Singapore Examinations and Assessment Board

CAMBRIDGE International Education

Singapore–Cambridge General Certificate of Education Advanced Level Higher 1 (2027)

Chemistry (Syllabus 8873)

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

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

   2.1 demonstrating the ways of thinking and doing in Science
   2.2 understanding the nature of scientific knowledge
   2.3 relating science, technology, society and environment

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

   3.1 understanding the structure, properties and transformation of matter at the atomic/molecular level and how they are related to each other
   3.2 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 **Fig. 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).

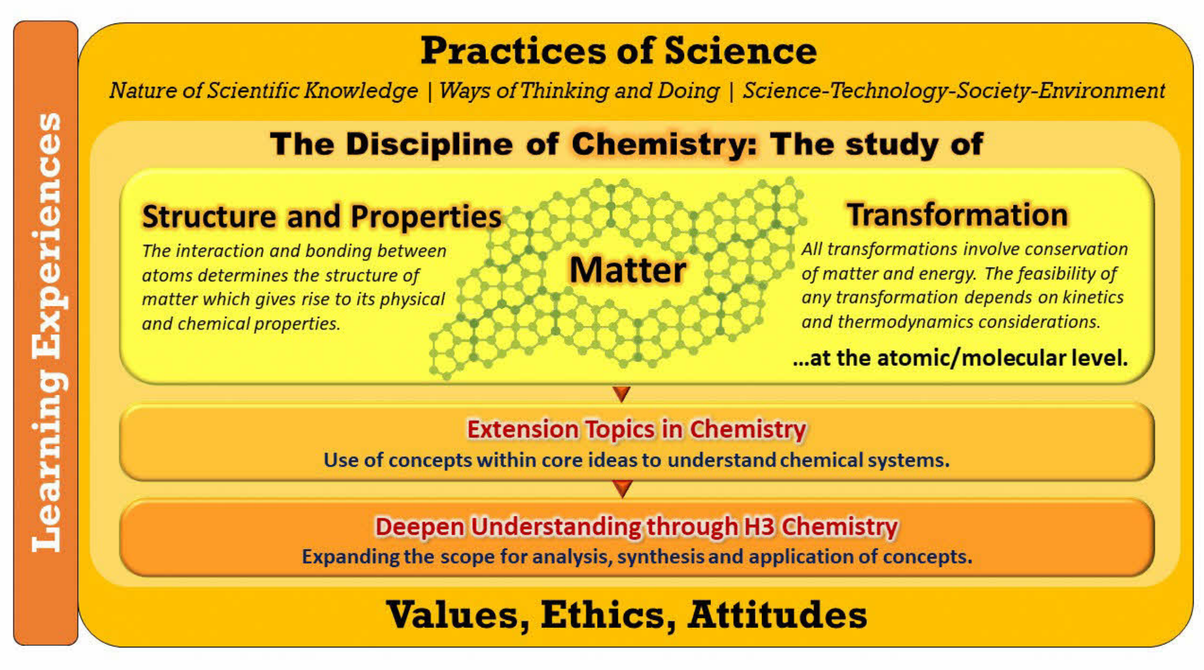


Fig. 1: A-Level Chemistry Curriculum Framework

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 H1 Chemistry syllabus are 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 Topic.*
  Concepts in the core ideas are applied to real-world context in the study of Polymers and Organic Chemistry

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.

[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.

ASSESSMENT OBJECTIVES

The *Assessment Objectives* listed below reflect those parts of the *Aims* and *Practices of Science* which 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*).

SCHEME OF ASSESSMENT

All candidates are required to enter for Papers 1 and 2.

Paper	Type of Paper	Duration	Weighting (%)	Marks
1	**Multiple Choice**	1 h	33	30
2	**Structured Questions**	2 h	67	80

Paper 1 (1 h, 30 marks)

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

All questions will include 4 options.

Paper 2 (2 h, 80 marks)
This paper consists of two sections. All answers will be written in spaces provided on the Question Paper.

Section A (60 marks)
A variable number of structured questions including data-based questions, all compulsory. The data-based question(s) constitute(s) 15–20 marks for this paper. The data-based question(s) provide(s) a good opportunity to test higher order thinking skills such as handling, applying, and evaluating information.

Section B (20 marks)
Candidates will be required to answer **one** out of two questions. Each question will carry 20 marks.

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

Weighting of Assessment Objectives

Assessment Objectives		Weighting (%)	Assessment Components
A	**Knowledge with understanding**	45	Papers 1, 2
B	**Handling, applying and evaluating information**	55	Papers 1, 2

ADDITIONAL INFORMATION

Data Booklet

Candidates will be provided with a *Data Booklet*, including the Periodic Table, for use in the theory papers.

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.

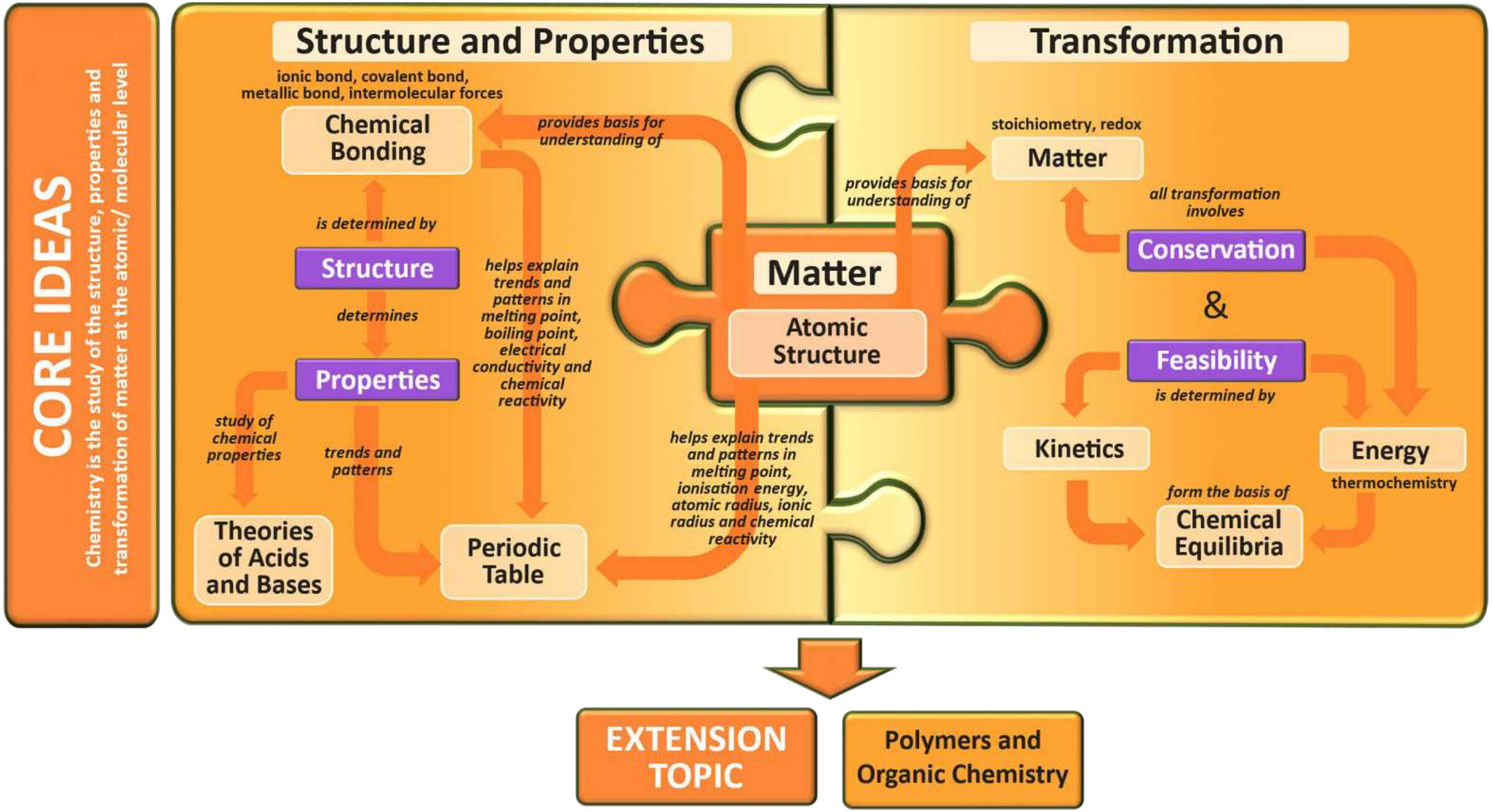
Units and significant figures

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



The H1 Chemistry curriculum provides students with the opportunity to appreciate the connections between the concepts in the Core Ideas of *Matter*, *Structure and Properties*, and *Transformation*, and to apply these to the study of Polymers and Organic Chemistry in the *Extension Topic*. This is illustrated in the H1 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 H1 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.

Transformation of matter involves the study of the feasibility and the extent of chemical reactions. Considerations of energetics and kinetics account for the feasibility while an understanding in equilibrium explains the extent of chemical reactions. The energetics dimension builds upon prior knowledge of thermochemistry, by contextualising the concept of enthalpy change in specific processes, e.g. combustion, bond breaking and lattice formation. To highlight the empirical aspects of Chemistry, methods for the determination of enthalpy changes will also be discussed. 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 energetics 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.

The extension topic on Polymers and Organic Chemistry features applications of core concepts to a real-world context where specific examples, such as plastics and proteins, provide the opportunity for students to apply their knowledge on structure and bonding to understand the properties and uses of these materials.

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 and p orbitals
[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 4)

(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 9)

(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 liquid and gaseous $CHCl_3$, Br_2 and the noble gases

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

(i) outline the importance of intermolecular forces to the liquefaction of gases when subjected to high pressure and/or low temperature

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

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

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

(m) 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]

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

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

3 THEORIES OF ACIDS AND BASES

Content

- Arrhenius and Brønsted-Lowry theories of acids and bases
- Acid dissociation constants, K_a
- Base dissociation constants, K_b
- The ionic product of water, K_w
- pH: choice of indicators
- Buffer solutions

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

(d) explain the terms pH; K_a; K_b; K_w
[the relationship $K_w = K_aK_b$ is **not** required]

(e) calculate $[H^+(aq)]$ and pH values for strong acids and strong bases

(f) explain the choice of suitable indicators for acid-base titrations, given appropriate data, in terms of the strengths of the acids and bases

(g) (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

4 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 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 1 and Group 17):
  (i) as reducing agents (Group 1) and oxidising agents (Group 17)
  (ii) thermal stability of 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 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 in 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 1 (lithium to caesium) and Group 17 (chlorine to iodine), candidates should be able to:

(f) describe and explain the relative reactivity of elements of:

(i) Group 1 as reducing agents in terms of ease of loss of electrons

(ii) Group 17 as oxidising agents in terms of ease of gain of electrons

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

5 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)
- Redox processes: electron transfer and changes in oxidation number (oxidation state)

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) describe and explain redox processes in terms of electron transfer and/or of changes in oxidation number (oxidation state) as exemplified by Fe^{3+}/Fe^{2+} and MnO_4^-/Mn^{2+}

(h) construct redox equations using the relevant half-equations

(i) 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]

(j) deduce stoichiometric relationships from calculations such as those in (i)

6 CHEMICAL ENERGETICS: THERMOCHEMISTRY

Content

- Enthalpy changes: ΔH, of formation; combustion; neutralisation; bond energy; lattice energy
- Hess' Law

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 7)

(c) explain and use the terms:

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

(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 carry out calculations involving given simple energy cycles and relevant energy terms (restricted to enthalpy changes of formation, combustion and neutralisation), 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) average bond energies
[construction of energy cycles is **not** required]

7 REACTION KINETICS

Content

- Simple rate equations; orders of reaction; rate constants
- Concept of activation energy
- Effect of concentration, temperature, and catalysts on reaction rate
- Heterogenous catalysts
- 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*; *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 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) calculating an initial rate using concentration data

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

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

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

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

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

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

(ii) interpret this catalytic effect in terms of the Boltzmann distribution

(h) outline the mode of action of heterogeneous catalysis, as exemplified by the catalytic removal of oxides of nitrogen in the exhaust gases from car engines

(i) 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 is **not** required. Details of the denaturation process will be discussed in 9 (m).]

8 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

(e) calculate the values of equilibrium constants in terms of concentrations 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 TOPIC

9 POLYMERS AND 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.

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.

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 in the syllabus.

Content

- Empirical, molecular and structural formulae
- Functional groups and the naming of organic compounds
- Common terms for organic reactions
- Isomerism: *constitutional (structural); cis-trans*
- Shapes of organic molecules; σ and π bonds
- Alkanes (as exemplified by ethane)
  - (i) combustion and substitution reaction
- Alkenes (as exemplified by ethene)
  - (i) combustion and addition reactions
- Halogenoalkanes (as exemplified by bromoethane)
  - (i) substitution
  - (ii) elimination
- Alcohols (as exemplified by ethanol)
  - (i) combustion
  - (ii) oxidation to carboxylic acids
  - (iii) elimination
- Aldehydes (as exemplified by ethanal)
  - (i) oxidation to carboxylic acid
  - (ii) reduction
- Ketones (as exemplified by propanone)
  - (i) reduction
- Carboxylic acids (as exemplified by ethanoic acid)
  - (i) ester formation
  - (ii) amide formation
- Amino acids (as exemplified by aminoethanoic acid)
- Structure and uses of polymers

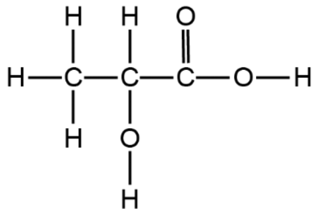
Candidates are expected to be able to interpret and use the following types of representations in the description of organic molecules. The examples given are for the compound lactic acid.

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

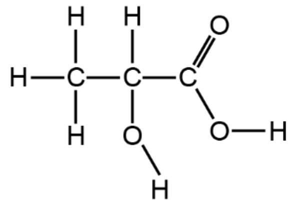
Molecular Formula: actual number of the atoms of the elements present in one molecule, e.g. $C_3H_6O_3$

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.



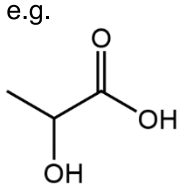
or



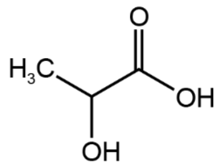
Where a benzene ring is part of the molecule, a displayed formula for benzene will not be expected to be drawn.

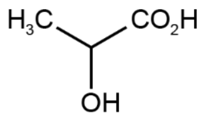
Skeletal Formula: simplified representation of an organic formula derived from the structural formula by removing hydrogen atoms (and their associated bonds) and carbon atoms from alkyl chains, leaving just the carbon-carbon bonds in the carbon skeleton and the associated functional groups.

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

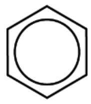


skeletal





partial skeletal

The  convention for representing the aromatic ring is preferred.

Learning Outcomes

Candidates should be able to:

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

(i) hydrocarbons (alkanes, alkenes and benzene)

(ii) halogenoalkanes

(iii) alcohols (including primary, secondary and tertiary)

(iv) aldehydes and ketones

(v) carboxylic acids

(vi) esters

(vii) amines

(viii) amides

(ix) amino acids

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

(i) functional group

(ii) addition, substitution, elimination

(iii) condensation, hydrolysis

(iv) oxidation and reduction
[in equations for organic redox reactions, the symbols [O] and [H] are acceptable]

(c) describe constitutional (structural) isomerism

(d) 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]

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

(f) (i) describe the shapes of the ethane, ethene and benzene molecules

(ii) explain the shapes of, and bond angles, in the ethane, ethene and benzene molecules in relation to σ and π carbon-carbon bonds
[knowledge of hybridisation is **not** required]

(iii) predict the shapes of, and bond angles in, molecules analogous to those specified in (f)(ii)

(g) describe the chemistry of the following classes of compounds:

(i) alkanes (exemplified by ethane) as being generally unreactive except in terms of combustion and substitution by chlorine in the presence of ultraviolet light at room temperature

(ii) alkenes (exemplified by ethene) in terms of combustion and addition reactions with bromine (in CCl_4) and hydrogen (using Ni catalyst)

(iii) halogenoalkanes (exemplified by bromoethane) in terms of substitution reaction to alcohols (using NaOH(aq), heat) and elimination reactions to alkenes (using NaOH in ethanol and heat)

(iv) alcohols (exemplified by ethanol) in terms of combustion, oxidation to carboxylic acids (using acidified $K_2Cr_2O_7$ or acidified $KMnO_4$ and heat) and elimination to alkenes (using concentrated H_3PO_4 catalyst and heat)

(v) aldehydes (exemplified by ethanal) and ketones (exemplified by propanone) in terms of their reduction to primary and secondary alcohols respectively (using $LiAlH_4$, or using H_2(g), Ni catalyst) and oxidation of aldehydes to carboxylic acids (using acidified $K_2Cr_2O_7$ or acidified $KMnO_4$ and heat)

(vi) carboxylic acids (exemplified by ethanoic acid) in terms of:
- reaction with alkalis and carbonates to form salts,
- condensation with alcohols to form esters (in the presence of concentrated H_2SO_4 catalyst), and with amines (exemplified by ethylamine) to form amides (in the presence of dicyclohexylcarbodiimide, DCC)
[knowledge of structure of DCC is **not** required]

(vii) esters (exemplified by ethyl ethanoate) and amides (exemplified by ethanamide) in terms of hydrolysis with aqueous acid (or aqueous alkali) and heat
[detailed conditions involving specific temperature and pressure values are **not** required]

(viii) amines (exemplified by ethylamine) with aqueous acid to form salts

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

(i) classify and explain the difference between addition and condensation polymers

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

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

(l) describe the specific bonds or interactions that stabilise the three-dimensional structure of a protein: hydrogen bonding, intermolecular forces and ionic linkages
[knowledge of the specific levels of structure of proteins, including a-helix and β-pleated sheet, is **not** required.]

(m) explain denaturation of proteins by extremes of temperature and pH changes, in terms of disruption of the bonds or interactions that hold the three-dimensional structure of the proteins (see also LO 7(i))

(n) apply knowledge of the loss and formation of three-dimensional structure to interpret real-world phenomena such as heating of egg whites and addition of vinegar to milk
[candidates are **not** required to identify the proteins in the substances.]

(o) classify and explain the difference between thermoplastic (linear, as exemplified by poly(ethene)) and thermosetting (cross-linked, as exemplified by poly(diallyl phthalate)) polymers with reference to structure, bonding and the following properties:

- (i) softening behaviour, including capacity to be recycled
- (ii) rigidity
- (iii) strength

(p) describe and explain the types of structure and bonding in relation to the properties and uses as exemplified by the following:

- (i) low density poly(ethene) (LDPE) in plastic bag and high density poly(ethene) (HDPE) in plastic bottles in relation to LDPE being softer and more flexible, and HDPE being harder and stiffer
- (ii) polyester and polyamide as fabric in relation to polyester (exemplified by poly(ethylene terephthalate) (PET)) as a fabric that is slightly less prone to creasing than polyamide (exemplified by nylon 6,6)
- (iii) poly(vinyl alcohol) (PVA) as a water-soluble polymer in eye drops and poly(vinyl chloride) (PVC) as a water-resistant polymer used in raincoats
- (iv) poly(propene) (PP) container instead of one made from poly(ethylene terephthalate) (PET) to store strongly alkaline cleaning solutions due to hydrolysis of PET

(q) predict physical properties of polymer from its structure

(r) recognise that poly(alkenes) are chemically inert and can therefore be difficult to biodegrade (see also 9(g)(i))

(s) recognise that polyesters and polyamides are generally biodegradable by hydrolysis (see also 9(g)(vii))

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

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	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 { atomic / isotopic } 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) { electrode / redox } potential	$(E^{\ominus})\ E$	V
standard enthalpy change of reaction	$\Delta H^{\ominus}$	$J\ mol^{-1}$, $kJ\ mol^{-1}$

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 (for pH calculations), 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 $\langle x \rangle$).

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 the following books helpful.

Cambridge International AS and A Level Chemistry 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

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.