CHEMISTRY SYLLABUS

Pre-University

Higher 1

Syllabus 8873

Implementation starting with
2020 Pre-University One Cohort

Ministry of Education
SINGAPORE

CONTENTS

1. INTRODUCTION

1.1 BACKGROUND

Design of the A-Level science curriculum

As scientific and technological advances influence and impact how we live, communicate and interact with each other, it is important to offer a science education that develops in individuals knowledge of the core ideas in science and an understanding of the practices associated with scientific inquiry, which will enable them to make decisions on science-related issues and challenges brought about by these advances. To develop such individuals, research in science education has shown that there is a need to strike a balance between teaching the products of science (e.g. core ideas, theories, and models), the processes of science and the nature of science. These products, processes and nature of science have been articulated in the revised H2 science curriculum. The H1 science curriculum, which is designed as a subset of H2 science, will also incorporate these key features.

Purpose of H1 science curriculum

While H2 Science develops in our students the disciplinary understanding, skills and attitudes necessary for further studies in the subject and related fields, H1 Science is designed to broaden students' learning that will support the development of scientific literacy. This is especially important for future citizens in an increasingly technologically-driven world and for leaders of the country to be equipped to make informed decisions based on sound scientific knowledge and principles about current and emerging science-related issues which are important to self, society and the world at large (for example, in appreciating the energy constraints faced by Singapore, or in understanding the mechanisms involved in epidemics).

Key changes to H1 science curriculum

The key changes to the H1 science curriculum are in tandem with the changes in the H2 science curriculum. Namely, the use of *Core Ideas* to frame the teaching and learning of science, and the introduction of the *Practices of Science* to place emphasis on science as a way of knowing and doing, beyond viewing it as an acquisition of a body of knowledge. Like H2 science, H1 science also encourages the use of real-world contexts in teaching and learning, and in using a wider range of pedagogies through *Learning Experiences*.

Differences between H2 and H1 science curriculum

The *Learning Experiences* outlined in H2 Science are largely relevant and applicable to H1 Science. However, the actual choice of pedagogy and *Learning Experiences* would need to be carefully adapted and designed to suit the teaching for H1 Science, especially in the area of science practical activities. There would be less emphasis on developing students' proficiency in handling equipment and in carrying out various laboratory tests and techniques. Instead, the focus of science practical experiences will be on developing students' scientific knowledge and providing opportunities for students to understand the evidence-based nature of scientific knowledge.

The *Practices of Science* is a key feature in H1 Science where greater emphasis would be placed on the development of those components that will enable students to become scientifically literate consumers and citizens who can use scientific understanding to explain and make informed choices concerning science-related issues. In particular, opportunities should be given for students to be engaged in discussion of important socio-scientific issues, such as the impact of climate change, the safe and responsible use of materials and the potential benefits and risks associated with the use of nuclear energy.

1.2 PURPOSE AND VALUE OF CHEMISTRY

Chemistry is the study of the structure, properties and transformation of matter at the atomic/molecular level. Hence, chemistry is often seen to play a central role in science. It is built on an understanding of the laws of physics that govern the nature of particles such as atoms, protons and electrons, and at the same time provides a basis for studying and understanding the molecules and reactions in biological systems.

H1 Chemistry aims to develop scientific literacy in our students through the acquisition of core chemistry knowledge and scientific thinking. This includes developing an understanding of the skills, ethics and attitudes relevant to the practices of science. In particular, the syllabus aims to develop in students the ability to navigate Chemistry between macroscopic phenomena, submicroscopic interactions and symbolic representations to communicate and explain the natural world.

1.3 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:
   - understanding the nature of scientific knowledge
   - demonstrating science inquiry skills
   - relating science and society

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

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

1.4 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.

Teaching students the nature of science helps them to develop an accurate understanding of what science is and how it is practised and applied in society. Students should be encouraged to consider relevant ethical issues, how scientific knowledge is developed, and the strengths and limitations of science. Teaching the nature of science also enhances the students' understanding of science content, increases their interest in science and helps show its human side. Science teaching should emphasise *how* we know as well as *what* we know.

Understanding the nature of scientific knowledge, demonstrating science inquiry skills and relating science and society are the three components that form our Practices of Science. 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 are emphasised.

The curriculum provides opportunities for students to reflect how the Practices of Science contribute to the accumulation of scientific knowledge. Students are encouraged to think about the 'whys' when planning and conducting investigations, developing models or engaging in scientific arguments. Through such reflection, they can come to understand the importance of each practice and develop a nuanced appreciation of the nature of science.

The Practices of Science comprise three components:

A. Understanding the nature of scientific knowledge
B. Demonstrating science inquiry skills
C. Relating science and society

A. Understanding the Nature of Scientific Knowledge

A1. Understand that science is an evidence-based, model-building enterprise concerned with the natural world

A2. Understand that the use of both logic and creativity is required in the generation of scientific knowledge

A3. Recognise that scientific knowledge is generated from consensus within the community of scientists through a process of critical debate and peer review

A4. Understand that scientific knowledge is reliable and durable, yet subject to revision in the light of new evidence

B. Demonstrating Science Inquiry Skills

B1. Identify scientific problems, observe phenomena and pose scientific questions/hypotheses

B2. Plan and conduct investigations by selecting the appropriate experimental procedures, apparatus and materials, with due regard for accuracy, precision and safety

B3. Obtain, organise and represent data in an appropriate manner

B4. Analyse and interpret data

B5. Construct explanations based on evidence and justify these explanations through reasoning and logical argument

B6. Use appropriate models to explain concepts, solve problems and make predictions

B7. Make decisions based on evaluation of evidence, processes, claims and conclusions

B8. Communicate scientific findings and information using appropriate language and terminology

C. Relating Science and Society

C1. Recognise that the application of scientific knowledge to problem solving could be influenced by other considerations such as economic, social, environmental and ethical factors

C2. Demonstrate an understanding of the benefits and risks associated with the application of science to society

C3. Use scientific principles and reasoning to understand, analyse and evaluate real-world systems as well as to generate solutions for problem solving

Developing 21st Century Competencies through the Learning of Science

To prepare our students for the future, a Framework for 21st Century Competencies (21CC) and Student Outcomes was developed by MOE (see Figure 1.1). This 21CC framework is meant to equip students with the key competencies and mindsets to be successful in the 21st century.

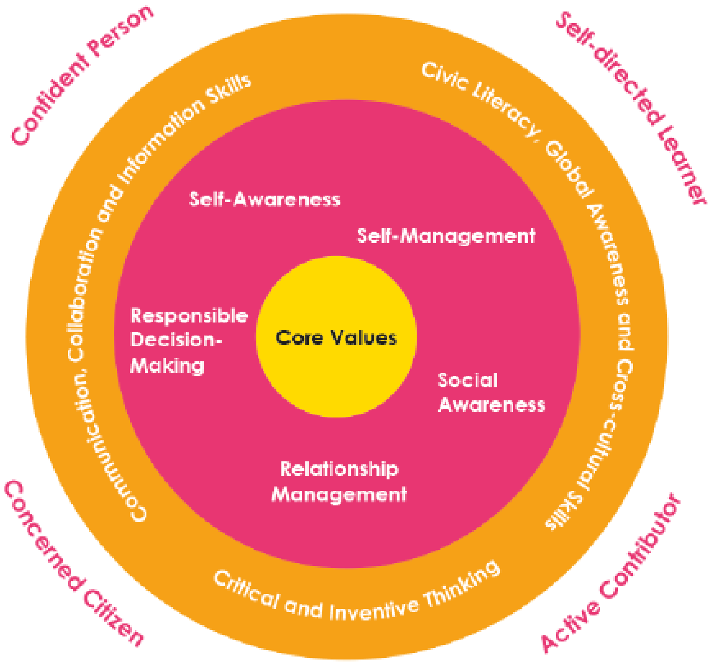


Figure 1.1. Framework for 21st Century Competencies and Student Outcomes

The features and intent of the Practices of Science are consistent with the emphasis on developing 21CC in our students.

The development of 21CC is not separate from the learning of science. The features of scientific inquiry, such as the processes of scientific investigation, reasoning, modelling and problem solving support a student's development of 21CC. The nature and limitations of science and scientific inquiry are developed effectively when scientific practices are learnt in the context of relevant science content. Deep disciplinary learning in science develops 21CC and promotes the process of learning for transfer to other areas of life.

1.5 H1 Chemistry Curriculum Framework

The key features of the H1 Chemistry Curriculum comprise Core Ideas and Extension Topics, Practices of Science and Learning Experiences, as illustrated in **Figure 1.2**.

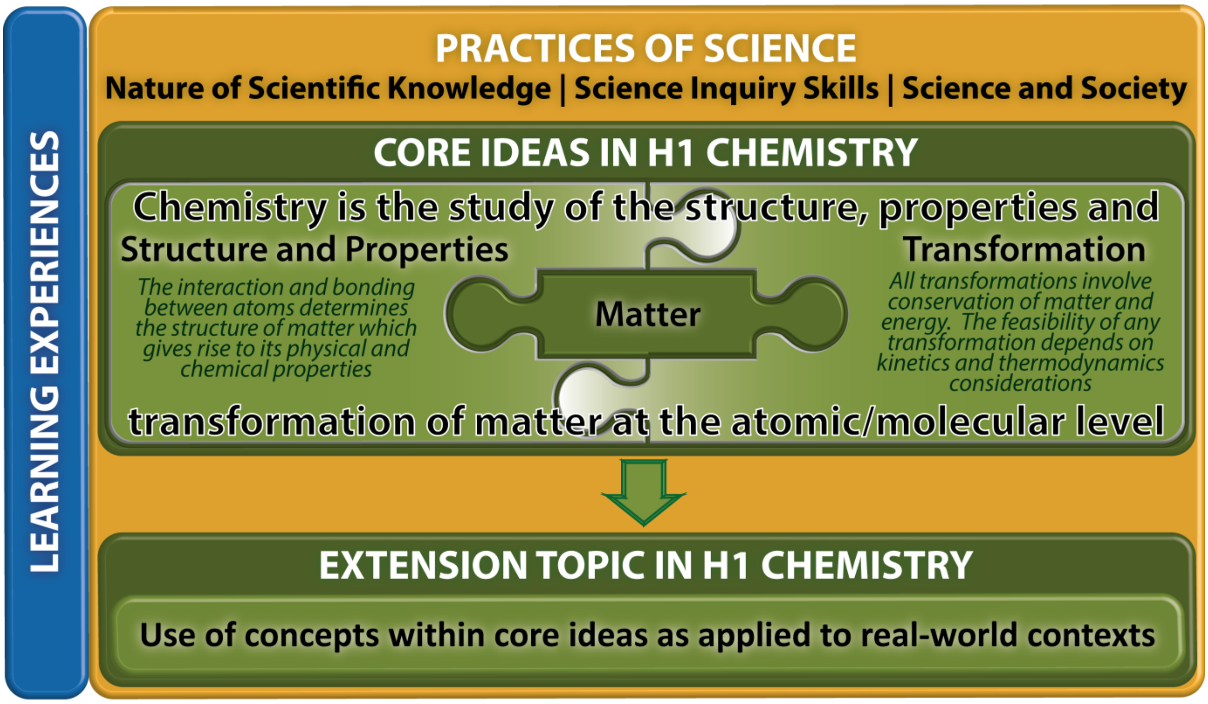


Figure 1.2. H1 Chemistry Curriculum Framework

Core Ideas and Extension Topics

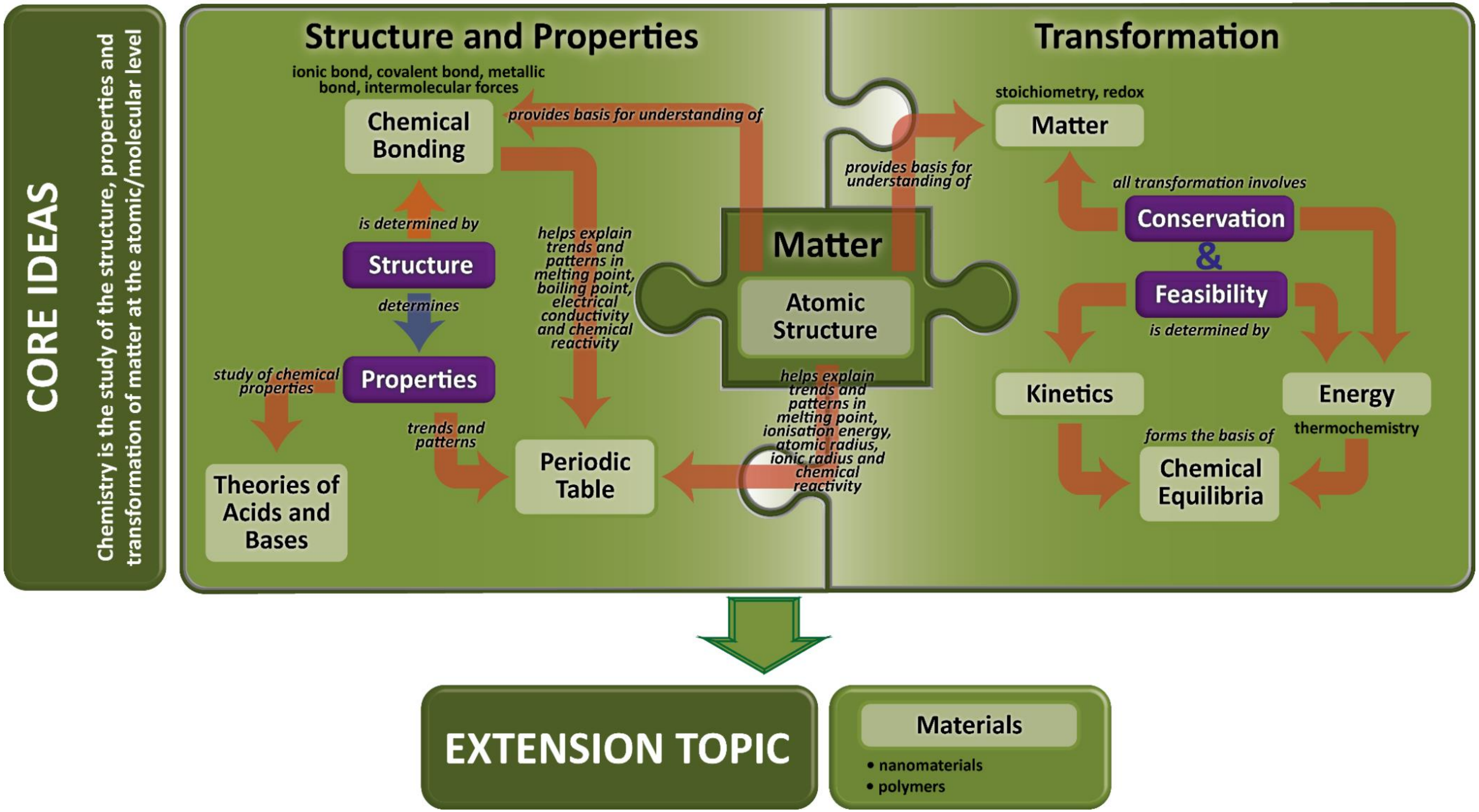
The topics in H1 Chemistry are organised as two levels underpinned by the Practices of Science:

- <u>Core Ideas</u>: The three Core Ideas of Chemistry are **Matter**, **Structure and Properties**, and **Transformation**. The 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.

- <u>Extension Topics</u>: Concepts in the Core Ideas are applied to real-world contexts in the study of nanomaterials and polymers.

2. CONTENT

2.1 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.

At A-Level, 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 visualise 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 (energetics and kinetics considerations) and extent of chemical reactions (concept of equilibrium). The energetics dimension builds upon prior knowledge of thermochemistry, mainly enthalpy changes (ΔH). 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) is understood via the equilibrium expression, which gives a measure of the extent of a reversible reaction. Factors which determine the position of equilibrium will also be examined. Chemical equilibria in aqueous media involving acids and bases will be dealt with in greater depth, in view of the relevance and prevalence of these concepts in real world contexts.

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

This curriculum framework 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 materials in the Extension Topic.

2.2 CORE IDEA 1: MATTER

1. ATOMIC STRUCTURE

The development of atomic theory has come a long way since John Dalton's work, and our understanding of the nature of matter and the structure of atoms has deepened with the work of scientists such as J. J. Thompson, Ernest Rutherford, Niels Bohr, Louis de Broglie, Erwin Schrödinger and Werner Heisenberg, just to name a few.

Today, the atom is still a basic unit of matter and the current quantum mechanical model of an atom features a dense central nucleus comprising protons and neutrons, surrounded by a cloud of electrons, and we also know that although the electron is a true fundamental particle, the proton and neutron are themselves made up of more elementary particles known as quarks.

In this section, the structure of an atom will be explored for a more in-depth understanding. This forms the basis for subsequent understanding of chemical bonds that give rise to the variety of chemical structures that exhibit a range of physical and chemical properties. In all processes involving the forming and breaking of chemical bonds, matter is conserved – atoms are neither created nor destroyed.

1. Atomic Structure

Guiding Questions
What makes up an atom? How has the understanding of atomic structure developed and evolved? What is the evidence showing that the electrons in an atom exist in discrete energy levels? What do you understand by electronic configuration? How are the electrons arranged in the atoms of a given element? How are the arrangement of an element's electrons and its position in the Periodic Table related?

Learning Outcomes

Students 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

(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

2.3 CORE IDEA 2: STRUCTURE AND PROPERTIES

2. CHEMICAL BONDING
3. THEORIES OF ACIDS AND BASES
4. THE PERIODIC TABLE

The concepts covered in this Core Idea will provide students with the opportunity to appreciate how the structure of atoms determines the type of bonding and interaction that can take place, and use these concepts to study and predict the patterns and trends in the chemical and physical properties of matter and its reactions.

The concept of the atomic structure provides the basis for the study of chemical bonding, which builds upon knowledge of how chemical bonds (e.g. ionic bonds, covalent bonds) are formed, and extends into an understanding of the electrostatic nature of chemical bonds. This helps in viewing the classification of chemical bonds on a continuum rather than as discrete descriptions, and augments the understanding of intermolecular forces of attraction. The study of the three-dimensional structures of elements and/or their compounds and the types of interactions present explains their chemical and physical properties.

The properties of aqueous and gaseous systems will be dealt with in this Core Idea. The chemical properties of acids and bases will be covered in greater depth with the introduction of Brønsted definition of acids and bases. The study of the property of real gases will focus on the importance of intermolecular forces leading to liquefaction.

The study of trends and patterns in the chemical and physical properties of elements in the Periodic Table is built upon prior knowledge of Period and Group trends acquired at the secondary science level. At the A-Level, trends in the physical and chemical properties of the elements and their compounds will be covered in greater depth.

2. Chemical Bonding

Guiding Questions

What holds particles together?

What are the different models that describe the forces that hold particles together?

How do these models explain the properties of matter?

How do we determine the shapes of molecules?

Learning Outcomes

Students 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 9.2)

(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

Learning Outcomes Students should be able to:
(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

Guiding Questions What are acids and bases? What models can be used to classify substances as acids or bases? What is a strong or weak acid/base? How can the strengths of acids and bases be represented and determined? What is the relationship between the concentration of acid, pH and strength of an acid? What are buffers? How do buffers work?
Learning Outcomes Students 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 their uses including the role of H_2CO_3/HCO_3^- in controlling pH in blood

4. The Periodic Table

Guiding Questions
What are the trends and variations in physical and chemical properties in elements and compounds?
How can the trends and variations in atomic, physical and chemical properties be explained?
How can we predict the properties of elements and their compounds?

Learning Outcomes
Students should be able to:

<u>Trends and variations in atomic and physical properties</u>
For elements in the third period (sodium to chlorine), and in Group 17 (chlorine to iodine):

(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 electronic 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

<u>Trends and variations in chemical properties</u>
For elements in the third period (sodium to chlorine):

(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 NaC*l*; $MgCl_2$; $AlCl_3$; $SiCl_4$; 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 NaC*l*; $MgCl_2$; $AlCl_3$; $SiCl_4$; PCl_5)

Learning Outcomes Students should be able to:
(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): (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, students 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

2.4 CORE IDEA 3: TRANSFORMATION

5. THE MOLE CONCEPT AND STOICHIOMETRY
6. CHEMICAL ENERGETICS: THERMOCHEMISTRY
7. REACTION KINETICS
8. CHEMICAL EQUILIBRIA

Transformation of matter involves a change in the chemical and/or physical properties of the substance. Chemical transformations involve the reorganisation or transfer of valence electrons among the reactants. In all transformations, matter and energy *must* be conserved. The conservation of matter is the basis of **stoichiometric** relationships in a balanced equation where atoms and charges are conserved. Not all transformations can be directly observed, though. While some changes can be observed at the macroscopic level (e.g. changes in colour, state, temperature, smell), others occur at the submicroscopic level without affecting the bulk properties of matter (e.g. processes in **dynamic equilibrium**). Also, not all transformation occurs within the timescale of observation; the rate of change (**kinetics**) needs to be considered. For example, the conversion of diamond to a more stable form, graphite, is so slow that it can never be observed within the life span of a human. Finally, the extent of the transformation will not be complete if the chemical or physical process is reversible. Changes in temperature, concentration or pressure, otherwise known as disturbances to the system, can affect the position of the **equilibrium** of the transformation.

Besides the characteristics of transformations, another fundamental question to ask is this: *Why do transformations take place at all?*

There are many examples in daily life in which changes occur and do not occur. The **structure and properties** of substances influence how they interact with each other and change, but do not guarantee that the change can take place. A deeper understanding involves **energy** as the key consideration for any transformation to take place.

5. The Mole Concept and Stoichiometry

Guiding Questions What is a mole? Why is it important in chemistry? What is the significance of a balanced equation? How can the amount of reactants and products in a chemical reaction be determined?
Learning Outcomes Students should be able to:
[the term relative formula mass or M_r will be used for ionic compounds] (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, students' 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

Guiding Questions

What are the energy changes in a chemical or physical process?
Why do some chemical or physical processes take place spontaneously?
How can we predict if a process is spontaneous?
How can we measure or find the energy change in a chemical or physical process?

Learning Outcomes

Students 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

Guiding Questions

What do we mean by rate of reaction? How can we measure it?
What are the factors affecting rate? Why?
How can we determine and express the relationship between rate and concentration mathematically? How are the other factors affecting rate featured in this equation?
What are the general types of catalysts? How are they similar and how do their modes of action differ?

Learning Outcomes

Students 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 (see also Section 9.1)

(i) describe enzymes as biological catalysts which may have specific activity

8. Chemical Equilibria

Guiding Questions

What are the characteristics of a system that has reached dynamic equilibrium? How can we describe such a system at equilibrium?
Why would systems tend towards a state of equilibrium?
What happens when a system at equilibrium is disturbed?
What are the factors to consider for optimal yield in a reversible reaction?

Learning Outcomes

Students 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

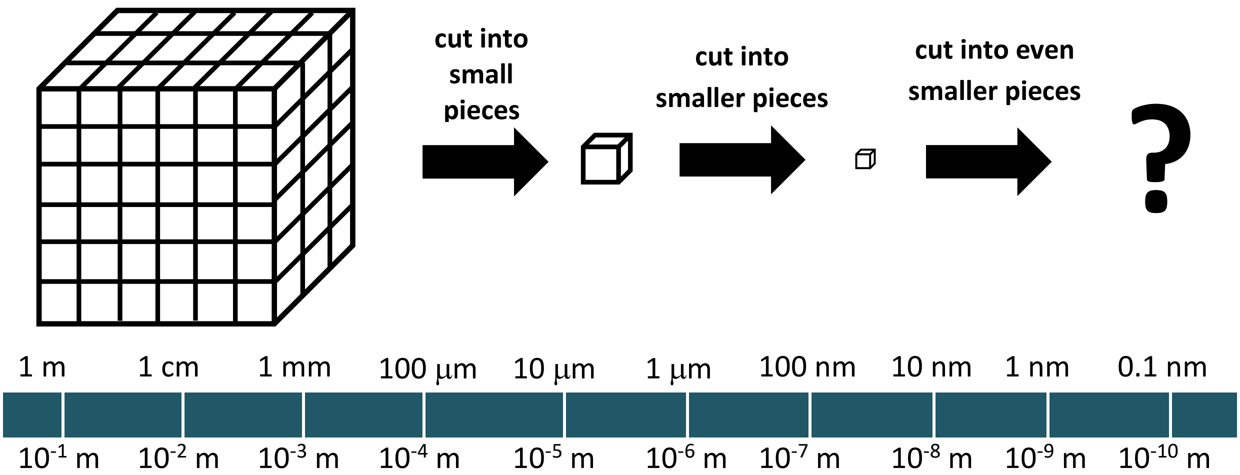
(f) calculate the quantities present at equilibrium, given appropriate data (such calculations will not require the solving of quadratic equations)

(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

2.5 EXTENSION TOPIC

9. MATERIALS

As described earlier, Chemistry is about the study of matter, its interactions and transformations. There is a limit to which matter can be cut into smaller pieces before it loses its properties and chemical identity. The ancient Greeks used the word *atoma* (meaning indivisible units) to describe this smallest unit of matter. "Indivisibility" became a central concept of modern atomic theory where the smallest unit of matter that retains its chemical identity is called an atom. All materials around us, be it natural or artificial, are made up of atoms. Atoms are very small, with a diameter about 0.1 nanometer (nm). In this extension topic, students will be able to apply some of the concepts in the core ideas to real-world materials starting from the nanoscale.



Much of the properties of a material depend on its composition, structure and bonding. In addition to that, the size of the material can also influence its properties; properties of a material at nanoscale (generally defined as having a length ≤ 100 nm) can be very different from its corresponding bulk material at a larger scale dimension. For example, gold, which is known to be yellow, appears wine-red when the gold particle clusters are 20 nm in diameter. Students will learn that a material with at least one dimension on the nanoscale is a *nanomaterial*, while a material with all 3 dimensions on the nanoscale is a *nanoparticle*[1]. A nanomaterial could be a collection of particles or even a molecule, so long as its size is within the nanoscale. C_{60} (carbon buckyball) is a molecule and is also a nanoparticle as its diameter is about 1 nm.

At H1 level, one contributing factor to the difference in the properties of nanomaterials compared to its bulk is its high surface area per unit volume, i.e. the proportion of atoms on the surface of the nanomaterial is large. As reactions and interactions occur on the surface of

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[1] The definition of nanoparticles and nanomaterials may differ slightly across various organizations as the definition depends on the specific application of the material.

materials, chemical reactions often proceed more quickly. This draws upon students' understanding of the factors affecting rate of reaction under the Core Idea – Transformation. The effects of forces of attraction could also be magnified, resulting in unexpected properties such as in the case of geckos, being able to overcome the force of gravity to climb across ceilings.

Polymers are macromolecules that may or may not be nanomaterials as their dimensions could extend beyond the nanoscale. The section on polymers extends the basic concepts of organic chemistry and polymerisation at O-Level. The study of organic chemistry at the A-Level is organised based on the chemistry of different **functional groups**. Functional groups are specific groups of atoms attached to a carbon backbone and they dictate the chemical and physical properties of molecules and draw the links between structure and bonding with the desired properties in everyday materials and the structural elucidation of unknown compounds.

There are many examples of nanomaterials and polymers in our natural world. Technology has also advanced to allow man to tap on the special properties at the nanoscale and polymers to create new materials to improve lives. While students learn about the chemistry and applications of scientific innovations, it is also important for them to consider the potential negative impacts and possible ways to mitigate them. Overall, this extension allows many opportunities to provide authentic contexts that link to the core ideas and to broaden the scope for discussion on issues related to Science and Society (see *Practices of Science*).

9.1 Nanomaterials

Guiding Questions What are nanomaterials? What are the effects of particle size on properties? How are the properties of nanomaterials related to its structure? What are the applications and potential implications from the use of nanoparticles?
Learning Outcomes Students should be able to:
(a) define the terms *nanomaterials* and *nanoparticles* (b) describe the large surface area to volume ratio of nanomaterials, explaining the effects on the following: (i) catalysis as exemplified by the use of platinum nanoparticles in catalytic converters (see also Section 7) (ii) interactions as exemplified by the wall climbing ability of geckos (c) describe the structure of graphene, a nanomaterial, and relate the following properties to its structure: (i) electrical conductivity (ii) tensile strength (d) recognise the potential effect of nanoparticles on human health and the environment

9.2 Polymers

Guiding Questions

What are the main classes of organic compounds?

What are some terms commonly used in the description of organic reactions and reactivities?

What is isomerism? What are the different types of isomerism?

What type of reactions do alkanes, alkenes, halogenoalkanes, aldehydes, ketones, alcohols, carboxylic acids, esters, amines and amides undergo?

What are polymers?

How are polymers formed and what are their uses?

How are the uses/properties of polymers related to their structure and bonding?

Learning Outcomes

Students 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

(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

Learning Outcomes Students should be able to:

(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
- (ii) alkenes (exemplified by ethene) in terms of combustion and addition reactions with bromine (in CCl_4) and hydrogen
- (iii) halogenoalkanes (exemplified by bromoethane) in terms of substitution reaction to alcohols and elimination reactions to alkenes
- (iv) aldehydes (exemplified by ethanal) and ketones (exemplified by propanone) in terms of their reduction to primary and secondary alcohols respectively; and oxidation of aldehydes to carboxylic acids
- (v) alcohols (exemplified by ethanol) in terms of combustion, oxidation to carboxylic acids and elimination to alkenes
- (vi) carboxylic acids (exemplified by ethanoic acid) in terms of condensation with alcohols to form esters (in the presence of concentrated sulfuric acid), 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 acids and bases

[detailed conditions involving specific temperature and pressure values are **not** required]

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

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

(j) 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

Learning Outcomes
Students should be able to:

(k) 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

(l) predict physical properties of polymer from its structure

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

Students 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.

When describing preparative reactions, students 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, students 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.

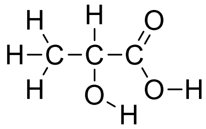
Students are expected to be able to interpret and use the following types of representations in the description of organic molecules. The examples given are for the compound lactic acid.

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

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

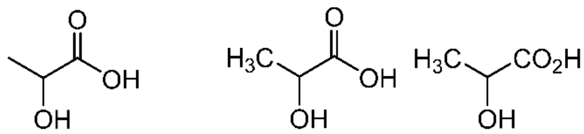
Structural Formula : shows how the constituent atoms of a molecule are joined together with minimal detail, using conventional groups, for an unambiguous structure, e.g. $CH_3CH(OH)CO_2H$

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

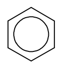
e.g. 

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 students' answers where they are unambiguous,

e.g. 

skeletal *partial skeletal*

The convention  for representing the aromatic ring is preferred.

3. PEDAGOGY

The starting point for the science curriculum is that every child wants to and can learn. The science curriculum nurtures students as inquirers and taps on their innate curiosity and desire to seek answers to questions or solve problems relating to science. Besides developing a strong conceptual understanding of scientific models and theories, students' curiosity is stimulated and they are encouraged to see the value of science and its applications and connection to their everyday lives.

3.1 DEVELOPING CONCEPTUAL UNDERSTANDING

Conceptual understanding is more than factual knowledge which is more commonly associated with the memorising of facts and definitions. Conceptual understanding is built by using facts as tools to discern patterns, connections, and deeper, transferable understanding. One approach to develop students' conceptual understanding is through conceptual change that occurs when they are dissatisfied with a prior conception and the available replacement conception is logical, reasonable and/or meaningful.

3.2 ENGAGING IN THE PRACTICES OF SCIENCE

Science is not just a body of knowledge but also a way of knowing and doing. The 'ways of thinking and doing' refer to a discipline's distinctive mode of inquiry and approach to working with the observations and knowledge about the world. Through the Practices of Science, students should appreciate the following:

- **Nature of scientific knowledge:** Students understand the nature of scientific knowledge implicitly through the process of 'doing science'. To complement this, an explicit approach may be used. This approach utilises elements from the history of science or the processes in science to improve students' views of the nature of scientific knowledge.

- **Science as an inquiry:** Scientific inquiry refers to the different approaches by which scientists study and develop an understanding of the natural and physical world around us. Inquiry-based instruction could be used to develop the different aspects of the Practices of Science together with the understanding of science concepts as well as the dispositions and attitudes associated with science. Inquiry-based strategies could include questioning, demonstrations, use of technology, as well as models and modelling.

- **Relating science and society:** Students should appreciate how science and technology are used in daily life. They should apply and experience the potential of science to generate creative solutions to solve a wide range of real-world problems, ranging from those affecting everyday lives to complex problems affecting humanity, while appreciating the values and ethical implications of these applications. Science education needs to equip students with the ability to articulate their ethical stance as they participate in discussions about socio-scientific issues that involve ethical dilemmas, with no single right answers.

3.3 PRACTICAL WORK

Science practical work supports the teaching and learning of science through developing the Practices of Science, experimental techniques, practical manipulative skills and conceptual understanding. It also cultivates interest in science and in learning science. In addition, attitudes like objectivity and integrity, which are important in the learning of the discipline of science, are reinforced.

3.4 THE SINGAPORE STUDENT LEARNING SPACE (SLS)

The Singapore Student Learning Space (SLS) is an online platform that supports teaching and learning, it

- **enables our students to learn anytime, anywhere**
  As SLS is available to all students and teachers in every school it can be a key lever to bring about more pervasive and seamless integration of technology in teaching and learning at schools. Students can access SLS through different devices and learn at their own pace.

- **allows our students to take greater ownership of their learning and work collaboratively**
  Students can do self-directed learning by accessing the resources in SLS on their own or complete learning packages assigned by teachers. Quizzes are auto-graded to give immediate feedback to students. These resources complement other teaching and learning resources such as lecture notes, tutorials, physical manipulatives, etc. There are learning tools available on SLS that enable students to curate and organise information, connect with peers and to create works to demonstrate their learning.

- **complements classroom teaching**
  Teachers can use the MOE curriculum-aligned resources in the SLS, curate own resources from the world-wide-web or develop own resources to complement their teaching. In addition, teachers are supported by visualisation tools in SLS to easily monitor students' learning progress and check for understanding.

- **is collectively shaped by schools and owned by all**
  As SLS is accessible by teachers across all Singapore schools, it provides a unique opportunity for teachers to work collectively to co-develop, adapt and share lessons. Teachers can make use of the co-editing and sharing capabilities in SLS to curate and share lesson designs.

Students can access the SLS through *https://vle.learning.moe.edu.sg/login*.

4. ASSESSMENT

Assessment is the process of gathering and analysing evidence about student learning. This information is used to make decisions about students, curricula and programmes. Assessment for Learning (AfL) is assessment conducted constantly during classroom instruction to support teaching and learning. With the feedback about the state of students' learning, teachers then adapt their teaching strategies and pace based on the students' needs. Assessment of Learning (AoL) aims to summarise how much or how well students have achieved at the end of a course of study over an extended period of time. The A-level examination is an example of AoL.

4.1 A-Level Examination

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.

4.2 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, name, describe, explain or outline*.

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.*

4.3 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 and Free Response 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:

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**	40	Papers 1, 2
B	**Handling, applying and evaluating information**	60	Papers 1, 2

For more information on assessment, please refer to the Singapore Examinations and Assessment Board http://www.seab.gov.sg/.

4.4 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, $\equiv$, $\bar{x}$ (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.

4.5 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.

4.6 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	mol^{-1}
base dissociation constant	K_b	mol dm^{-3}
bond energy	–	kJ mol^{-1}
charge on the electron	e	C
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}
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
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	–
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	–
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}
standard entropy change of reaction	$\Delta S^{\ominus}$	J K^{-1} mol^{-1}, kJ K^{-1} 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

4.7 ADDITIONAL INFORMATION

Data Booklet

A Data Booklet is available 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.

5. RESOURCES AND REFERENCES

Students may find the following references 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 CD-ROM (2nd Edition) by Lawrie Ryan and Roger Norris, published by Cambridge University Press

A Level Chemistry (4th Edition) by E. N. Ramsden, published by Oxford University Press

Understanding Chemistry for Advanced Level (3rd Edition), by Ted Lister and Janet Renshaw, published by Oxford University Press

AS and A Level Chemistry through Diagrams by Michael Lewis, published by Oxford University Press

Chemistry in Context (6th Edition) by Graham Hill and John Holman, published by Oxford University Press

Chemistry in Context Laboratory Manual and Study Guide (5th 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

Chemical Ideas (Salters Advanced Chemistry) by Adelene Cogill, et al., published by Pearson Education Limited

Science at the nanoscale: An introductory textbook by Chin Wee Shong, Sow Chong Haur and Andrew T. S. Wee, published by Pan Stanford Publishing

The Language of Mathematics in Science: A Guide for Teachers of 11–16 Science (2016) by R Boohan, published by the Association for Science Education. ISBN 9780863574559.

https://www.ase.org.uk/mathsinscience