitudes undergird the study of science and the use of related knowledge and skills to make a positive contribution to humanity.

The *Practices of Science* highlight the ways of thinking and doing that are inherent in the scientific approach, with the aim of equipping students with the understanding, skills, and attitudes shared by the scientific disciplines, including an appropriate approach to ethical issues.

The content in the H2 Chemistry syllabus is organised into two levels:

- *Core Ideas.*
  There are three core ideas, namely Matter, Structure and Properties, and Transformation, which are fundamental in the study of Chemistry. Concepts in these core ideas are inter-related and form the basis for which further learning and understanding of chemical phenomena and reactions is built upon.

- *Extension Topics.*
  Concepts in the core ideas extend into the learning of different chemical systems such as the chemistry of organic compounds, including polymers, the chemistry of aqueous solutions, electrochemistry, and the chemistry of transition elements. As an example, an understanding of concepts of Chemical Bonding and The Periodic Table is extended to the study of the Chemistry of Transition Elements where students learn to appreciate the similarity and differences when comparing with main group metals.

Organising the content through the two levels highlights the importance of conceptual understanding in core ideas and how they extend to different chemical systems.

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[2] Details on Values, Ethics and Attitudes can be found in the Teaching and Learning Guide.

[3] The Learning Experiences can be found in the Teaching and Learning Guide.

Teachers are encouraged to weave in real-world contexts into LEs for the different topics to draw connections between concepts and everyday life, develop scientific literacy and enable learners to see the impact of chemistry on our society and environment. Two interwoven themes are emphasised in the syllabus, they are **Environmental Sustainability** and **Materials**. With these themes in the syllabus, students have opportunities to relate what they learnt to global issues such as impact of climate change and appreciate the push for scientific innovation to address global needs and environmental challenges.

LEs would include instructional activities that deepen conceptual understanding and embed the *Practices of Science*, experimental (practical work) activities and ICT tools that can be used to build students' understanding.

ASSESSMENT OBJECTIVES

The *Assessment Objectives* listed below reflect those parts of the *Aims* and *Practices of Science* that will be assessed.

A Knowledge with understanding

Candidates should be able to demonstrate knowledge and understanding in relation to:

1 scientific phenomena, facts, laws, definitions, concepts and theories

2 scientific vocabulary, terminology and conventions (including symbols, quantities and units)

3 scientific instruments and apparatus, including techniques of operation and aspects of safety

4 scientific quantities and their determination

5 scientific and technological applications with their social, economic and environmental implications.

The syllabus content defines the factual knowledge that candidates may be required to recall and explain. Questions testing these objectives will often begin with one of the following words: *define, state, describe, explain or outline* (see the *Glossary of Terms*).

B Handling, applying and evaluating information

Candidates should be able (in words or by using symbolic, graphical and numerical forms of presentation) to:

1 locate, select, organise and present information from a variety of sources

2 handle information, distinguishing the relevant from the extraneous

3 manipulate numerical and other data and translate information from one form to another

4 analyse and evaluate information so as to identify patterns, report trends and conclusions, and draw inferences

5 present reasoned explanations for phenomena, patterns and relationships

6 apply knowledge, including principles, to novel situations

7 bring together knowledge, principles, concepts and skills from different areas of chemistry, and apply them in a particular context

8 evaluate information and hypotheses

9 construct arguments to support hypotheses or to justify a course of action

10 demonstrate an awareness of the limitations of Chemistry theories and models.

These *Assessment Objectives* cannot be precisely specified in the syllabus content because questions testing such skills may be based on information which is unfamiliar to the candidate. In answering such questions, candidates are required to use principles and concepts that are within the syllabus and apply them in a logical, reasoned or deductive manner to a novel situation. Questions testing these objectives will often begin with one of the following words: *predict, suggest, construct, calculate* or *determine* (see the *Glossary of Terms*).

C Experimental skills and investigations

Candidates should be able to:

1 follow a detailed set or sequence of instructions and use techniques, apparatus and materials safely and effectively

2 make, record and present observations and measurements with due regard for precision and accuracy

3 interpret and evaluate observations and experimental data

4 identify a problem, devise and plan investigations, select techniques, apparatus and materials

5 evaluate methods and techniques and suggest possible improvements.

SCHEME OF ASSESSMENT

All candidates are required to enter for Papers 1, 2, 3 and 4

Paper	Type of Paper	Duration	Weighting (%)	Marks
1	**Multiple Choice**	1 hour	15	30
2	**Structured Questions**	2 hours	30	75
3	**Structured Questions**	2 hours	35	75
4	**Practical**	2 hours 30 minutes	20	50

Paper 1 (1 hour, 30 marks)

This paper consists of 30 compulsory multiple choice questions. Five to eight items will be of the multiple completion type.

All questions will include 4 options.

Paper 2 (2 hours, 75 marks)

This paper consists of a variable number of structured questions including data-based questions. All questions are compulsory and answered on the question paper. The data-based question(s) constitute(s) 20–25 marks for this paper.

The data-based question(s) provide(s) good opportunity to test higher order thinking skills such as handling, applying, and evaluating information. Some questions will also require candidates to integrate knowledge and understanding from different areas and topics of the chemistry syllabus.

Paper 3 (2 hours, 75 marks)

This paper consists of two sections:

- Section A is worth 55 marks consisting of 3–4 structured questions, all compulsory. Each question constitutes 15–25 marks.

- Section B is worth 20 marks consisting of *two* questions, each of 20 marks. Candidates are to answer any *one* question.

These questions will require candidates to integrate knowledge and understanding from different areas and topics of the chemistry syllabus.

Paper 4 (2 hours 30 min, 50 marks)

This paper will assess appropriate aspects of objectives C1 to C5 in the following skill areas:

- Planning (P)
- Manipulation, measurement and observation (MMO)
- Presentation of data and observations (PDO)
- Analysis, conclusions and evaluation (ACE)

The assessment of Planning (P) will have a weighting of 4%. The assessment of skill areas MMO, PDO and ACE will have a weighting of 16%.

The scope of the practical paper is indicated in the Practical Assessment section. The assessment of PDO and ACE may also include questions on data-analysis which do not require practical equipment and apparatus.

Candidates will **not** be permitted to refer to books and laboratory notebooks during the assessment.

Weighting of Assessment Objectives

Assessment Objectives		Weighting (%)	Assessment Components
A	**Knowledge with understanding**	36	Papers 1, 2, 3
B	**Handling, applying and evaluating information**	44	Papers 1, 2, 3
C	**Experimental skills and investigations**	20	Paper 4

ADDITIONAL INFORMATION

Data Booklet

Candidates will be provided with a *Data Booklet*, including the Periodic Table, for use in the theory papers. The Qualitative Analysis Notes on pages 38 to 40 will be made available for use in the practical assessment.

Nomenclature

Candidates will be expected to be familiar with the nomenclature used in the syllabus. The proposals in '*Signs, Symbols and Systematics*' (The Association for Science Education Companion to 16–19 Science, 2000) will generally be adopted although the traditional names sulfate, sulfite, nitrate, nitrite, sulfurous and nitrous acids will be used in question papers. Sulfur (and all compounds of sulfur) will be spelt with f (not with ph) in question papers, however candidates can use either spelling in their answers.

Units and significant figures

Candidates should be aware that misuse of units and/or significant figures, i.e. failure to quote units where necessary, the inclusion of units in quantities defined as ratios or quoting answers to an inappropriate number of significant figures, is liable to be penalised.

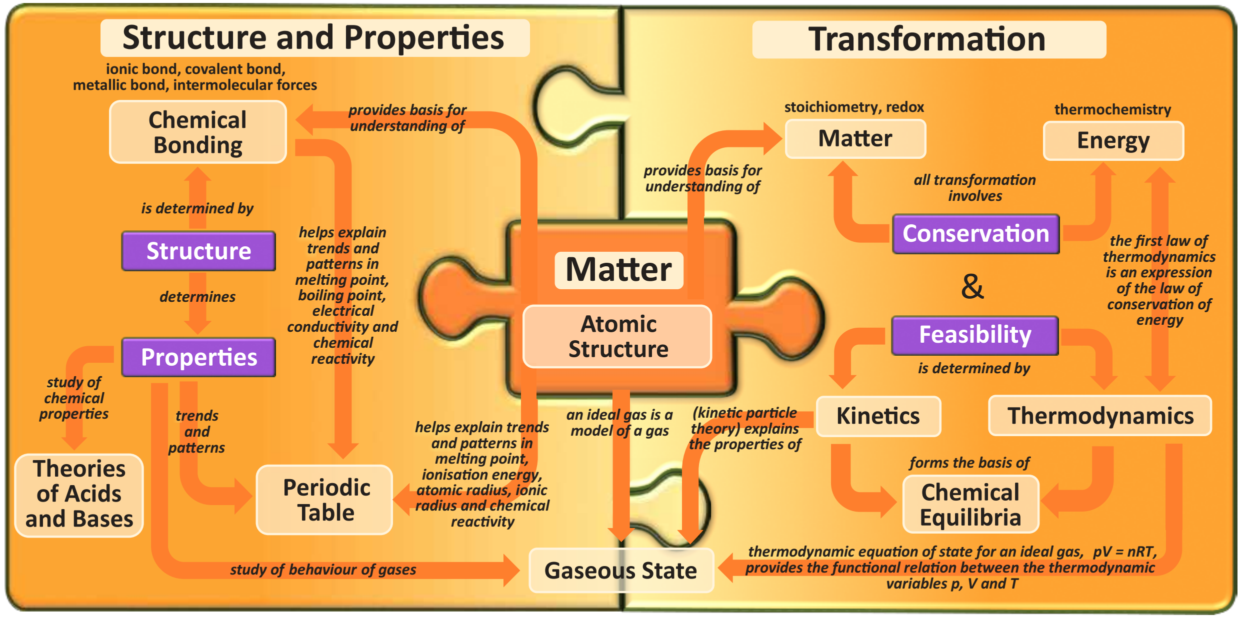
Disallowed Subject Combinations

Candidates may not simultaneously offer Chemistry at H1 and H2 levels.

CONTENT OVERVIEW

CORE IDEAS

Chemistry is the study of the structure, properties and transformation of matter at the atomic/ molecular level



EXTENSION TOPICS

Chemistry of Aqueous Solutions

- acid and base dissociation constant
- ionic product of water
- pH
- buffer solutions
- solubility product
- common ion effect

Organic Chemistry

- introduction (nomenclature, shapes, functional groups)
- isomerism (constitutional and stereoisomerism)
- organic reaction mechanisms (free-radical substitution, electrophilic addition, electrophilic substitution, nucleophilic addition, nucleophilic substitution), terminologies associated with organic reactivities
- functional group reactions (alkanes, alkenes, arenes, halogenoalkanes, halogenoarenes, alcohols, phenols, aldehydes, ketones, carboxylic acids, acyl chlorides, esters, amines, amides, amino acids, nitriles)

Electrochemistry

- standard electrode (redox) potentials
- standard cell potentials and their interpretation
- batteries and fuel cells
- factors affecting electrolysis
- the Faraday constant
- industrial applications of electrolysis

Chemistry of the Transition Elements

- general physical and characteristic chemical properties of the first row transition elements from Sc to Cu
- colour of complexes

The H2 Chemistry curriculum provides students with the opportunity to appreciate the connections between the concepts in the Core Ideas of **Matter**, **Structures and Properties**, and **Transformation**, and to apply these to the study of different chemical systems in the Extension Topics. This is illustrated in the H2 Chemistry *Content Map*.

Chemistry is about the study of matter, its interactions and transformations. At a macroscopic level, we observe matter and its interactions everywhere in our daily life. The submicroscopic level looks at the structure of matter that gives rise to these interactions. At O-Level, students have been introduced to the fundamental idea that matter is made up of particles and the simple atomic model (electrons in discrete shells around a positively charged nucleus). This allows students to apply the key ideas of conservation of matter and energy in the quantitative treatment of reactions such as stoichiometry and thermochemistry.

In H2 Chemistry, an in-depth study of the electronic structure of atoms provides the basis for the study of chemical bonding. The Valence Shell Electron Pair Repulsion (VSEPR) model is used to rationalise the three-dimensional structure of molecules, which determines the type of interactions possible and also helps to explain the physical and chemical properties. Knowledge of structure and bonding is also important to study and predict trends in properties of matter and its reactions. Modern organic chemistry is based on the concept that the four valence bonds of a carbon atom are oriented in a tetrahedral configuration, which led to the development of the stereochemical concept. This has important applications, particularly in the pharmaceutical industry as many drugs are active only in one particular enantiomeric form.

Transformation of matter involves the study of the feasibility and the extent of chemical reactions. Considerations of thermodynamics and kinetics account for the feasibility while an understanding in equilibrium explains the extent of chemical reactions. The chemical thermodynamics dimension builds upon prior knowledge of thermochemistry, mainly enthalpy changes (ΔH). Together with entropy changes (ΔS), a mathematical relationship is established which gives the true measure of the thermodynamics feasibility of a reaction – the Gibbs free energy (ΔG). For aqueous redox reactions, the more convenient notion of electrode potential (E) is used, and the resultant cell potential (E_{cell}) gives a measure of thermodynamics feasibility instead. The chemical kinetics facet of a reaction can be understood quantitatively by relating the rate of reaction to the concentration of reactants. The qualitative aspect which deals with the factors affecting rate of reactions will be covered based on the collision theory.

The concepts in chemical thermodynamics and kinetics will form the basis for the study of Chemical Equilibrium. Theoretically all reactions are reversible, and the notion of dynamic equilibrium will be introduced. The concept of equilibrium constant (K) gives a measure of the extent of a reversible reaction. Factors which determine the position of equilibrium will also be examined. Chemical equilibria involving aqueous acids and bases will be dealt with in greater depth, in view of the relevance and prevalence of these concepts which cuts across chemical systems.

Finally, the concepts of structure and bonding, thermodynamics and kinetics are combined and applied in the topics of Organic Chemistry and the Chemistry of Transition Elements. Apart from being major sub-disciplines in Chemistry in their own right, the latter topics contextualise the theoretical principles by providing a wealth of concrete examples of chemical transformations.

SUBJECT CONTENT

CORE IDEA 1 – MATTER

1 ATOMIC STRUCTURE

Content

- The nucleus of the atom: neutrons and protons, isotopes, proton and nucleon numbers
- Electrons: electronic energy levels, ionisation energies, atomic orbitals, extranuclear structure

Learning Outcomes

Candidates should be able to:

(a) identify and describe protons, neutrons and electrons in terms of their relative charges and relative masses

(b) deduce the behaviour of beams of protons, neutrons and electrons in an electric field

(c) describe the distribution of mass and charges within an atom

(d) deduce the numbers of protons, neutrons and electrons present in both atoms and ions given proton and nucleon numbers (and charge)

(e) (i) describe the contribution of protons and neutrons to atomic nuclei in terms of proton number and nucleon number

(ii) distinguish between isotopes on the basis of different numbers of neutrons present

(f) describe the number and relative energies of the s, p and d orbitals for the principal quantum numbers 1, 2 and 3 and also the 4s and 4p orbitals

(g) describe the shapes of s, p and d orbitals (see also Section 13)
[knowledge of wave functions is **not** required]

(h) state the electronic configuration of atoms and ions given the proton number (and charge)

(i) explain the factors influencing the ionisation energies of elements (see the *Data Booklet)* (see also Section 5)

(j) deduce the electronic configurations of elements from successive ionisation energy data

(k) interpret successive ionisation energy data of an element in terms of the position of that element within the Periodic Table

CORE IDEA 2 – STRUCTURE AND PROPERTIES

2 CHEMICAL BONDING

Content

- Ionic bonding, metallic bonding, covalent bonding and co-ordinate (dative covalent) bonding
- Shapes of simple molecules and bond angles
- Bond polarities and polarity of molecules
- Intermolecular forces, including hydrogen bonding
- Bond energies and bond lengths
- Lattice structure of solids
- Bonding and physical properties

Learning Outcomes

Candidates should be able to:

(a) show understanding that all chemical bonds are electrostatic in nature and describe:

  (i) ionic bond as the electrostatic attraction between oppositely charged ions

  (ii) covalent bond as the electrostatic attraction between a shared pair of electrons and positively charged nuclei

  (iii) metallic bond as the electrostatic attraction between a lattice of positive ions and delocalised electrons

(b) describe, including the use of 'dot-and-cross' diagrams,

  (i) ionic bonding as in sodium chloride and magnesium oxide

  (ii) covalent bonding as in hydrogen; oxygen; nitrogen; chlorine; hydrogen chloride; carbon dioxide; methane; ethene

  (iii) co-ordinate (dative covalent) bonding, as in formation of the ammonium ion and in the Al_2Cl_6 molecule

(c) describe covalent bonding in terms of orbital overlap (limited to s and p orbitals only), giving σ and π bonds (see also Section 11.1)

(d) explain the shapes of, and bond angles in, molecules such as BF_3 (trigonal planar); CO_2 (linear); CH_4 (tetrahedral); NH_3 (trigonal pyramidal); H_2O (bent); SF_6 (octahedral) by using the Valence Shell Electron Pair Repulsion theory

(e) predict the shapes of, and bond angles in, molecules analogous to those specified in (d)

(f) explain and deduce bond polarity using the concept of electronegativity
[quantitative treatment of electronegativity is **not** required]

(g) deduce the polarity of a molecule using bond polarity and its molecular shape (analogous to those specified in (d))

(h) describe the following forces of attraction (electrostatic in nature):

  (i) intermolecular forces, based on permanent and induced dipoles, as in $CHCl_3(l)$; $Br_2(l)$ and the liquid noble gases

  (ii) hydrogen bonding, using ammonia and water as examples of molecules containing –NH and –OH groups

(i) outline the importance of hydrogen bonding to the physical properties of substances, including ice and water

(j) explain the terms *bond energy* and *bond length* for covalent bonds

(k) compare the reactivities of covalent bonds in terms of bond energy, bond length and bond polarity

(l) describe, in simple terms, the lattice structure of a crystalline solid which is:

  (i) ionic, as in sodium chloride and magnesium oxide

  (ii) simple molecular, as in iodine

  (iii) giant molecular, as in graphite and diamond

  (iv) hydrogen-bonded, as in ice

  (v) metallic, as in copper

  [the concept of the ‘unit cell’ is **not** required]

(m) describe, interpret and/or predict the effect of different types of structure and bonding on the physical properties of substances

(n) suggest the type of structure and bonding present in a substance from given information

3 THE GASEOUS STATE

Content

- Ideal gas behaviour and deviations from it
- $pV = nRT$ and its use in determining a value for M_r
- Dalton’s Law and its use in determining the partial pressures of gases in a mixture

Learning Outcomes

Candidates should be able to:

(a) state the basic assumptions of the kinetic theory as applied to an ideal gas

(b) explain qualitatively in terms of intermolecular forces and molecular size:

  (i) the conditions necessary for a gas to approach ideal behaviour

  (ii) the limitations of ideality at very high pressures and very low temperatures

(c) state and use the general gas equation $pV = nRT$ in calculations, including the determination of M_r

(d) use Dalton’s Law to determine the partial pressures of gases in a mixture (see also Section 9)

4 THEORIES OF ACIDS AND BASES

Content

- Arrhenius, Brønsted-Lowry and Lewis theories of acids and bases

Learning Outcomes

Candidates should be able to:

(a) show understanding of, and apply the Arrhenius theory of acids and bases

(b) show understanding of, and apply the Brønsted-Lowry theory of acids and bases, including the concept of conjugate acids and conjugate bases

(c) show understanding of, and apply the Lewis theory of acids and bases (including non-aqueous system e.g. reaction between BF_3 and NH_3)

5 THE PERIODIC TABLE

Content

- Periodicity of atomic and physical properties of the elements: variation with proton number across the third period (sodium to chlorine) and down the group (Group 2 and Group 17) of:
  - (i) electronic configuration
  - (ii) atomic radius and ionic radius
  - (iii) ionisation energy
  - (iv) electronegativity
  - (v) melting point
  - (vi) electrical conductivity

- Periodicity of chemical properties of the elements in the third period:
  - (i) variation in oxidation number and bonding of the oxides (sodium to sulfur only) and of the chlorides (sodium to phosphorus only)
  - (ii) reactions of these oxides and chlorides with water
  - (iii) acid/base behaviour of these oxides and the corresponding hydroxides

- Periodicity of chemical properties of the elements down the group (Group 2 and Group 17):
  - (i) as reducing agents (Group 2) and oxidising agents (Group 17)
  - (ii) thermal stability of Group 2 carbonates and Group 17 hydrides

Learning Outcomes

Trends and variations in atomic and physical properties

For elements in the third period (sodium to chlorine), and in Group 2 (magnesium to barium) and Group 17 (chlorine to iodine), candidates should be able to:

(a) recognise variation in the electronic configurations across a Period and down a Group

(b) describe and explain qualitatively the general trends and variations in atomic radius, ionic radius, first ionisation energy and electronegativity:

(i) across a Period in terms of shielding and nuclear charge

(ii) down a Group in terms of increasing number of electron shells, shielding and nuclear charge

(c) interpret the variation in melting point and in electrical conductivity across a Period in terms of structure and bonding in the elements (metallic, giant molecular, or simple molecular)

(d) describe and explain the trend in volatility of the Group 17 elements in terms of instantaneous dipole-induced dipole attraction

Trends and variations in chemical properties

For elements across the third period (sodium to chlorine) candidates should be able to:

(e) (i) state and explain the variation in the highest oxidation number of the elements in oxides (for Na_2O; MgO; Al_2O_3; SiO_2; P_4O_{10}; SO_3) and chlorides (for $NaCl$; $MgCl_2$; $AlCl_3$; $SiCl_4$; PCl_5)

(ii) state and explain the variation in bonding in oxides and chlorides in terms of electronegativity (with the exception of $AlCl_3$)

(iii) describe the reactions of the oxides with water (for Na_2O; MgO; Al_2O_3; SiO_2; P_4O_{10}; SO_3)

(iv) describe and explain the acid/base behaviour of oxides (for Na_2O; MgO; Al_2O_3; SiO_2; P_4O_{10}; SO_3) and hydroxides (for $NaOH$; $Mg(OH)_2$; $Al(OH)_3$), including, where relevant, amphoteric behaviour in reaction with sodium hydroxide (only) and acids

(v) describe and explain the reactions of the chlorides with water (for $NaCl$; $MgCl_2$; $AlCl_3$; $SiCl_4$; PCl_5)

(vi) suggest the types of structure and bonding present in the oxides and chlorides from observations of their chemical and physical properties

For elements in Group 2 (magnesium to barium) and Group 17 (chlorine to iodine) candidates should be able to:

(f) describe and deduce from $E^\ominus$ values the relative reactivity of elements of:

(i) Group 2 as reducing agents

(ii) Group 17 as oxidising agents

(g) describe and explain the trend in thermal stability of:

(i) Group 2 carbonates in terms of the charge density of the cation and the polarisability of the large anion

(ii) Group 17 hydrides in terms of bond energies

In addition, candidates should be able to:

(h) predict the characteristic properties of an element in a given Group by using knowledge of chemical periodicity

(i) deduce the nature, possible position in the Periodic Table, and identity of unknown elements from given information of physical and chemical properties

CORE IDEA 3 – TRANSFORMATION

6 THE MOLE CONCEPT AND STOICHIOMETRY

Content

- Relative masses of atoms and molecules
- The mole, the Avogadro constant
- The calculation of empirical and molecular formulae
- Reacting masses and volumes (of solutions and gases)

Learning Outcomes

[the term relative formula mass or M_r will be used for ionic compounds]

Candidates should be able to:

(a) define the terms *relative atomic*, *isotopic*, *molecular* and *formula mass*

(b) define the term *mole* in terms of the Avogadro constant

(c) calculate the relative atomic mass of an element given the relative abundances of its isotopes

(d) define the terms *empirical* and *molecular formula*

(e) calculate empirical and molecular formulae using combustion data or composition by mass

(f) write and/or construct balanced equations

(g) perform calculations, including use of the mole concept, involving:

  (i) reacting masses (from formulae and equations)

  (ii) volumes of gases (e.g. in the burning of hydrocarbons)

  (iii) volumes and concentrations of solutions

  [when performing calculations, candidates’ answers should reflect the number of significant figures given or asked for in the question]

(h) deduce stoichiometric relationships from calculations such as those in (g)

7 CHEMICAL ENERGETICS: THERMOCHEMISTRY AND THERMODYNAMICS (GIBBS FREE ENERGY AND ENTROPY)

Content

- Enthalpy changes: ΔH, of formation; combustion; hydration; solution; neutralisation; atomisation; bond energy; lattice energy; electron affinity
- Hess’ Law, including Born-Haber cycles
- Entropy and Free Energy

Learning Outcomes

Candidates should be able to:

(a) explain that most chemical reactions are accompanied by energy changes, principally in the form of heat usually associated with the breaking and forming of chemical bonds; the reaction can be exothermic (ΔH negative) or endothermic (ΔH positive)

(b) construct and interpret an energy profile diagram, in terms of the enthalpy change of the reaction and of the activation energy (see also Section 8)

(c) explain and use the terms:

  (i) *enthalpy change of reaction* and *standard conditions*, with particular reference to: formation; combustion; hydration; solution; neutralisation; atomisation

  (ii) *bond energy* (ΔH positive, i.e. bond breaking) (see also Section 2)

  (iii) *lattice energy* (ΔH negative, i.e. gaseous ions to solid lattice)

(d) calculate enthalpy changes from appropriate experimental results, including the use of the relationship: heat change = $mc\Delta T$

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

(f) apply Hess' Law to construct simple energy cycles, e.g. Born-Haber cycle, and carry out calculations involving such cycles and relevant energy terms (including ionisation energy and electron affinity), with particular reference to:

  (i) determining enthalpy changes that cannot be found by direct experiment, e.g. an enthalpy change of formation from enthalpy changes of combustion

  (ii) the formation of a simple ionic solid and of its aqueous solution

  (iii) average bond energies

(g) explain and use the term *entropy*

(h) discuss the effects on the entropy of a chemical system by the following:

  (i) change in temperature

  (ii) change in phase

  (iii) change in the number of particles (especially for gaseous systems)

  [quantitative treatment is **not** required]

(i) predict whether the entropy change for a given process or reaction is positive or negative

(j) state and use the equation involving *standard Gibbs free energy change of reaction,* $\Delta G^\ominus$:
$\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus$
[the calculation of standard entropy change, $\Delta S^\ominus$, for a reaction using standard entropies, $S^\ominus$, is **not** required]

(k) state whether a reaction or process will be spontaneous by using the sign of $\Delta G^\ominus$

(l) understand the limitations in the use of $\Delta G^\ominus$ to predict the spontaneity of a reaction

(m) predict the effect of temperature change on the spontaneity of a reaction, given standard enthalpy and entropy changes

8 REACTION KINETICS

Content

- Simple rate equations; orders of reaction; rate constants
- Concept of activation energy
- Effect of concentration, temperature, and catalysts on reaction rate
- Homogeneous and heterogeneous catalysis
- Enzymes as biological catalysts

Learning Outcomes

Candidates should be able to:

(a) explain and use the terms: *rate of reaction*; *rate equation*; *order of reaction*; *rate constant*; *half-life of a reaction*; *rate-determining step*; *activation energy*; *catalysis*

(b) construct and use rate equations of the form rate = $k[A]^m[B]^n$ (limited to simple cases of single-step reactions and of multi-step processes with a rate-determining step, for which m and n are 0, 1 or 2), including:

  (i) deducing the order of a reaction by the initial rates method

  (ii) justifying, for zero- and first-order reactions, the order of reaction from concentration-time graphs

  (iii) verifying that a suggested reaction mechanism is consistent with the observed kinetics

  (iv) predicting the order that would result from a given reaction mechanism

  (v) calculating an initial rate using concentration data

  [integrated forms of rate equations are **not** required]

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

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

(d) calculate a rate constant using the initial rates method

(e) devise a suitable experimental technique for studying the rate of a reaction, from given information

(f) explain qualitatively, in terms of frequency of collisions, the effect of concentration changes on the rate of a reaction

(g) show understanding, including reference to the Boltzmann distribution, of what is meant by the term *activation energy*

(h) explain qualitatively, in terms both of the Boltzmann distribution and of collision frequency, the effect of temperature change on a rate constant (and hence, on the rate) of a reaction

(i) (i) explain that, in the presence of a catalyst, a reaction has a different mechanism, i.e. one of lower activation energy, giving a larger rate constant

  (ii) interpret this catalytic effect on a rate constant in terms of the Boltzmann distribution

(j) outline the different modes of action of homogeneous and heterogeneous catalysis, including:

  (i) the Haber process

  (ii) the catalytic removal of oxides of nitrogen in the exhaust gases from car engines (see also Section 11.4)

  - (iii) the catalytic role of atmospheric oxides of nitrogen in the oxidation of atmospheric sulfur dioxide
  - (iv) catalytic role of Fe^{2+} in the $I^{-}/S_2O_8^{2-}$ reaction

(k) describe enzymes as protein molecules that act as biological catalysts with high specificity (in the reactions that they catalyse and in their choice of substrates as exemplified by the lock-and-key model), temperature sensitivity and pH sensitivity
[knowledge of the levels of structure of proteins and the details of the denaturation process are **not** required]

9 CHEMICAL EQUILIBRIA

Content

- Chemical equilibria: reversible reactions; dynamic equilibrium
  - (i) factors affecting chemical equilibria
  - (ii) equilibrium constants
  - (iii) the Haber process

Learning Outcomes

Candidates should be able to:

(a) explain, in terms of rates of the forward and reverse reactions, what is meant by a *reversible reaction* and *dynamic equilibrium*

(b) state Le Chatelier's Principle and apply it to deduce qualitatively (from appropriate information) the effects of changes in concentration, pressure or temperature, on a system at equilibrium

(c) deduce whether changes in concentration, pressure or temperature or the presence of a catalyst affect the value of the equilibrium constant for a reaction

(d) deduce expressions for equilibrium constants in terms of concentrations, K_c, and partial pressures, K_p
[treatment of the relationship between K_p and K_c is **not** required]

(e) calculate the values of equilibrium constants in terms of concentrations or partial pressures from appropriate data

(f) calculate the quantities present at equilibrium, given appropriate data (such calculations will not require the solving of quadratic equations)

(g) describe and explain the conditions used in the Haber process, as an example of the importance of an understanding of chemical equilibrium in the chemical industry

EXTENSION TOPICS

10 CHEMISTRY OF AQUEOUS SOLUTIONS

This topic deals with acid-base equilibria in aqueous solution. Hence the Brønsted-Lowry definitions of acid/base are primarily used in the understanding of pH of solutions (see Section 4).

10.1 ACID-BASE EQUILIBRIA

Content

- Acid dissociation constants, K_a and the use of pK_a
- Base dissociation constants, K_b and the use of pK_b
- The ionic product of water, K_w
- pH: choice of pH indicators
- Buffer solutions

Learning Outcomes

Candidates should be able to:

(a) explain qualitatively the differences in behaviour between strong and weak acids and bases in terms of the extent of dissociation

(b) explain the terms pH; K_a; pK_a; K_b; pK_b; K_w and apply them in calculations, including the relationship $K_w = K_aK_b$

(c) calculate [H^+(aq)] and pH values for strong acids, weak monobasic (monoprotic) acids, strong bases, and weak monoacidic bases
[calculations involving weak acids/bases will **not** require solving of quadratic equations]

(d) describe the changes in pH during acid-base titrations and explain these changes in terms of the strengths of the acids and bases

(e) explain the choice of suitable indicators for acid-base titrations, given appropriate data

(f) (i) explain how buffer solutions control pH

(ii) describe and explain the uses of buffer solutions, including the role of CO_3^{2-}/HCO_3^- in maintaining pH in oceans, and how the rapid increase in atmospheric carbon dioxide gas contributed to ocean acidification

(g) calculate the pH of buffer solutions, given appropriate data

10.2 SOLUBILITY EQUILIBRIA

Content

- Solubility product; the common ion effect and complex ion formation

Learning Outcomes

Candidates should be able to:

(a) show understanding of, and apply, the concept of solubility product, K_{sp}

(b) calculate K_{sp} from concentrations and *vice versa*

(c) discuss the effects on the solubility of ionic salts by the following:

  (i) common ion effect

  (ii) formation of complex ion, as exemplified by the reactions of halide ions with aqueous silver ions followed by aqueous ammonia (see also Section 13)

11 ORGANIC CHEMISTRY

Preamble

Although there are features of organic chemistry topics that are distinctive, it is intended that appropriate cross-references with other sections/topics in the syllabus should be made.

In their study of organic chemistry, candidates may wish to group the organic reactions in terms of the mechanisms in the syllabus where possible. Candidates may wish to compare and contrast the different mechanisms.

When describing preparative reactions, candidates will be expected to quote the reagents, e.g. aqueous NaOH, the essential practical conditions, e.g. reflux, high temperature and pressure, and the identity of each of the major products. Detailed conditions involving specific temperature and pressure values are **not** required.

Detailed knowledge of practical procedures is also **not** required: however, candidates may be expected to suggest (from their knowledge of the reagents, essential conditions and products) what steps may be needed to purify/extract a required product from the reaction mixture. In equations for organic redox reactions, the symbols [O] and [H] are acceptable.

11.1 INTRODUCTION

Content

- Empirical, molecular and structural formulae
- Functional groups and the naming of organic compounds
- Shapes of organic molecules; σ and π bonds

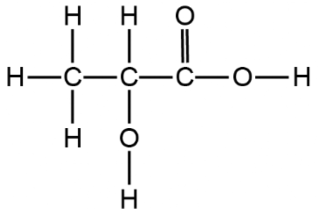
Candidates are expected to be able to interpret and use the following types of representations in the description of organic molecules. The examples given are for the compound (+)-lactic acid.

Empirical Formula: simplest ratio of the number of atoms of the elements present in one molecule, e.g. CH_2O

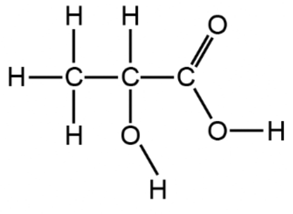
Molecular Formula: actual number of the atoms of the elements present in one molecule, e.g. $C_3H_6O_3$

Structural Formula: shows how the constituent atoms of a molecule are joined together with minimal detail, using conventional groups, for an unambiguous structure, e.g. $CH_3CH(OH)CO_2H$

Full Structural or Displayed Formula: detailed structure of molecule showing the relative placing of atoms and the number of bonds between them,
e.g.



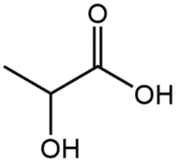
or



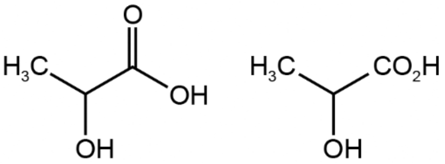
Where a benzene ring is part of the molecule, a displayed formula for benzene will not be expected to be drawn.

Skeletal Formula: simplified representation of an organic formula derived from the structural formula by removing hydrogen atoms (and their associated bonds) and carbon atoms from alkyl chains, leaving just the carbon-carbon bonds in the carbon skeleton and the associated functional groups.

Skeletal or partial skeletal representations may be used in question papers and are acceptable in candidates' answers where they are unambiguous,
e.g.



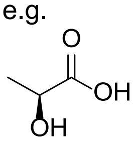
skeletal



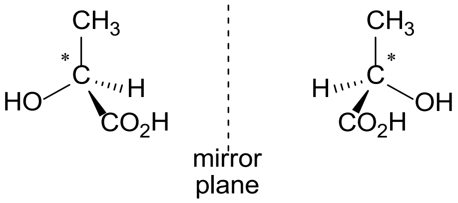
partial skeletal

The  convention for representing the aromatic ring is preferred.

Stereochemical Formula: show spatial arrangement of bonds, atoms and groups in molecule in 3-D,
e.g.

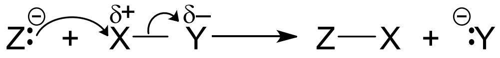


When drawing a pair of enantiomers, candidates should indicate the three-dimensional structures according to the convention used in the example below.

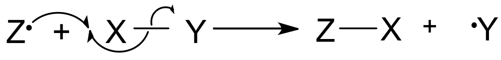


Candidates are expected to be able to interpret and use the curly arrow notation to represent the movement of electrons in organic reaction mechanisms.

For movement of a *pair* of electrons (**full arrow**):



For movement of a *single* unpaired electron (**half arrow**):



Learning Outcomes

Candidates should be able to:

(a) interpret, and use the nomenclature, general formulae and displayed formulae of the following classes of compound:

- (i) hydrocarbons (alkanes, alkenes and arenes)
- (ii) halogen derivatives (halogenoalkanes and halogenoarenes)
- (iii) hydroxyl compounds (alcohols and phenols)
- (iv) carbonyl compounds (aldehydes and ketones)

(v) carboxylic acids and derivatives (acyl chlorides and esters)

(vi) nitrogen compounds (amines, amides, amino acids and nitriles)

(b) describe sp^3 hybridisation, as in ethane molecule, sp^2 hybridisation, as in ethene and benzene molecules, and sp hybridisation, as in ethyne molecule

(c) explain the shapes of, and bond angles in, the ethane, ethene, benzene, and ethyne molecules in relation to σ and π carbon-carbon bonds

(d) predict the shapes of, and bond angles in, molecules analogous to those specified in (c)

11.2 ISOMERISM

Content

- Isomerism: *constitutional (structural); cis-trans; enantiomerism*

Learning Outcomes

Candidates should be able to:

(a) describe constitutional (structural) isomerism

(b) describe *cis-trans* isomerism in alkenes, and explain its origin in terms of restricted rotation due to the presence of π bonds
[use of *E*, *Z* nomenclature is **not** required]

(c) explain what is meant by a chiral centre

(d) deduce whether a given molecule is chiral based on the presence or absence of chiral centres and/or a plane of symmetry

(e) recognise that an optically active sample rotates plane-polarised light and contains chiral molecules

(f) recognise that enantiomers have identical physical properties except in the direction in which they rotate plane-polarised light
[usage of the term diastereomers is **not** required]

(g) recognise that enantiomers have identical chemical properties except in their interactions with another chiral molecule

(h) recognise that different stereoisomers exhibit different biological properties, for example in drug action

(i) deduce the possible isomers for an organic molecule of known molecular formula

(j) identify chiral centres and/or *cis-trans* isomerism in a molecule of given structural formula

11.3 ORGANIC REACTIONS AND MECHANISMS

Content

- Common terms for organic reactions and reactivities
- Reactivity of some classes of compounds and their characteristic organic reaction mechanisms

Learning Outcomes

Candidates should be able to:

(a) interpret and use the following terminology associated with organic reactions:

  (i) functional group

  (ii) degree of substitution: primary, secondary, tertiary, quaternary

  (iii) homolytic and heterolytic fission

  (iv) carbocation

  (v) free radical

  (vi) electrophile (Lewis acid), nucleophile (Lewis base)

  (vii) addition, substitution, elimination, condensation, hydrolysis

  (viii) oxidation and reduction

  [in equations for organic redox reactions, the symbols [O] and [H] are acceptable]

(b) interpret and use the following terminology associated with organic reactivities:

  (i) delocalisation

  (ii) electronic effect (electron-donating and electron-withdrawing effect)

  (iii) steric effect (steric hindrance)

(c) explain the general unreactivity of alkanes, including towards polar reagents

(d) explain the general reactivity of alkenes towards electrophilic reagents/electrophiles

(e) explain, in terms of delocalisation of π electrons, the difference between benzene and alkene:

  (i) reactivity towards electrophiles

  (ii) preference of benzene to undergo substitution rather than addition reaction

(f) interpret the different reactivities of halogenoalkanes, with particular reference to hydrolysis, and to the relative strengths of the carbon-halogen bonds

(g) explain the unreactivity of chlorobenzene compared to halogenoalkanes towards nucleophilic substitution, in terms of the delocalisation of the lone pair of electrons on the halogen and steric hindrance

(h) explain the reactivity of carbonyl compounds towards nucleophilic reagents, such as hydrogen cyanide

(i) apply (a) and (b) to the understanding of mechanisms in terms of organic structure and bonding

(j) recognise that the mechanisms of polar reactions involve the flow of electrons from electron-rich to electron-poor sites

(k) describe the mechanism of free-radical substitution with particular reference to the initiation, propagation and termination reactions, exemplified by reaction of ethane with chlorine

(l) describe the mechanism of electrophilic addition in alkenes, using bromine (Br_2 (in CCl_4)) with ethene as an example

(m) (i) describe the mechanism of electrophilic substitution in arenes, using the mono-bromination of benzene as an example

(ii) describe the effect of the delocalisation of electrons in arenes in such reactions

(n) describe and explain the mechanisms of nucleophilic substitutions in halogenoalkanes:

(i) S_N1, in terms of stability of the carbocation intermediates

(ii) S_N2, in terms of steric hindrance in the halogenoalkanes

(o) describe the mechanism of the nucleophilic addition reactions of hydrogen cyanide with aldehydes and ketones

In each of the sections below, 11.4 to 11.10, candidates will be expected to be able to predict the reaction products of a given compound in reactions that are chemically similar to those specified.

11.4 HYDROCARBONS

Content

- Alkanes (exemplified by ethane)
  - (i) free-radical substitution reactions
- Alkenes (exemplified by ethene)
  - (i) electrophilic addition, including Markovnikov's rule
  - (ii) reduction and oxidation reactions
- Arenes (exemplified by benzene and methylbenzene)
  - (i) influence of delocalised π electrons on structure and properties
  - (ii) electrophilic substitution reactions
  - (iii) oxidation of side-chain
- Hydrocarbons as fuels

Learning Outcomes

Candidates should be able to:

(a) describe the chemistry of alkanes as exemplified by the following reactions of ethane:

(i) combustion

(ii) free-radical substitution by chlorine and by bromine in the presence of ultraviolet light at room temperature (see also 11.3(c), 11.3(k))

(b) describe the chemistry of alkenes as exemplified, where relevant, by the following reactions of ethene:

(i) electrophilic addition of steam ($H_2O(g)$ with H_3PO_4 catalyst), hydrogen halides ($HX(g)$) and halogens ($X_2(aq)$ or X_2 (in CCl_4)) (see also 11.3(d), 11.3(l))

(ii) reduction via catalytic hydrogenation, using $H_2(g)$ and Ni catalyst (catalytic addition of hydrogen; see also 8(j))

(iii) oxidation by cold, alkaline solution of manganate(VII) ions to form the diol

(iv) oxidation by hot, acidified solution of manganate(VII) ions leading to the rupture of the carbon-to-carbon double bond in order to determine the position of alkene linkages in larger molecules

(c) apply Markovnikov's rule to the addition of hydrogen halides to unsymmetrical alkenes, and explain the composition of products in terms of the stability of carbocation intermediates

(d) describe the chemistry of the benzene ring as exemplified by the following reactions of benzene and methylbenzene (see also Section 4, 11.3(e) and 11.3(m)(i)):

  (i) electrophilic substitution reactions with chlorine using $AlCl_3$ as catalyst and with bromine using $AlBr_3$ as catalyst (recognise the use of Lewis acid as catalysts)

  (ii) nitration with a mixture of concentrated nitric acid and concentrated sulfuric acid, with the reaction mixture maintained at 30°C for methylbenzene and 50°C for benzene (recognise concentrated sulfuric acid as a Brønsted-Lowry acid catalyst)

  (iii) Friedel-Crafts alkylation with halogenoalkanes using $AlCl_3$ or $AlBr_3$ as catalyst (recognise the use of Lewis acid as catalysts)

(e) describe the chemistry of the alkyl side-chain of benzene ring as exemplified by the following reactions of methylbenzene:

  (i) free-radical substitution by chlorine and by bromine in the presence of ultraviolet light at room temperature

  (ii) complete oxidation to give benzoic acid using hot alkaline $KMnO_4$ and then dilute acid, or using hot acidified $KMnO_4$

(f) predict whether halogenation will occur in the side-chain or aromatic nucleus in arenes depending on reaction conditions

(g) apply the knowledge of positions of substitution in the electrophilic substitution reactions of mono-substituted arenes

(h) recognise the environmental consequences of:

  (i) carbon monoxide, oxides of nitrogen and unburnt hydrocarbons arising from the internal combustion engine and of their catalytic removal

  (ii) gases that contribute to the enhanced greenhouse effect

11.5 HALOGEN DERIVATIVES

Content

- Halogenoalkanes
  - (i) nucleophilic substitution
  - (ii) elimination
- Relative strength of the carbon-halogen bond
- Unreactivity of halogenoarenes

Learning Outcomes

Candidates should be able to:

(a) recall the chemistry of halogenoalkanes as exemplified by:

  (i) the following nucleophilic substitution reactions of bromoethane:
    - hydrolysis using NaOH(aq) and heat
    - formation of nitriles using KCN in ethanol and heat
    - formation of primary amines by reaction with ammonia in ethanol heated under pressure

  (ii) the elimination of hydrogen bromide from 2-bromopropane using NaOH in ethanol and heat

(b) explain the stereochemical outcome in nucleophilic substitution involving optically active substrates (see also 11.3(n)):

   (i) inversion of configuration in S_N2 mechanism

   (ii) racemisation in S_N1 mechanism

(c) suggest characteristic reactions to differentiate between:

   (i) different halogenoalkanes (see also 11.3(f))

   (ii) halogenoalkanes and halogenoarenes (see also 11.3(g))
   e.g. hydrolysis, followed by testing of the halide ions

(d) explain the uses of fluoroalkanes and fluorohalogenoalkanes in terms of their relative chemical inertness

(e) recognise the effect of chlorofluoroalkanes (CFCs) on the ozone layer, and that their proposed replacements, hydrofluoroalkanes (HFCs) and hydrochlorofluoroalkanes (HCFCs), have significant environmental impact too
[the mechanistic details of how CFCs and HCFCs deplete the ozone layer are **not** required]

11.6 HYDROXY COMPOUNDS

Content

- Alcohols (exemplified by ethanol)
  (i) formation of halogenoalkanes
  (ii) reaction with sodium; oxidation; dehydration
  (iii) the tri-iodomethane test
- Phenol
  (i) its acidity; reaction with bases and sodium
  (ii) nitration of, and bromination of, the aromatic ring

Learning Outcomes

Candidates should be able to:

(a) recall the chemistry of alcohols, exemplified by ethanol:

   (i) combustion

   (ii) nucleophilic substitution to give halogenoalkanes using hydrogen halides, HX or PCl_5

   (iii) reaction with sodium

   (iv) oxidation to:
   - carbonyl compounds using acidified $K_2Cr_2O_7$, heat with distillation
   - carboxylic acids using primary alcohols, acidified $KMnO_4$ and heat (under reflux)
   - carboxylic acids using primary alcohols, acidified $K_2Cr_2O_7$ and heat (under reflux)

   (v) dehydration to alkenes using concentrated H_3PO_4 catalyst and heat

(b) suggest characteristic distinguishing reactions for the different classes of alcohols (primary, secondary and tertiary alcohols), e.g. mild oxidation

(c) deduce the presence of a $CH_3CH(OH)–$ group in an alcohol from its reaction with warm alkaline aqueous iodine to form tri-iodomethane

(d) recall the chemistry of phenol, as exemplified by the following reactions:

  (i) with bases

  (ii) with sodium

  (iii) nitration of the benzene ring (using dilute HNO_3) to form a mixture of 2-nitrophenol and 4-nitrophenol, and bromination of the benzene ring (using aqueous Br_2) to form 2,4,6-tribromophenol

(e) explain the relative acidities of water, phenol and ethanol in aqueous medium (interpret as Brønsted-Lowry acids)

11.7 CARBONYL COMPOUNDS

Content

- Aldehydes (exemplified by ethanal)
  - (i) oxidation to carboxylic acid
  - (ii) nucleophilic addition with hydrogen cyanide
  - (iii) characteristic tests for aldehydes
- Ketones (exemplified by propanone and phenylethanone)
  - (i) nucleophilic addition with hydrogen cyanide
  - (ii) characteristic tests for ketones

Learning Outcomes

Candidates should be able to:

(a) describe the formation of aldehydes and ketones from, and their reduction to, primary and secondary alcohols respectively (using $LiA\ell H_4$, or using $H_2(g)$, Ni catalyst)

(b) describe the reactions of hydrogen cyanide (using KCN catalyst) with aldehydes and ketones (see also 11.3(o))

(c) describe the use of 2,4-dinitrophenylhydrazine (2,4-DNPH) to detect the presence of carbonyl compounds

(d) deduce the nature (aldehyde or ketone) of an unknown carbonyl compound from the results of simple tests (i.e. warming in Fehling's and Tollens' reagents; ease of oxidation)

(e) deduce the presence of a $CH_3CO–$ group in a carbonyl compound from its reaction with warm alkaline aqueous iodine to give tri-iodomethane

11.8 CARBOXYLIC ACIDS AND DERIVATIVES

Content

- Carboxylic acids (exemplified by ethanoic acid and benzoic acid)
  - (i) formation from primary alcohols and nitriles
  - (ii) salt, ester and acyl chloride formation
- Acyl chlorides (exemplified by ethanoyl chloride)
  - (i) ease of hydrolysis compared with alkyl and aryl chlorides
  - (ii) reaction with alcohols, phenols and primary amines
- Esters (exemplified by ethyl ethanoate and phenyl benzoate)
  - (i) formation from carboxylic acids and from acyl chlorides
  - (ii) hydrolysis (under acidic and under basic conditions)

Learning Outcomes

Candidates should be able to:

(a) describe the formation of carboxylic acids from:
  - primary alcohols using acidified $KMnO_4$ or acidified $K_2Cr_2O_7$, and heat (under reflux)
  - aldehydes using acidified $KMnO_4$ or acidified $K_2Cr_2O_7$, and heat (under reflux)
  - nitriles by heating with dilute acid (or dilute alkali followed by acidification)

(b) describe the reactions of carboxylic acids in the formation of:

  (i) salts via reaction with metals, alkalis or carbonates

  (ii) esters via condensation with alcohols (using concentrated H_2SO_4 catalyst and heat), using ethyl ethanoate as an example

  (iii) acyl chlorides via reaction with PCl_5 using ethanoyl chloride as an example

  (iv) primary alcohols via reduction with $LiAlH_4$, using ethanol as an example

(c) explain the acidity of carboxylic acids and of chlorine-substituted ethanoic acids in terms of their structures

(d) describe the hydrolysis of acyl chlorides with water

(e) describe the condensation reactions of acyl chlorides with alcohols, phenols and primary amines

(f) explain the relative ease of hydrolysis of acyl chlorides, alkyl chlorides and aryl chlorides

(g) describe the formation of esters from the condensation reaction of acyl chlorides, using phenyl benzoate as an example

(h) describe the acid and base hydrolysis of esters using aqueous acid (or aqueous alkali) and heat

11.9 NITROGEN COMPOUNDS

Content

- Amines (exemplified by ethylamine and phenylamine)
  (i) their formation
  (ii) salt formation
  (iii) other reactions of phenylamine
- Amides (exemplified by ethanamide)
  (i) formation from acyl chlorides
  (ii) neutrality of amides
  (iii) hydrolysis (under acidic and under basic conditions)
- Amino acids (exemplified by aminoethanoic acid)
  (i) their acid and base properties

Learning Outcomes

Candidates should be able to:

(a) describe the formation of amines as exemplified by:
  - ethylamine through reduction of amide using $LiAlH_4$ and nitrile using $LiAlH_4$ or $H_2(g)$, Ni catalyst (see also Section 11.5)
  - phenylamine through the reduction of nitrobenzene using Sn and concentrated HCl with heating, followed by NaOH(aq)

(b) describe the reaction of amines in the formation of salts

(c) describe and explain the basicity of primary, secondary and tertiary amines in the gaseous phase (interpret as Lewis bases)

(d) explain the relative basicities of ammonia, ethylamine and phenylamine in aqueous medium, in terms of their structures

(e) describe the reaction of phenylamine with aqueous bromine

(f) describe the formation of amides from the condensation reaction between RNH_2 and $R'COCl$

(g) explain why amide is neutral in terms of delocalisation of the lone pair of electrons on nitrogen

(h) describe the chemistry of amides, exemplified by the following reactions:

  (i) hydrolysis using aqueous acid (or aqueous alkali) and heat

  (ii) reduction to amines with $LiAlH_4$

(i) describe the acid/base properties of amino acids

11.10 POLYMERS

Content

- Addition and condensation of polymers
- Proteins
  (i) formation of proteins
  (ii) hydrolysis of proteins
- Biodegradability of poly(alkenes), polyesters and polyamides

Learning Outcomes

Candidates should be able to:

(a) recognise polymers as macromolecules built up from monomers, with average relative molecular mass of at least 1000 or at least 100 repeat units

(b) classify and explain the difference between addition polymers (as exemplified by poly(alkenes)) and condensation polymers (as exemplified by polyesters and polyamides)

(c) describe proteins as an example of condensation polymers made up of α-amino acids as monomers, forming peptide (amide) bonds

(d) describe the hydrolysis of proteins using aqueous acid (or aqueous alkali) and heat

(e) recognise that poly(alkenes) are chemically inert and can therefore be difficult to biodegrade (see also 11.3(c))

(f) recognise that polyesters and polyamides are generally biodegradable by hydrolysis (see also 11.8(h) and 11.9(h)(i))

(g) recognise that materials are a finite resource and the importance of recycling plastics, considering the economic, environmental and social factors

12 ELECTROCHEMISTRY

Content

- Redox processes: electron transfer and changes in oxidation number (oxidation state)
- Electrode potentials
  - (i) standard electrode (redox) potentials, $E^\ominus$; the redox series
  - (ii) standard cell potentials, $E^\ominus_{\text{cell}}$, and their uses
  - (iii) batteries and fuel cells
- Electrolysis
  - (i) factors affecting the amount of substance liberated during electrolysis
  - (ii) the Faraday constant; the Avogadro constant; their relationship
  - (iii) industrial uses of electrolysis

Learning Outcomes

Candidates should be able to:

(a) describe and explain redox processes in terms of electron transfer and/or of changes in oxidation number (oxidation state)

(b) define the terms:

- (i) *standard electrode (redox) potential*
- (ii) *standard cell potential*

(c) describe the standard hydrogen electrode

(d) describe methods used to measure the standard electrode potentials of:

- (i) metals or non-metals in contact with their ions in aqueous solution
- (ii) ions of the same element in different oxidation states

(e) calculate a standard cell potential by combining two standard electrode potentials

(f) use standard cell potentials to:

- (i) explain/deduce the direction of electron flow from a simple cell
- (ii) predict the spontaneity of a reaction

(g) understand the limitations in the use of standard cell potentials to predict the spontaneity of a reaction

(h) construct redox equations using the relevant half-equations (see also Section 13)

(i) state and apply the relationship $\Delta G^\ominus = -nFE^\ominus$ to electrochemical cells, including the calculation of $E^\ominus$ for combined half reactions

(j) predict qualitatively how the value of an electrode potential varies with the concentration of the aqueous ion

(k) state the possible advantages of developing other types of cell, e.g. the H_2/O_2 fuel cell and improved batteries (as in electric vehicles) in terms of smaller size, lower mass and higher voltage

(l) state the relationship, $F = Le$, between the Faraday constant, the Avogadro constant and the charge on the electron

(m) predict the identity of the substance liberated during electrolysis from the state of electrolyte (molten or aqueous), position in the redox series (electrode potential) and concentration

(n) calculate:

  (i) the quantity of charge passed during electrolysis

  (ii) the mass and/or volume of substance liberated during electrolysis

(o) explain, in terms of the electrode reactions, the industrial processes of:

  (i) the anodising of aluminium

  (ii) the electrolytic purification of copper

  [technical details are **not** required]

13 AN INTRODUCTION TO THE CHEMISTRY OF TRANSITION ELEMENTS

Content

- General physical and characteristic chemical properties of the first set of transition elements, scandium to copper
- Colour of complexes

Learning Outcomes

Candidates should be able to:

(a) explain that a transition element is a d block element whose atom has an incomplete d subshell, or which can give rise to cations with an incomplete d subshell

(b) state the electronic configuration of a first row transition element and its ions (see also 1(h))

(c) explain why atomic radii and first ionisation energies of the transition elements are relatively invariant

(d) contrast, qualitatively, the melting point and density of the transition elements with those of calcium as a typical s block element

(e) describe the tendency of transition elements to have variable oxidation states

(f) predict from a given electronic configuration, the likely oxidation states of a transition element

(g) describe and explain the use of Fe^{3+}/Fe^{2+}, MnO_4^{-}/Mn^{2+} and $Cr_2O_7^{2-}/Cr^{3+}$ as examples of redox systems (see also Section 12)

(h) predict, using $E^{\ominus}$ values, the likelihood of redox reactions (see also 12(f)(ii))

(i) define the terms *ligand* and *complex* as exemplified by the complexes of copper(II) ions with water, ammonia and chloride ions as ligands
(includes the transition metal complexes found in the Qualitative Analysis Notes)

(j) explain qualitatively that ligand exchange may occur, as exemplified by the formation of the complexes in (i), including the colour changes involved, and CO/O_2 exchange in haemoglobin

(k) describe, using the shape and orientation of the d orbitals, the splitting of degenerate d orbitals into two energy levels in octahedral complexes

(l) explain, in terms of d orbital splitting and d-d transition, why transition element complexes are usually coloured
[knowledge of the relative order of ligand field strength is **not** required]

(m) explain how some transition elements and/or their compounds can act as catalysts (see also 8(j))

PRACTICAL ASSESSMENT

Scientific subjects are, by their nature, experimental. It is therefore important that, wherever possible, the candidates carry out appropriate practical work to support the learning of this subject and to develop the expected practical skills.

Paper 4 Practical

This paper is designed to assess a candidate's competence in those practical skills which can realistically be assessed within the context of a formal practical assessment.

Candidates will be assessed in the following skill areas:

(a) Planning (P)

Candidates should be able to:

- define question/problem using appropriate knowledge and understanding
- give a clear logical account of the experimental procedure to be followed
- describe how the data should be used in order to reach a conclusion
- assess the risks of the experiment and describe precautions that should be taken to keep risks to a minimum

(b) Manipulation, measurement and observation (MMO)

Candidates should be able to:

- demonstrate a high level of manipulative skills in all aspects of practical activity
- make and record accurate observations with good details and measurements to an appropriate degree of precision
- make appropriate decisions about measurements or observations
- recognise anomalous observations and/or measurements (where appropriate) with reasons indicated

(c) Presentation of data and observations (PDO)

Candidates should be able to:

- present all information in an appropriate form
- manipulate measurements effectively in order to identify trends/patterns
- present all quantitative data to an appropriate number of decimal places/significant figures

(d) Analysis, conclusions and evaluation (ACE)

Candidates should be able to:

- analyse and interpret data or observations appropriately in relation to the task
- draw conclusion(s) from the interpretation of experimental data or observations and underlying principles
- make predictions based on their data and conclusions
- identify significant sources of errors, limitations of measurements and/or experimental procedures used, and explain how they affect the final result(s)
- state and explain how significant errors/limitations may be overcome or reduced, as appropriate, including how experimental procedures may be improved

One, or more, of the questions may incorporate some assessment of Skill P, set in the context of the syllabus content, requiring candidates to apply and integrate knowledge and understanding from different sections of the syllabus. It may also require the treatment of given experimental data in drawing relevant conclusion and analyse a proposed plan.

The assessment of skills MMO, PDO and ACE will also be set mainly in the context of the syllabus content. The assessment of PDO and ACE may also include questions on data-analysis which do not require practical equipment and apparatus.

Candidates should be able to use appropriate apparatus/equipment to record a range of measurements such as mass, time, volume and temperature. In addition, candidates are expected to have been exposed to a range of experimental techniques in the following areas:

1) Titration, e.g. acid-base titration (with suitable indicators such as methyl orange, screened methyl orange, thymolphthalein and thymol blue), redox titration, iodimetric titration, indirect titration, including the preparation of standard solutions. Other types of titrations may also be required, where appropriate, sufficient working details will be given.

2) Gravimetric analysis, e.g. volatilisation gravimetry

3) Gas collection. Candidates would **not** be required to carry out gas collection experiments involving displacement of water or using gas syringes during the practical examination.

4) Thermochemistry, including thermometric titration

5) Chemical kinetics, e.g. continuous and initial rate methods

6) Qualitative inorganic analysis involving an element, a compound or a mixture. Systematic analysis will **not** be required. Candidates should be familiar with the reactions of cations, reactions of anions and test for gases as detailed in the Qualitative Analysis Notes. Candidates would **not** be required to carry out tests involving hexane, sulfur dioxide gas, nitrite ions or sulfite ions.
   Reactions involving ions not included in the Qualitative Analysis Notes may be tested: in such cases, candidates will **not** be expected to identify the ions but only to draw conclusions of a general nature. Candidates should **not** attempt tests, other than those specified, on substances, except when it is appropriate to test for a gas.

7) Qualitative organic analysis requiring a knowledge of simple organic reactions as outlined in Section 11.4 to 11.10, e.g. test-tube reactions indicating the presence of unsaturation (C=C), alcoholic, phenolic, carbonyl, carboxyl and amino groups, may be set. Candidates should be familiar with the tests for organic compounds as detailed in the Qualitative Analysis Notes.
   Candidates would **not** be required to carry out tests involving 2,4-dinitrophenylhydrazine, phosphorus(V) chloride or phenol.

8) Simple organic synthesis and purification, including use of water bath, setting up and use of reflux and distillation apparatus. Conducting a large scale organic synthesis involving reflux, distillation and purification would not be expected during the practical examination.

This is not intended to be an exhaustive list.

Candidates are **not** allowed to refer to notebooks, textbooks or any other information in the Practical Examination. Qualitative Analysis Notes will be included in the question paper for the use of candidates in the examination.

Within the Scheme of Assessment, the practical paper constitutes 20% of the Higher 2 examination. It is therefore recommended that the schemes of work include learning opportunities that apportion a commensurate amount of time for the development and acquisition of practical skills.

Apparatus List

This list given below has been drawn up in order to give guidance to Centres concerning the apparatus that is expected to be generally available for examination purposes. The list is not intended to be exhaustive: in particular, items (such as Bunsen burners, tripods) that are commonly regarded as standard equipment in a chemical laboratory are not included.

Unless otherwise stated, the rate of allocation is "per candidate".

two burettes, 50 cm^3
two pipettes, 25 cm^3
one pipette, 10 cm^3
teat/dropping pipettes
one pipette filler
two conical flasks within the range 150 cm^3 to 250 cm^3
two conical flasks, 100 cm^3
volumetric flask, 250 cm^3
two measuring cylinders, 10 cm^3
measuring cylinders, 25 cm^3, 50 cm^3 and 100 cm^3
two filter funnels
two porcelain crucibles, approximately 15 cm^3, with lids
one pipe-clay triangle
one evaporating basin, at least 30 cm^3
beakers, squat form with lip: 100 cm^3, 250 cm^3
thermometers: –10 °C to +110 °C at 1 °C
–5 °C to +50 °C at 0.2 °C
a polystyrene, or other plastic beaker of approximate capacity 150 cm^3
test-tubes (some of which should be Pyrex or hard glass), approximately 125 mm × 15 mm
boiling tubes, approximately 150 mm × 25 mm
stopwatch to measure to an accuracy of about 1 s
balance, single-pan, direct reading, 0.01 g or better (1 per 8–12 candidates)
stands and clamps suitable for burettes and pipettes
wash bottle

The apparatus and material requirements for Paper 4 will vary year on year. Centres will be notified in advance of the details of the apparatus and materials required for each practical examination.

Reagents

This list given below has been drawn up in order to give guidance to Centres concerning the standard reagents that are expected to be generally available for examination purposes. The list is not intended to be exhaustive and Centres will be notified in advance of the full list of all the reagents that are required for each practical examination.

aqueous sodium hydroxide (approximately 2.0 mol dm^{-3})
aqueous ammonia (approximately 2.0 mol dm^{-3})
hydrochloric acid (approximately 2.0 mol dm^{-3})
nitric acid (approximately 2.0 mol dm^{-3})
sulfuric acid (approximately 1.0 mol dm^{-3})
aqueous silver nitrate (approximately 0.05 mol dm^{-3})
aqueous barium nitrate (approximately 0.2 mol dm^{-3})
limewater (a saturated solution of calcium hydroxide)
aqueous potassium manganate(VII) (approximately 0.02 mol dm^{-3})
aqueous potassium iodide (approximately 0.1 mol dm^{-3})
aluminium foil
red and blue litmus paper or Universal Indicator paper

Qualitative Analysis Notes

The tests shown on pages 38 to 40 will be printed at the back of the 9476 Paper 4 as Qualitative Analysis Notes.

Qualitative Analysis Notes
[ppt. = precipitate]

(a) Reactions of aqueous cations

cation	*reaction with*	
	$NaOH(aq)$	$NH_3(aq)$
aluminium, $Al^{3+}(aq)$	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, $NH_4^+(aq)$	ammonia produced on heating	–
barium, $Ba^{2+}(aq)$	no ppt. (if reagents are pure)	no ppt.
calcium, $Ca^{2+}(aq)$	white ppt. with high $[Ca^{2+}(aq)]$	no ppt.
chromium(III), $Cr^{3+}(aq)$	grey-green ppt. soluble in excess giving dark green solution	grey-green ppt. insoluble in excess
copper(II), $Cu^{2+}(aq)$,	pale blue ppt. insoluble in excess	blue ppt. soluble in excess giving dark blue solution
iron(II), $Fe^{2+}(aq)$	green ppt., turning brown on contact with air insoluble in excess	green ppt., turning brown on contact with air insoluble in excess
iron(III), $Fe^{3+}(aq)$	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
magnesium, $Mg^{2+}(aq)$	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), $Mn^{2+}(aq)$	off-white ppt., rapidly turning brown on contact with air insoluble in excess	off-white ppt., rapidly turning brown on contact with air insoluble in excess
zinc, $Zn^{2+}(aq)$	white ppt. soluble in excess	white ppt. soluble in excess

(b) Reactions of anions

anion	*reaction*
carbonate, CO_3^{2-}	CO_2 liberated by dilute acids
chloride, $Cl^-(aq)$	gives white ppt. with $Ag^+(aq)$ (soluble in $NH_3(aq)$)
bromide, $Br^-(aq)$	gives pale cream ppt. with $Ag^+(aq)$ (partially soluble in $NH_3(aq)$)
iodide, $I^-(aq)$	gives yellow ppt. with $Ag^+(aq)$ (insoluble in $NH_3(aq)$)
nitrate, $NO_3^-(aq)$	NH_3 liberated on heating with $OH^-(aq)$ and Al foil
nitrite, $NO_2^-(aq)$	NH_3 liberated on heating with $OH^-(aq)$ and Al foil; NO liberated by dilute acids (colourless NO → (pale) brown NO_2 in air)
sulfate, $SO_4^{2-}(aq)$	gives white ppt. with $Ba^{2+}(aq)$ (insoluble in excess dilute strong acids)
sulfite, $SO_3^{2-}(aq)$	SO_2 liberated with dilute acids; gives white ppt. with $Ba^{2+}(aq)$ (soluble in dilute strong acids)

(c) Tests for gases

gas	*test and test result*
ammonia, NH_3	turns damp red litmus paper blue
carbon dioxide, CO_2	gives a white ppt. with limewater (ppt. dissolves with excess CO_2)
chlorine, Cl_2	bleaches damp litmus paper
hydrogen, H_2	"pops" with a lighted splint
oxygen, O_2	relights a glowing splint
sulfur dioxide, SO_2	turns aqueous acidified potassium manganate(VII) from purple to colourless

(d) Colour of halogens

halogen	*colour of element*	*colour in aqueous solution*	*colour in hexane*
chlorine, Cl_2	greenish yellow gas	pale yellow	pale yellow
bromine, Br_2	reddish brown gas / liquid	orange	orange-red
iodine, I_2	black solid / purple gas	brown	purple

(e) Tests for organic compounds

organic compounds	*reactions*
alkene	decolourises orange Br_2(aq)
chloroalkane	heat with NaOH(aq), white ppt. formed on adding dilute HNO_3, followed by Ag^+(aq)
bromoalkane	heat with NaOH(aq), pale cream ppt. formed on adding dilute HNO_3, followed by Ag^+(aq)
iodoalkane	heat with NaOH(aq), yellow ppt. formed on adding dilute HNO_3, followed by Ag^+(aq)
alcohol	• forms white fumes with solid PCl_5 • decolourises purple acidified $KMnO_4$(aq) on heating (for primary and secondary alcohols) • gives pale yellow ppt. with alkaline I_2(aq) on warming (for alcohols with $CH_3CH(OH)–$ group)
phenol	decolourises orange Br_2(aq) and forms a white ppt
carbonyl compounds (aldehydes and ketones)	• gives orange ppt. with 2,4-dinitrophenylhydrazine • gives pale yellow ppt. with alkaline I_2(aq) on warming (for carbonyl compounds with $CH_3CO–$ group) • gives red-brown ppt. with Fehling's solution on warming (for aliphatic aldehydes) • gives silver mirror with Tollens' reagent on warming (for aldehydes)
carboxylic acid	• CO_2 liberated with Na_2CO_3(aq) • gives white fumes with solid PCl_5
phenylamine	decolourises orange Br_2(aq) and form a white ppt
primary amide	NH_3 liberated on heating with NaOH(aq)

SUMMARY OF KEY QUANTITIES AND UNITS

The list below is intended as a guide to the more important quantities which might be encountered in teaching and used in question papers. The list is not exhaustive.

Quantity	Usual symbols	Unit
Base quantities		
amount of substance	n	mol
electric current	I	A
length	l	m
mass	m	kg, g
thermodynamic temperature	T	K
time	t	s
Other quantities		
acid dissociation constant	K_a	mol dm^{-3}
atomic mass	$\mathrm{m_a}$	g, kg
Avogadro constant	L, N_A	mol^{-1}
base dissociation constant	K_b	mol dm^{-3}
bond energy	–	kJ mol^{-1}
concentration	c	mol dm^{-3}
density	ρ	kg m^{-3}, g dm^{-3}, g cm^{-3}
electric potential difference	V	V
electromotive force	E	V
electron affinity	–	kJ mol^{-1}
elementary charge	e	C
enthalpy change of reaction	ΔH	J, kJ
equilibrium constant	K, K_p, K_c	as appropriate
Faraday constant	F	C mol^{-1}
frequency	v, f	Hz
half-life	$T_{½}$, $t_{½}$	s
heat capacity	C	J K^{-1}
ionic product, solubility product	K, K_{sp},	as appropriate
ionic product of water	K_w	mol^2 dm^{-6}
ionisation energy	I	kJ mol^{-1}
lattice energy	–	kJ mol^{-1}
molar gas constant	R	J K^{-1} mol^{-1}
molar mass	M	g mol^{-1}
mole fraction	x	–
molecular mass	m	g, kg
neutron number	N	–
nucleon number	A	–
number of molecules	N, N_A	–
number of molecules per unit volume	n	m^{-3}
order of reaction	n, m	–
partition coefficient	K	–
Planck constant	h	J s
pH	pH	–
pressure	p	Pa
proton number	Z	–
rate constant	k	as appropriate
relative $\left\{\begin{array}{l}\text{atomic}\\\text{isotopic}\end{array}\right\}$ mass	A_r	–
relative molecular mass	M_r	–
specific heat capacity	c	J g^{-1} K^{-1}, kJ kg^{-1} K^{-1}
speed of electromagnetic waves	c	m s^{-1}
(standard) $\left\{\begin{array}{l}\text{electrode}\\\text{redox}\end{array}\right\}$ potential	$(E^{\ominus})$ E	V
standard enthalpy change of reaction	$\Delta H^{\ominus}$	J mol^{-1}, kJ mol^{-1}

standard entropy change of reaction	$\Delta S^{\ominus}$	$\text{J K}^{-1}\text{ mol}^{-1}$, $\text{kJ K}^{-1}\text{ mol}^{-1}$
standard Gibbs free energy change of reaction	$\Delta G^{\ominus}$	J mol^{-1}, kJ mol^{-1}
temperature	θ, t	°C
volume	V, v	m^3, dm^3
wavelength	λ	m, mm, nm

MATHEMATICAL REQUIREMENTS

It is assumed that candidates will be competent in the techniques described below.

Make calculations involving addition, subtraction, multiplication and division of quantities.

Make approximate evaluations of numerical expressions.

Express small fractions as percentages, and vice versa.

Calculate an arithmetic mean.

Transform decimal notation to power of ten notation (standard form).

Use calculators to evaluate logarithms, squares, square roots, and reciprocals.

Change the subject of an equation (most such equations involve only the simpler operations but may include positive and negative indices and square roots).

Substitute physical quantities into an equation using consistent units so as to calculate one quantity.
Check the dimensional consistency of such calculations, e.g. the units of a rate constant k.

Solve simple algebraic equations.

Comprehend and use the symbols/notations $<$, $>$, $\approx$, $/$, Δ, $\equiv$, $\overline{x}$ (or $<x>$).

Test tabulated pairs of values for direct proportionality by a graphical method or by constancy of ratio.

Select appropriate variables and scales for plotting a graph, especially to obtain a linear graph of the form $y = mx + c$.

Determine and interpret the slope and intercept of a linear graph.

Choose by inspection a straight line that will serve as the ‘least bad’ linear model for a set of data presented graphically.

Understand (i) the slope of a tangent to a curve as a measure of rate of change, (ii) the ‘area’ below a curve where the area has physical significance, e.g. Boltzmann distribution curves.

Comprehend how to handle numerical work so that significant figures are neither lost unnecessarily nor used beyond what is justified.

Estimate orders of magnitude.

Formulate simple algebraic equations as mathematical models, e.g. construct a rate equation, and identify failures of such models.

Calculators

Any calculator used must be on the Singapore Examinations and Assessment Board list of approved calculators.

GLOSSARY OF TERMS

It is hoped that the glossary (which is relevant only to science subjects) will prove helpful to candidates as a guide, i.e. it is neither exhaustive nor definitive. The glossary has been deliberately kept brief not only with respect to the number of terms included but also to the descriptions of their meanings. Candidates should appreciate that the meaning of a term must depend in part on its context.

1 *Define* (*the term(s) ...*) is intended literally, only a formal statement or equivalent paraphrase being required.

2 *What do you understand by/What is meant by (the term(s) ...)* normally implies that a definition should be given, together with some relevant comment on the significance or context of the term(s) concerned, especially where two or more terms are included in the question. The amount of supplementary comment intended should be interpreted in the light of the indicated mark value.

3 *State* implies a concise answer with little or no supporting argument, e.g. a numerical answer that can be obtained ‘by inspection’.

4 *List* requires a number of points, generally each of one word, with no elaboration. Where a given number of points is specified, this should not be exceeded.

5 *Explain* may imply reasoning or some reference to theory, depending on the context.

6 *Describe* requires candidates to state in words (using diagrams where appropriate) the main points of the topic. It is often used with reference either to particular phenomena or to particular experiments. In the former instance, the term usually implies that the answer should include reference to (visual) observations associated with the phenomena.
In other contexts, *describe and give an account of* should be interpreted more generally, i.e. the candidate has greater discretion about the nature and the organisation of the material to be included in the answer. *Describe and explain* may be coupled in a similar way to *state and explain.*

7 *Discuss* requires candidates to give a critical account of the points involved in the topic.

8 *Outline* implies brevity, i.e. restricting the answer to giving essentials.

9 *Predict* implies that the candidate is not expected to produce the required answer by recall but by making a logical connection between other pieces of information. Such information may be wholly given in the question or may depend on answers extracted in an early part of the question.

10 *Deduce* is used in a similar way as *predict* except that some supporting statement is required, e.g. reference to a law/principle, or the necessary reasoning is to be included in the answer.

11 *Comment* is intended as an open-ended instruction, inviting candidates to recall or infer points of interest relevant to the context of the question, taking account of the number of marks available.

12 *Suggest* is used in two main contexts, i.e. either to imply that there is no unique answer (e.g. in chemistry, two or more substances may satisfy the given conditions describing an ‘unknown’), or to imply that candidates are expected to apply their general knowledge to a ‘novel’ situation, one that may be formally ‘not in the syllabus’.

13 *Find* is a general term that may variously be interpreted as calculate, measure, determine etc.

14 *Calculate* is used when a numerical answer is required. In general, working should be shown, especially where two or more steps are involved.

15 *Measure* implies that the quantity concerned can be directly obtained from a suitable measuring instrument, e.g. length, using a rule, or angle, using a protractor.

16 *Determine* often implies that the quantity concerned cannot be measured directly but is obtained by calculation, substituting measured or known values of other quantities into a standard formula, e.g. relative molecular mass.

17 *Estimate* implies a reasoned order of magnitude statement or calculation of the quantity concerned, making such simplifying assumptions as may be necessary about points of principle and about the values of quantities not otherwise included in the question.

18 *Sketch,* when applied to graph work, implies that the shape and/or position of the curve need only be qualitatively correct, but candidates should be aware that, depending on the context, some quantitative aspects may be looked for, e.g. passing through the origin, having an intercept, asymptote or discontinuity at a particular value.
In diagrams, sketch implies that a simple, freehand drawing is acceptable: nevertheless, care should be taken over proportions and the clear exposition of important details.

19 *Construct* is often used in relation to chemical equations where a candidate is expected to write a balanced equation, not by factual recall but by analogy or by using information in the question.

20 *Compare* requires candidates to provide both the similarities and differences between things or concepts.

21 *Classify* requires candidates to group things based on common characteristics.

22 *Recognise* is often used to identify facts, characteristics or concepts that are critical (relevant/appropriate) to the understanding of a situation, event, process or phenomenon.

TEXTBOOKS AND REFERENCES

Teachers may find reference to the following books helpful.

Cambridge International AS and A Level Chemistry (2nd edition) by Peter Cann and Peter Hughes, published by Hodder Education

Cambridge International AS and A Level Chemistry Coursebook with Digital Access by Lawrie Ryan and Roger Norris, published by Cambridge University Press

Chemistry in Context (7th Edition) by Graham Hill and John Holman, published by Oxford University Press

Experiments and Exercises in Basic Chemistry (7th Edition) by Steve Murov and Brian Stedjee, published by Wiley

Why Chemical Reactions Happen? By James Keeler and Peter Wothers, published by Oxford University Press

Oxford Chemistry Primers: Foundations of Organic Chemistry by M. Hornby & J. Peach, published by Oxford University Press

Oxford Chemistry Primers: Structure and Reactivity in Organic Chemistry by H. Maskill, published by Oxford University Press

Oxford Chemistry Primers: Mechanisms of Organic Chemistry by H. Maskill, published by Oxford University Press

The Language of Mathematics in Science: A Guide for Teachers of 11–16 Science by R Boohan, published by the Association for Science Education. ISBN 9780863574559.
https://www.ase.org.uk/mathsinscience

Teachers are encouraged to choose texts for class use which they feel will be of interest to their students and will support their own teaching style.

Many publishers are also producing videos and software appropriate for A-Level Chemistry students.