CHEMISTRY SYLLABUS

Pre-University

Higher 2

Syllabus 9729

Implementation starting with
2016 Pre-University One Cohort

Ministry of Education
SINGAPORE

CONTENTS

1. INTRODUCTION

1.1 BACKGROUND

Design of the A-Level science curriculum

The Higher 2 (H2) science subjects are the central pieces of the science curriculum at the A-Level, and were reviewed with the intention to shape how science is taught and learnt at the pre-university level. The curriculum aims to lay a strong foundation of knowledge, skills and attitudes in order to prepare our students well for university, work and life in the future.

The curriculum design took into consideration MOE's key initiatives of Student-Centric, Values-Driven Education (SVE), the development of 21st Century Competencies (21CC) in our students, changes to other equivalent qualifications, feedback and observations from local universities, findings from science education research and feedback from schools and teachers.

Purpose of H2 science curriculum

A strong background in science prepares students to take on careers in science and engineering-related sectors as well as opens up in-roads to many opportunities even in fields not traditionally associated with the hard sciences. Beyond career considerations, science education should also contribute to the development of a scientifically literate citizenry. Therefore, the purpose of the H2 science curriculum should encompass the following aims:

- For all students: As future citizens in an increasingly technologically-driven world and as future leaders of the country, they should be equipped to make informed decisions based on sound scientific knowledge and principles about current and emerging issues which are important to one's self, society and the world at large (for example, in appreciating the energy constraints faced by Singapore, or understanding the mechanisms involved in epidemics);

- For students who intend to pursue science further: As practitioners and innovators, the learner of science should possess a deeper grasp of scientific knowledge and be well-versed in scientific practices, at the level of rigour befitting the A-Level certification.

Key changes to H2 science curriculum

- **Use of core ideas to frame the teaching and learning of science**
  Core ideas represent the enduring understanding that emerges from learning each science subject. These ideas cut across traditional content boundaries, providing a broader way of thinking about phenomena in the natural world. This is to shift the students' learning mentality from a compartmentalised view of scientific knowledge to a more coherent and integrated understanding of science. The use of core ideas in science

to frame the curriculum can help to build deep conceptual understanding in students so that they can better apply these concepts to solve problems in novel situations and contexts.

- **Understand that science as a discipline is more than the acquisition of a body of knowledge**
  The Practices of Science emphasises that science as a discipline is more than the acquisition of a body of knowledge (e.g. scientific facts, concepts, laws, and theories); it is also a way of knowing and doing. The Practices of Science includes an understanding of the nature of scientific knowledge and how such knowledge is generated, established and communicated. Please refer to Section 1.4 for more details.

- **Use of a range of appropriate real-world contexts in the teaching and learning of H2 science**
  Research[1] shows that students find the teaching and learning of science more meaningful and interesting when set in appropriate contexts. The use of real-world contexts also provide authentic platforms to bring out classroom discourse and deliberations on the social, economic, moral and ethical dimensions of science based on sound scientific explanations.

- **Strengthen the teaching of science through the use of a wider range of pedagogies**
  The use of inquiry-based pedagogical approaches, which include the skilful use of Information and Communication Technology (ICT), will engage students in critical thinking, reasoning and argument. In addition, through practical and hands-on activities, students will learn and assimilate key concepts and skills better. Students enjoy practical work and regard it as a constructive learning activity. Science education should also aim to develop students as independent and self-directed learners with the habit of inquiry and constant pursuit of knowledge.

---

[1] Bennett, J., Lubben, F. & Hogarth, S. (2007). Bringing science to life: A synthesis of the research evidence on the effects of context-based and STS approaches to science teaching. *Sci. Ed.*, 91(3), 347–370.

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.

H2 Chemistry aims to develop students' understanding of the chemical concepts and how these concepts are related within chemistry and to other science disciplines. A key feature in the study of H2 Chemistry is the development of students' ability to navigate between the macroscopic phenomena, submicroscopic interactions and symbolic representations to attain a deep conceptual understanding of the behaviours of chemical systems. It will enable students to extend this way of viewing and thinking about the behaviours of chemical systems to physical and biological phenomena, which are present in many aspects of daily life, e.g. environmental pollution and food science.

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 further studies in related fields

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

3. develop in students the understanding, skills, ethics and attitudes relevant to the Practices of Science, including the following:
    - understanding the nature of scientific knowledge
    - demonstrating science inquiry skills
    - relating science and society

4. 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 sub-microscopic, 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[2] 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.

---

[2] 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 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.

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.

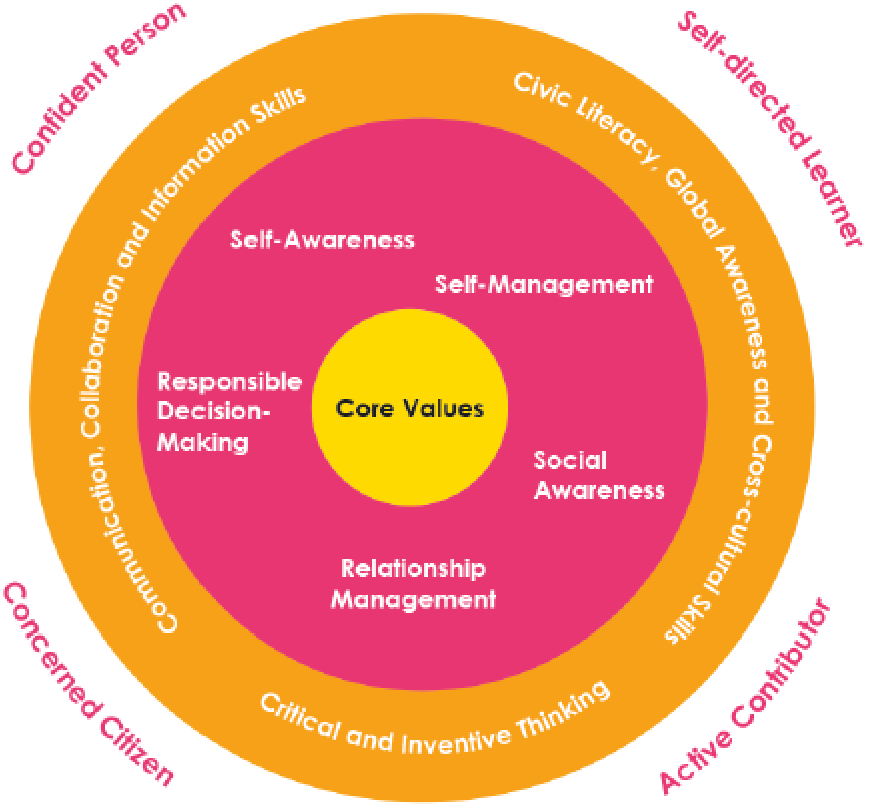


Figure 1.1: Framework for 21st Century Competencies and Student Outcomes

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 H2 CHEMISTRY CURRICULUM FRAMEWORK

The key features of the H2 Chemistry Curriculum comprise Core Ideas and Extension Topics, Practices of Science and Learning Experiences, as illustrated in Figure 1.2.

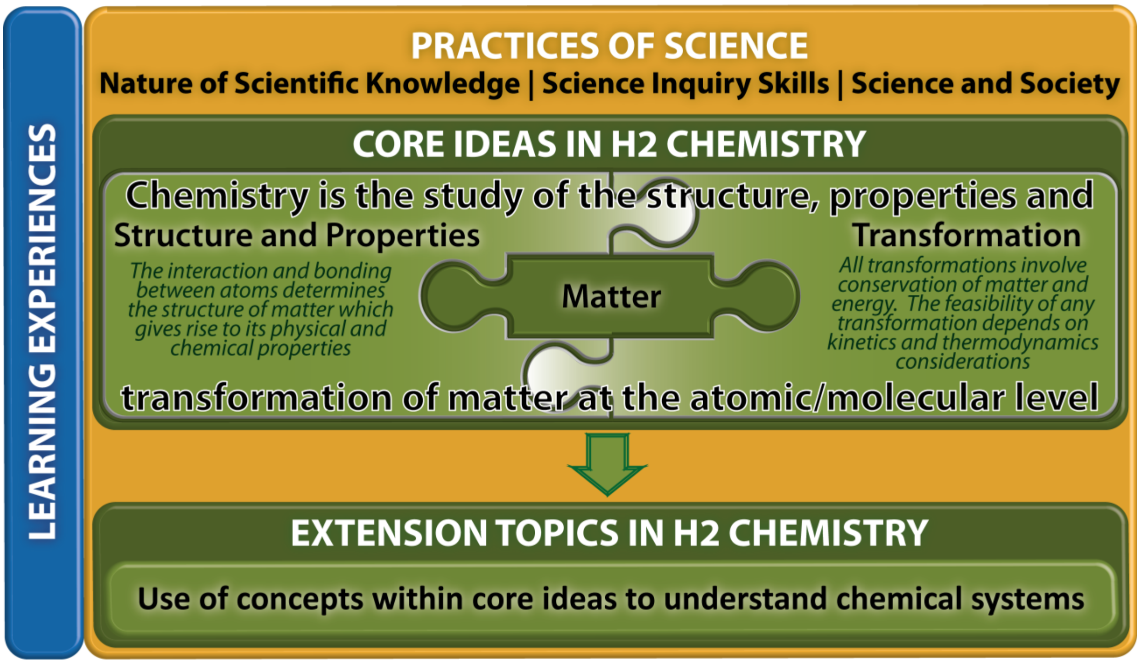


Figure 1.2: H2 Chemistry Curriculum Framework

Core Ideas and Extension Topics

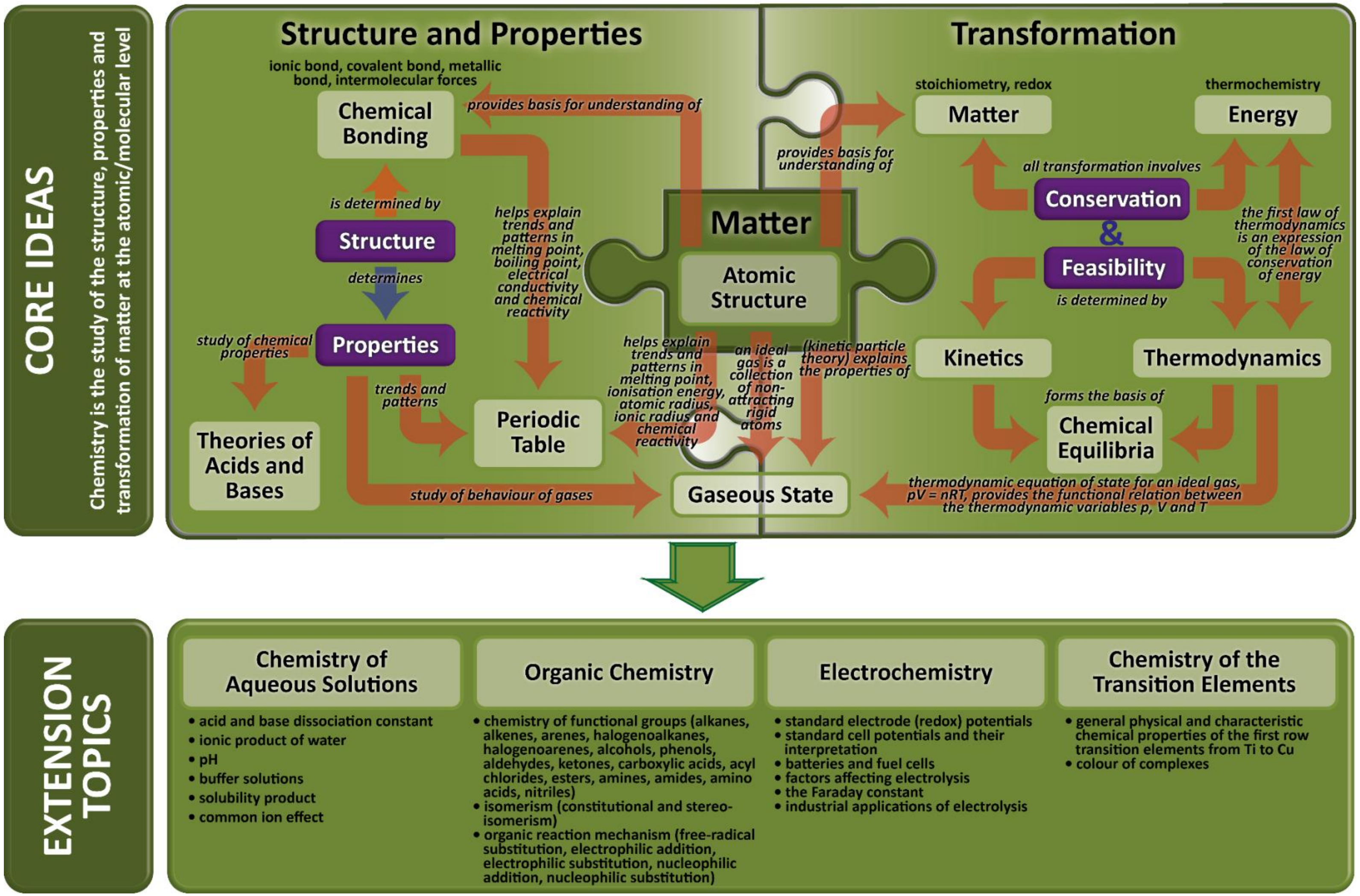
The topics in H2 Chemistry are organised into two levels underpinned by the Practices of Science:

- Core Ideas: 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.

- Extension Topics: Concepts in the Core Ideas extend into the learning of different chemical systems such as the chemistry of organic compounds and transition elements. As an example, an understanding of the concepts of Chemical Bonding and The Periodic Table is extended to the study of the chemistry of transition metals where students learn to appreciate the similarities and differences when comparing with main group metals.

2. CONTENT

2.1 H2 CHEMISTRY CONTENT MAP



CORE IDEAS

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

Structure and Properties

ionic bond, covalent bond, metallic bond, intermolecular forces

Chemical Bonding

provides basis for understanding of

is determined by

Structure

determines

Properties

helps explain trends and patterns in melting point, boiling point, electrical conductivity and chemical reactivity

study of chemical properties

Theories of Acids and Bases

trends and patterns

Periodic Table

study of behaviour of gases

Matter

Atomic Structure

helps explain trends and patterns in melting point, ionisation energy, atomic radius, ionic radius and chemical reactivity

an ideal gas is a collection of non-attracting rigid atoms

(kinetic particle theory) explains the properties of

Gaseous State

Transformation

provides basis for understanding of

stoichiometry, redox

Matter

thermochemistry

Energy

all transformation involves

Conservation

&

Feasibility

is determined by

the first law of thermodynamics is an expression of the law of conservation of energy

Kinetics

Thermodynamics

forms the basis of

Chemical Equilibria

thermodynamic equation of state for an ideal gas, $pV = nRT$, provides the functional relation between the thermodynamic variables p, V and T

EXTENSION TOPICS

Chemistry of Aqueous Solutions

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

Organic Chemistry

- chemistry of functional groups (alkanes, alkenes, arenes, halogenoalkanes, halogenoarenes, alcohols, phenols, aldehydes, ketones, carboxylic acids, acyl chlorides, esters, amines, amides, amino acids, nitriles)
- isomerism (constitutional and stereo-isomerism)
- organic reaction mechanism (free-radical substitution, electrophilic addition, electrophilic substitution, nucleophilic addition, nucleophilic substitution)

Electrochemistry

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

Chemistry of the Transition Elements

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

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. Modern organic chemistry is based on the concept that the four valence bonds of a carbon atom are oriented in a tetrahedral configuration, which led to the development of the stereochemical concept. This has important applications, particularly in the pharmaceutical industry as many drugs are active only in one particular enantiomeric form.

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

The concepts in chemical thermodynamics and kinetics will form the basis for the study of Chemical Equilibrium. Theoretically all reactions are reversible, and the notion of dynamic equilibrium will be introduced. The concept of equilibrium constant (K) 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 which cuts across chemical systems.

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 different chemical systems in the Extension Topics.

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

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

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

Learning Outcomes Students should be able to:
(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. THE GASEOUS STATE
4. THEORIES OF ACIDS AND BASES
5. 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 and Lewis's definitions of acids and bases. The study of the properties and behaviours of both ideal and real gases will focus on the use of the ideal gas equation to understand the relationship between the different variables (pressure, volume, amount and temperature).

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 11.1)

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

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

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

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

Learning Outcomes
Students should be able to:

(h) describe the following forces of attraction (electrostatic in nature):
  (i) intermolecular forces, based on permanent and induced dipoles, as in $CHCl_3(l)$; $Br_2(l)$ and the liquid noble gases
  (ii) hydrogen bonding, using ammonia and water as examples of molecules containing –NH and –OH groups

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

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

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

(l) describe, in simple terms, the lattice structure of a crystalline solid which is:
  (i) ionic, as in sodium chloride and magnesium oxide
  (ii) simple molecular, as in iodine
  (iii) giant molecular, as in graphite and diamond
  (iv) hydrogen-bonded, as in ice
  (v) metallic, as in copper
  [the concept of the 'unit cell' is **not** required]

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

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

3. The Gaseous State

Guiding Questions

What is an ideal gas?

What conditions are needed for a gas to behave ideally?

What is the relationship between the pressure, volume, temperature and amount of a gas?

How do the individual components of a gas mixture contribute to the pressure of the mixture?

Learning Outcomes

Students should be able to:

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

(b) explain qualitatively in terms of intermolecular forces and molecular size:
  (i) the conditions necessary for a gas to approach ideal behaviour
  (ii) the limitations of ideality at very high pressures and very low temperatures

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

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

4. Theories of Acids and Bases

Guiding Questions

What are acids and bases?

What models can be used to classify substances as acids or bases?

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

5. The Periodic Table

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:

Trends and variations in atomic and physical properties

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

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

(b) describe and explain qualitatively the 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 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):

(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)

Learning Outcomes

Students should be able to:

- (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

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

- (i) Group 2 as reducing agents
- (ii) Group 17 as oxidising agents

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

- (i) Group 2 carbonates in terms of the charge density of the cation and the polarisability of the large anion
- (ii) Group 17 hydrides in terms of bond energies

In addition, 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

6. THE MOLE CONCEPT AND STOICHIOMETRY
7. CHEMICAL ENERGETICS: THERMOCHEMISTRY AND THERMODYNAMICS (GIBBS FREE ENERGY AND ENTROPY)
8. REACTION KINETICS
9. 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 – energy (and/or matter) tends to be dispersed during a chemical or physical change. At the A-Level, the feasibility of a transformation can be understood in terms of the Gibbs free energy, which should be minimised for the transformation to be feasible.

6. 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*, based on the ^{12}C scale

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

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

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

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

(f) write and/or construct balanced equations

(g) perform calculations, including use of the mole concept, involving:
  (i) reacting masses (from formulae and equations)
  (ii) volumes of gases (e.g. in the burning of hydrocarbons)
  (iii) volumes and concentrations of solutions
  [when performing calculations, students’ answers should reflect the number of significant figures given or asked for in the question]

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

7. Chemical Energetics: Thermochemistry and Thermodynamics (Gibbs Free Energy and Entropy)

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 8)

(c) explain and use the terms:
  (i) *enthalpy change of reaction* and *standard conditions*, with particular reference to: formation; combustion; hydration; solution; neutralisation; atomisation
  (ii) *bond energy* (ΔH positive, i.e. bond breaking) (see also Section 2)
  (iii) *lattice energy* (ΔH negative, i.e. gaseous ions to solid lattice)

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

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

(f) apply Hess' Law to construct simple energy cycles, e.g. Born-Haber cycle, and carry out calculations involving such cycles and relevant energy terms (including ionisation energy and electron affinity), with particular reference to:
  (i) determining enthalpy changes that cannot be found by direct experiment, e.g. an enthalpy change of formation from enthalpy changes of combustion
  (ii) the formation of a simple ionic solid and of its aqueous solution
  (iii) average bond energies

(g) explain and use the term *entropy*

Learning Outcomes

Students should be able to:

(h) discuss the effects on the entropy of a chemical system by the following:
  (i) change in temperature
  (ii) change in phase
  (iii) change in the number of particles (especially for gaseous systems)
  (iv) mixing of particles
  [quantitative treatment is **not** required]

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

(j) state and use the equation involving *standard Gibbs free energy change of reaction,* $\Delta G^\ominus$:

$$\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus$$

[the calculation of standard entropy change, $\Delta S^\ominus$, for a reaction using standard entropies, $S^\ominus$, is **not** required]

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

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

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

8. Reaction Kinetics

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 can we infer about the mechanism of a reaction from the order of reaction? Why do many reactions not occur in a single step?
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*; *rate-determining step*; *activation energy*; *catalysis*

(b) construct and use rate equations of the form rate = $k[A]^m[B]^n$ (limited to simple cases of single-step reactions and of multi-step processes with a rate-determining step, for which *m* and *n* are 0, 1 or 2), including:
   (i) deducing the order of a reaction by the initial rates method
   (ii) justifying, for zero- and first-order reactions, the order of reaction from concentration-time graphs
   (iii) verifying that a suggested reaction mechanism is consistent with the observed kinetics
   (iv) predicting the order that would result from a given reaction mechanism
   (v) calculating an initial rate using concentration data
   [integrated forms of rate equations are **not** required]

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

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

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

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

Learning Outcomes
Students should be able to:

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

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

(i)
  (i) explain that, in the presence of a catalyst, a reaction has a different mechanism, i.e. one of lower activation energy, giving a larger rate constant
  (ii) interpret this catalytic effect on a rate constant in terms of the Boltzmann distribution

(j) outline the different modes of action of homogeneous and heterogeneous catalysis, including:
  (i) the Haber process
  (ii) the catalytic removal of oxides of nitrogen in the exhaust gases from car engines (see also Section 11.3)
  (iii) the catalytic role of atmospheric oxides of nitrogen in the oxidation of atmospheric sulfur dioxide
  (iv) catalytic role of Fe^{2+} in the $I^-/S_2O_8^{2-}$ reaction

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

(l) explain the relationship between substrate concentration and the rate of an enzyme-catalysed reaction in biochemical systems

9. 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, and partial pressures, K_p
[treatment of the relationship between K_p and K_c is **not** required]

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

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

(g) show understanding that the position of equilibrium is dependent on the standard Gibbs free energy change of reaction, $\Delta G^{\ominus}$.
[Quantitative treatment is **not** required]

(h) 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 TOPICS

10. CHEMISTRY OF AQUEOUS SOLUTIONS
11. ORGANIC CHEMISTRY
12. ELECTROCHEMISTRY
13. AN INTRODUCTION TO THE CHEMISTRY OF TRANSITION ELEMENTS

Concepts in the Core Ideas will extend into the learning of different chemical systems such as the chemistry of organic compounds and transition elements.

Since water is the most common solvent on Earth, there are many chemical reactions in the natural world that occur in aqueous solutions. Hence, it is important to explore aqueous chemical reactions in the topic of Solution Chemistry. Some of the more important aqueous chemical reactions are acid-base, precipitation and complexation. This topic builds on students' understanding of the Theories of Acids and Bases (Core Idea 2: Structure and Properties), which is largely qualitative in nature, to a more quantitative approach to the understanding of acid-base Equilibria (Core Idea 3: Transformation). Precipitation reactions require both quantitative and qualitative understanding of dissolution and precipitation of sparingly soluble solids and the factors affecting these reactions (Core Idea 3: Transformation).

Electrochemistry involves the study of redox reactions, where electrode potential (E) and the resultant cell potential (E_{cell}) are used as measures of thermodynamic feasibility (Core Idea 3: Transformation). These redox reactions involve transfer of electrons, which would require understanding of concepts in Atomic Structure (Core Idea 1: Matter). In all these reactions, matter and energy are conserved (Core Idea 3: Transformation). Not all redox reactions are thermodynamically feasible; in electrolytic systems, energy needs to be provided to drive the redox reactions (Core Idea 3: Transformation).

Organic chemistry is the study of the structure, properties, composition, reactions and preparation of carbon-containing compounds. Carbon, with an electronic configuration of $1s^2\ 2s^2\ 2p^2$, has four valence electrons (Core Idea 1: Matter) and is able to form single, double and triple bonds with a variety of other atoms. Carbon is also unique among the elements in its unsurpassable ability to self-link into chains or rings of almost infinite size, giving rise to the millions of organic compounds known. One way of classifying and understanding the vast number of organic compounds is through the notion of functional groups. The characteristic reaction of each organic functional group can be understood in terms of the nature of the reacting species and the type of reaction involved, which are related to the organic structure and bonding (Core Idea 2: Structure and Properties). Most reactions in organic chemistry are polar in nature, involving the flow of pair(s) of electrons from a nucleophilic/Lewis basic (electron-rich) site to an electrophilic/Lewis acidic (electron-poor) site. Concepts in Reaction Kinetics and Chemical Energetics provide the basis for understanding organic reaction mechanisms (Core Idea 3: Transformation).

An understanding of the concepts in Atomic Structure (Core Idea 1: Matter), Chemical Bonding and The Periodic Table (Core Idea 2: Structure and Properties) and Reaction Kinetics and Chemical Equilibrium (Core Idea 3: Transformation) is extended to the study of the Chemistry of Transition Elements. In this topic, students will learn about the chemical and physical properties of the first-row transition elements and compare them with the main group metals.

10. Chemistry of Aqueous Solutions

10.1 Acid-Base Equilibria

This topic deals with acid-base equilibria in aqueous solution. Hence, the Brønsted–Lowry definitions of acid/base are primarily used in the understanding of the pH of solutions (See Section 4: Theories of Acids and Bases).

Guiding Questions

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 (base), pH (pOH) and strength of an acid (base)?

What are buffers? How do buffers work? How can the pH of buffers be determined?

What are the changes in pH during acid-base titrations? How can these pH changes be explained?

Learning Outcomes

Students should be able to:

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

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

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

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

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

(f) (i) explain how buffer solutions control pH
    (ii) describe and explain their uses, including the role of H_2CO_3/HCO_3^- in controlling pH in blood

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

10.2 Solubility Equilibria

Guiding Questions

What is a saturated solution?

What is solubility and solubility product? How are they related?

When and why does precipitation take place?

Learning Outcomes

Students should be able to:

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

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

(c) discuss the effects on the solubility of ionic salts by the following:
   (i) common ion effect
   (ii) formation of complex ion, as exemplified by the reactions of halide ions with aqueous silver ions followed by aqueous ammonia (see also Section 13)

11. Organic Chemistry

Organic chemistry is the study of the structure, properties, composition, reactions and preparation of carbon-containing compounds, which include not only hydrocarbons but also compounds with any number of other elements, such as hydrogen (most compounds contain at least one carbon–hydrogen bond), nitrogen, oxygen, halogens, phosphorus, silicon and sulfur.[3] It is one of the major branches of chemistry.

Carbon, with an electronic configuration of $1s^2\ 2s^2\ 2p^2$, has four valence electrons (Core Idea 1: Matter) and is able to form single, double and triple bonds with a variety of other atoms. Carbon is also unique among the elements in its unsurpassable ability to self-link into chains or rings of almost infinite size, giving rise to the millions of organic compounds known.

The study of organic chemistry at the A-Level, as shown in the Organic Chemistry Map on the following page, 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. These are also the sites of reactivity in organic compounds.

For each of the functional group, besides looking at the characteristic physical properties of the homologous series, synthetic methods to install the functional group in molecules will be examined. Characteristic reactions of the different functional groups will also be explored.

Despite going by a functional group approach, ultimately the characteristic reaction of each functional group can be understood in terms of the nature of the reacting species and the type of reaction involved, which are related to the **organic structure and bonding** (Core Idea 2: Structure and Properties), as can be seen in the Organic Chemistry Map. Mechanistically, most reactions in organic chemistry are **polar** in nature (with the exception of those involving free radicals), entailing the flow of pair(s) of electrons from a *nucleophilic*/Lewis basic (electron-rich) site to an *electrophilic*/Lewis acidic (electron-poor) site.

Specifically, the mechanisms of five of the general types of reactions will be discussed in detail, namely free-radical substitution (exemplified by alkanes), electrophilic addition (exemplified by alkenes), electrophilic aromatic substitution (exemplified by arenes), nucleophilic substitution (exemplified by halogenoalkanes) and nucleophilic addition (exemplified by carbonyl compounds), which can be understood on the basis of both kinetic and energetic considerations (Core Idea 3: Transformation).

The reaction of one functional group lends itself to the construction of another functional group, and vice versa. The recognition of such functional group interconversion (FGI) is invaluable to the study of organic chemistry. At the A-Level, most reactions involve the simple conversion of one functional group to another, which can usually be performed in

---

[3] American Chemical Society (2015). *Organic chemistry*. Retrieved from http://www.acs.org/content/acs/en/careers/college-to-career/areas-of-chemistry/organic-chemistry.html

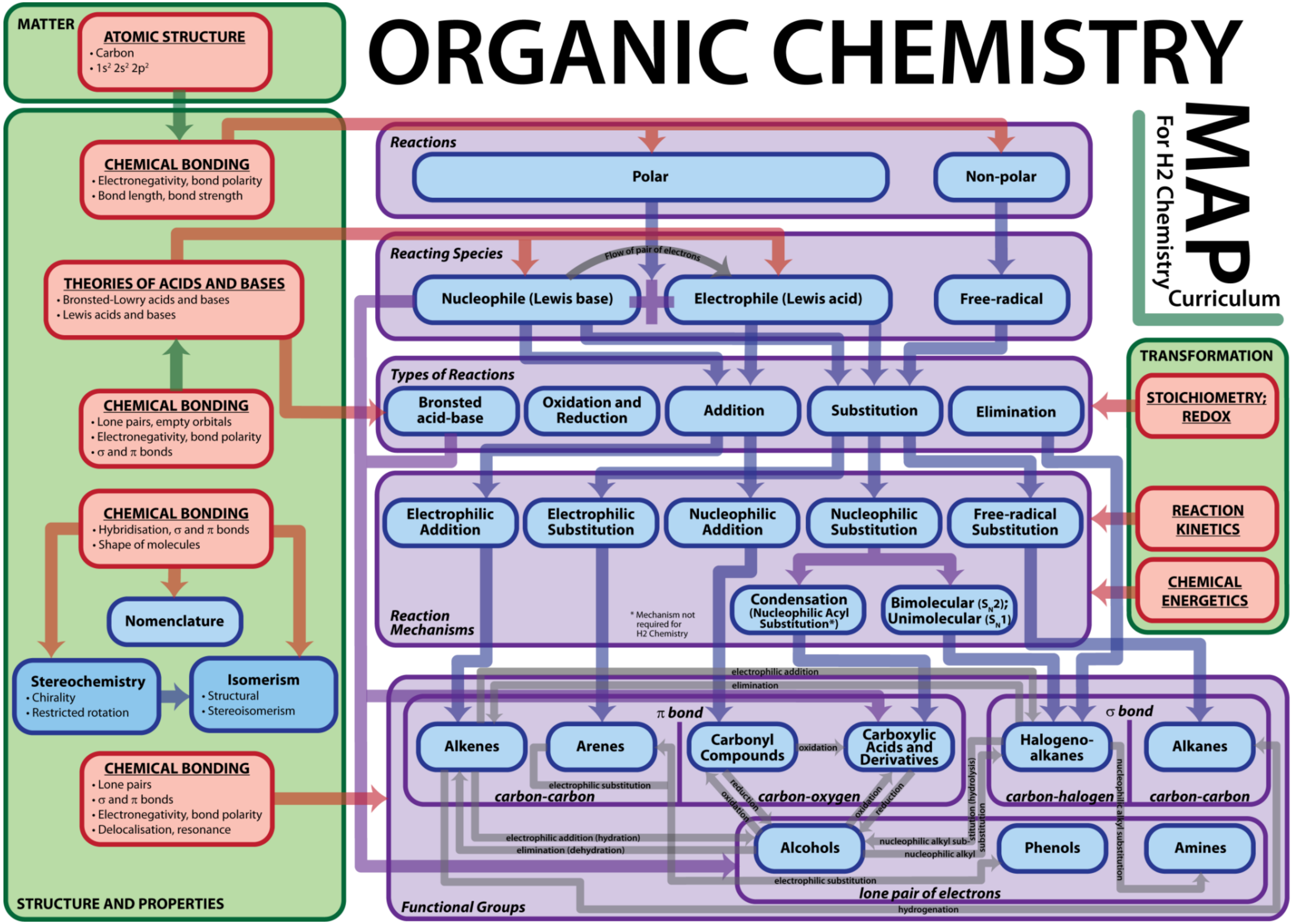
either direction readily. For instance, secondary alcohols can be oxidised to give ketones, which can in turn be reduced back to secondary alcohols.

It should be noted that many of these reactions do not involve the formation or cleavage of carbon-carbon covalent bonds. Reactions that result in changes to the carbon backbone are important in organic synthesis as they lend themselves to the construction of varied carbon skeletons. Examples of such reactions are the oxidative cleavage of the carbon-carbon double bond, iodoform reaction and addition of HCN to carbonyl compounds.

Good knowledge and understanding of the reactions of functional groups can be applied to the synthesis of desired molecular architectures and the structural elucidation of unknown compounds.

ORGANIC CHEMISTRY MAP

For H2 Chemistry Curriculum



MATTER

ATOMIC STRUCTURE
- Carbon
- $1s^2\ 2s^2\ 2p^2$

STRUCTURE AND PROPERTIES

CHEMICAL BONDING
- Electronegativity, bond polarity
- Bond length, bond strength

THEORIES OF ACIDS AND BASES
- Bronsted-Lowry acids and bases
- Lewis acids and bases

CHEMICAL BONDING
- Lone pairs, empty orbitals
- Electronegativity, bond polarity
- σ and π bonds

CHEMICAL BONDING
- Hybridisation, σ and π bonds
- Shape of molecules

Nomenclature

Stereochemistry
- Chirality
- Restricted rotation

Isomerism
- Structural
- Stereoisomerism

CHEMICAL BONDING
- Lone pairs
- σ and π bonds
- Electronegativity, bond polarity
- Delocalisation, resonance

Reactions

Polar · **Non-polar**

Reacting Species

Nucleophile (Lewis base) · **Electrophile (Lewis acid)** · **Free-radical**

Types of Reactions

Bronsted acid-base · **Oxidation and Reduction** · **Addition** · **Substitution** · **Elimination**

Reaction Mechanisms

Electrophilic Addition · **Electrophilic Substitution** · **Nucleophilic Addition** · **Nucleophilic Substitution** · **Free-radical Substitution**

Condensation (Nucleophilic Acyl Substitution*) · **Bimolecular (S_N2); Unimolecular (S_N1)**

* Mechanism not required for H2 Chemistry

TRANSFORMATION

STOICHIOMETRY; REDOX

REACTION KINETICS

CHEMICAL ENERGETICS

Functional Groups

π bond — *carbon-carbon*: **Alkenes**, **Arenes**; *carbon-oxygen*: **Carbonyl Compounds**, **Carboxylic Acids and Derivatives**

σ bond — *carbon-halogen*: **Halogeno-alkanes**; *carbon-carbon*: **Alkanes**

lone pair of electrons: **Alcohols**, **Phenols**, **Amines**

11.1 Introduction

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 determines the shapes of molecules?

What are the main types of organic reactions?

How do electrons flow in polar organic reactions?

Learning Outcomes

Students should be able to:

(a) interpret, and use the nomenclature, general formulae and displayed formulae of the following classes of compound:
  (i) hydrocarbons (alkanes, alkenes and arenes)
  (ii) halogen derivatives (halogeno-alkanes and halogenoarenes)
  (iii) hydroxyl compounds (alcohols and phenols)
  (iv) carbonyl compounds (aldehydes and ketones)
  (v) carboxylic acids and derivatives (acyl chlorides and esters)
  (vi) nitrogen compounds (amines, amides, amino acids and nitriles)

(b) interpret, and use the following terminology associated with organic reactions:
  (i) functional group
  (ii) degree of substitution: primary, secondary, tertiary, quaternary
  (iii) homolytic and heterolytic fission
  (iv) carbocation
  (v) free radical, initiation, propagation, termination
  (vi) electrophile (Lewis acid), nucleophile (Lewis base)
  (vii) addition, substitution, elimination, condensation, hydrolysis
  (viii) oxidation and reduction
  [in equations for organic redox reactions, the symbols [O] and [H] are acceptable]

(c) interpret, and use the following terminology associated with organic reactivities:
  (i) delocalisation
  (ii) electronic effect (electron-donating and electron-withdrawing effect)
  (iii) steric effect (steric hindrance)

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

Learning Outcomes
Students should be able to:

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

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

(g) apply (b) and (c) to the understanding of mechanisms in terms of organic structure and bonding

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

In each of the sections 11.3 to 11.8, 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 their study of organic chemistry, students may wish to group the organic reactions in terms of the mechanisms in the syllabus where possible. Students may wish to compare and contrast the different mechanisms.

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

Detailed knowledge of practical procedures is also **not** required; however, 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.

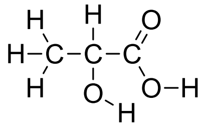
Students are expected to be able to interpret and use the following types of representations in the description of organic molecules. The examples given are for the compound (+)-lactic acid.

Empirical Formula : simplest ratio of the 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. $C_3H_6O_3$

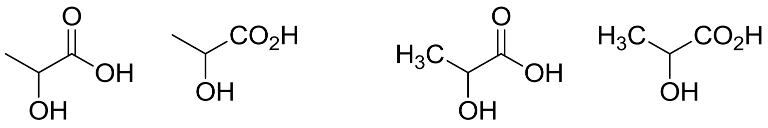
Structural Formula : shows how the constituent atoms of a molecule are joined together with minimal detail, using conventional groups, for an unambiguous structure, e.g. $CH_3CH(OH)CO_2H$

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

e.g. 

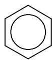
Skeletal Formula : simplified representation of an organic formula derived from the structural formula by removing hydrogen atoms (and their associated bonds) and carbon atoms from alkyl chains, leaving just the carbon-carbon bonds in the carbon skeleton and the associated functional groups.

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

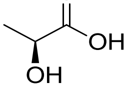


skeletal

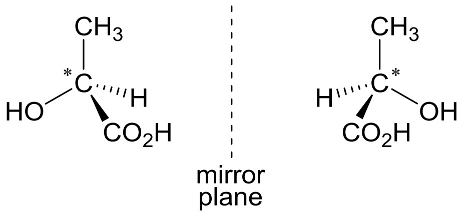
partial skeletal

The convention  for representing the aromatic ring is preferred.

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

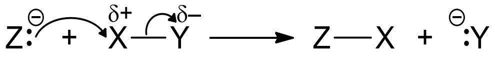
e.g. 

When drawing a pair of optical isomers, students should indicate the three-dimensional structures according to the convention used in.

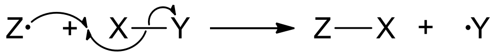


Students are expected to be able to interpret and use the curly arrow notation to represent the movement of electrons in organic reaction mechanisms.

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



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



11.2 Isomerism

Guiding Questions

What is isomerism? What are the different types of isomerism?
What are the structural criteria for exhibition of the different types of isomerism?
How do the physical and chemical properties of different types of isomers differ?

Learning Outcomes

Students should be able to:

(a) describe constitutional (structural) isomerism

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

(c) explain what is meant by a chiral centre

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

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

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

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

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

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

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

11.3 Hydrocarbons

Guiding Questions

Alkanes

Why are alkanes generally unreactive, particularly towards polar reagents?

Which class of reagents do alkanes react with and why? What type of reactions do alkanes undergo and why?

How do alkanes react with halogens?

Alkenes

Which classes of reagents do alkenes react with and why? What types of reactions do alkenes undergo and why?

How do alkenes react with electrophiles?

What is the major product obtained when an unsymmetrical alkene reacts with hydrogen halide and why?

Arenes

How does the reactivity of benzene compare with that of alkene and why?

Which class of reagents does benzene react with and why? What types of reactions does benzene undergo and why?

How does benzene react with an electrophile?

What types of reactions do the alkyl side-chains of arenes undergo and why?

How does the substituent on mono-substituted arenes determine the reactivity towards, and the substitution position of, an incoming electrophile?

What are the environmental concerns arising from the use of hydrocarbons?

Learning Outcomes

Students should be able to:

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

(b) describe the chemistry of alkanes as exemplified by the following reactions of ethane:
  (i) combustion
  (ii) free-radical substitution by chlorine and by bromine

(c) describe the mechanism of free-radical substitution with particular reference to the initiation, propagation and termination reactions

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

Learning Outcomes
Students should be able to:

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

  (i) electrophilic addition of water/steam, hydrogen halides and halogens
  (ii) reduction via catalytic hydrogenation (catalytic addition of hydrogen; see also 8(j))
  (iii) oxidation by cold, alkaline solution of manganate(VII) ions to form the diol
  (iv) oxidation by hot, acidified solution of manganate(VII) ions leading to the rupture of the carbon-to-carbon double bond in order to determine the position of alkene linkages in larger molecules

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

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

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

  (i) reactivity towards electrophiles
  (ii) preference of benzene to undergo substitution rather than addition reaction

(i) describe the chemistry of the benzene ring as exemplified by the following reactions of benzene and methylbenzene:

  (i) electrophilic substitution reactions with chlorine and with bromine
  (recognise the use of Lewis acid as catalysts; see also Section 4)
  (ii) nitration with concentrated nitric acid
  (recognise concentrated sulfuric acid as a Brønsted-Lowry acid catalyst; see also Section 4)
  (iii) Friedel-Crafts alkylation with halogenoalkanes
  (recognise the use of Lewis acid as catalysts; see also Section 4)

(j) (i) describe the mechanism of electrophilic substitution in arenes, using the mono-bromination of benzene as an example
  (ii) describe the effect of the delocalisation of electrons in arenes in such reactions

Learning Outcomes

Students should be able to:

(k) describe the chemistry of the alkyl side-chain of benzene ring as exemplified by the following reactions of methylbenzene:
  (i) free-radical substitution by chlorine and by bromine
  (ii) complete oxidation to give benzoic acid

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

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

(n) recognise the environmental consequences of:
  (i) carbon monoxide, oxides of nitrogen and unburnt hydrocarbons arising from the internal combustion engine and of their catalytic removal
  (ii) gases that contribute to the enhanced greenhouse effect

(o) recognise that petroleum, a chemical feedstock, is a finite resource and the importance of recycling

11.4 Halogen Derivatives

Guiding Questions

Halogenoalkanes

How are halogenoalkanes synthesised?

Which classes of reagents do halogenoalkanes react with and why? What types of reactions do halogenoalkanes undergo and why?

How do halogenoalkanes react with nucleophiles? What are the factors that determine the mechanism of nucleophilic substitution?

How does the reactivity compare among different halogenoalkanes?

Halogenoarenes

How are halogenoarenes synthesised?

How does the reactivity of a halogenoarene compare with that of a halogenoalkane towards nucleophilic reagents?

Learning Outcomes

Students should be able to:

(a) recall the chemistry of halogenoalkanes as exemplified by:
  (i) the following nucleophilic substitution reactions of bromoethane: hydrolysis; formation of nitriles; formation of primary amines by reaction with ammonia
  (ii) the elimination of hydrogen bromide from 2-bromopropane

(b) describe and explain the mechanisms of nucleophilic substitutions in halogenoalkanes:
  (i) S_N1, in terms of stability of the carbocation intermediates
  (ii) S_N2, in terms of steric hindrance of the halogenoalkanes

(c) explain the stereochemical outcome in nucleophilic substitution involving optically active substrates:
  (i) inversion of configuration in S_N2 mechanism
  (ii) racemisation in S_N1 mechanism

(d) interpret the different reactivities of halogenoalkanes, with particular reference to hydrolysis, and to the relative strengths of the C–Hal bonds

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

Learning Outcomes
Students should be able to:

(f) suggest characteristic reactions to differentiate between:
  (i) different halogenoalkanes
  (ii) halogenoalkanes and halogeno-arenes
  e.g. hydrolysis, followed by testing of the halide ions

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

(h) recognise the concern about the effect of chlorofluoroalkanes (CFCs) on the ozone layer [the mechanistic details of how CFCs deplete the ozone layer are **not** required]

11.5 Hydroxy Compounds

Guiding Questions

How are alcohols synthesised?

Which classes of reagents do alcohols react with and why? What types of reactions do alcohols undergo and why?

Which classes of reagents do phenols react with and why? What types of reactions do phenols undergo and why?

How does the reactivity of phenol compare to that of benzene towards electrophiles?

How do we compare the relative acidity of hydroxy compounds?

Learning Outcomes

Students should be able to:

(a) recall the chemistry of alcohols, exemplified by ethanol:
  (i) combustion
  (ii) nucleophilic substitution to give halogenoalkanes
  (iii) reaction with sodium
  (iv) oxidation to carbonyl compounds and carboxylic acids
  (v) dehydration to alkenes

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

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

(d) recall the chemistry of phenol, as exemplified by the following reactions:
  (i) with bases
  (ii) with sodium
  (iii) nitration of, and bromination of, the benzene ring

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

11.6 Carbonyl Compounds

Guiding Questions

How are carbonyl compounds synthesised?

Which class of reagents do carbonyl compounds react with and why? What types of reactions do carbonyl compounds undergo and why?

How do carbonyl compounds react with HCN in nucleophilic addition?

Learning Outcomes

Students should be able to:

(a) describe the formation of aldehydes and ketones from, and their reduction to, primary and secondary alcohols respectively

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

(c) explain the differences in reactivity between carbonyl compounds and alkenes towards nucleophilic reagents, such as lithium aluminium hydride and hydrogen cyanide

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

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

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

11.7 Carboxylic Acids and Derivatives

Guiding Questions

Carboxylic acids

How are carboxylic acids synthesised?

What types of reactions do carboxylic acids undergo and why?

Acid derivatives

How are acyl chlorides and esters synthesised?

What types of reactions do acyl chlorides and esters undergo and why?

How does the ease of hydrolysis of acyl chlorides compare with that of alkyl and aryl chlorides?

How do we compare the acidity of organic compounds in aqueous medium?

Learning Outcomes

Students should be able to:

(a) describe the formation of carboxylic acids from alcohols, aldehydes and nitriles

(b) describe the reactions of carboxylic acids in the formation of:
  (i) salts
  (ii) esters on condensation with alcohols, using ethyl ethanoate as an example
  (iii) acyl chlorides, using ethanoyl chloride as an example
  (iv) primary alcohols, via reduction with lithium aluminium hydride, using ethanol as an example

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

(d) describe the hydrolysis of acyl chlorides

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

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

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

(h) describe the acid and base hydrolysis of esters

11.8 Nitrogen Compounds

Guiding Questions

Amines

How are amines synthesised?

What types of reactions do amines undergo and why?

Phenylamines

How are phenylamines synthesised?

What types of reactions do phenylamines undergo and why?

What are the effects of the delocalisation of the lone pair of electrons on nitrogen of phenylamine into the benzene ring?

Amides

How are amides synthesised?

Why are amides neutral?

What types of reactions do amides undergo and why?

Amino acids

What are the properties of amino acids?

What types of reactions do amino acids undergo and why?

How do we compare the basicity of organic nitrogen compounds?

Learning Outcomes

Students should be able to:

(a) describe the formation of amines as exemplified by ethylamine (through amide and nitrile reduction; see also Section 11.4) and by phenylamine (through the reduction of nitrobenzene)

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

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

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

(e) describe the reaction of phenylamine with aqueous bromine

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

Learning Outcomes
Students should be able to:

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

(h) describe the chemistry of amides, exemplified by the following reactions:
  (i) hydrolysis on treatment with aqueous alkali or acid
  (ii) reduction to amines with lithium aluminium hydride

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

(j) describe the formation of peptide (amide) bonds between α-amino acids, and hence explain protein formation

(k) describe the hydrolysis of proteins

12. Electrochemistry

Guiding Questions

Electrochemical cell

What happens in a redox reaction?

How can the tendency of a substance to be reduced or oxidised be measured?

What are the factors affecting electrode potential?

How can the direction and feasibility of a redox reaction be predicted, and what are the limitations?

Electrolytic cell

What are the factors affecting the discharge of a substance during electrolysis?

How can we calculate the amount of substance liberated during electrolysis?

What are some industrial applications of electrolysis?

What are the differences between an electrochemical cell and an electrolytic cell?

Learning Outcomes

Students should be able to:

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

(b) define the terms:
  (i) *standard electrode (redox) potential*
  (ii) *standard cell potential*

(c) describe the standard hydrogen electrode

(d) describe methods used to measure the standard electrode potentials of:
  (i) metals or non-metals in contact with their ions in aqueous solution
  (ii) ions of the same element in different oxidation states

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

(f) use standard cell potentials to:
  (i) explain/deduce the direction of electron flow from a simple cell
  (ii) predict the spontaneity of a reaction

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

Learning Outcomes
Students should be able to:

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

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

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

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

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

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

(n) calculate:
    (i) the quantity of charge passed during electrolysis
    (ii) the mass and/or volume of substance liberated during electrolysis

(o) explain, in terms of the electrode reactions, the industrial processes of:
    (i) the anodising of aluminium
    (ii) the electrolytic purification of copper
    [technical details are **not** required]

13. An Introduction to the Chemistry of Transition Elements

Guiding Questions

What are transition elements?
What are the characteristic properties of transition elements? How are these properties similar or different from a typical s-block element?
Are there any trends/patterns in the properties of transition elements?
What are some examples/applications of transition elements/their compounds?

Learning Outcomes

Students should be able to:

For 1st set of transition elements from titanium to copper

(a) explain what is meant by a transition element, in terms of d block elements forming one or more stable ions with partially filled d subshells

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

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

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

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

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

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

(h) predict, using $E^\ominus$ values, the likelihood of redox reactions

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

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

Learning Outcomes
Students should be able to:

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

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

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

3. PEDAGOGY

Teaching science involves tapping on the learner's innate curiosity and desire to answer a question or solve a problem relating to science. Besides developing a strong conceptual understanding of scientific models and theories, students are given opportunities to use scientific inquiry and cultivate the ability to think and act in ways associated with scientific inquiry. This includes students asking questions about knowledge and issues that they can relate to in their daily lives, society and the environment; collecting and using evidence; and formulating and communicating explanations based on scientific knowledge.

Learning science is more than acquiring the facts and the outcomes of scientific investigations as a body of knowledge. Science is also a way of knowing and doing. Through the Practices of Science, students should acquire an appreciation of the nature of scientific knowledge, the scientific enterprise as well as an understanding of the skills and processes in scientific inquiry:

- **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:** Broadly, 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. Strategies that could be used to support inquiry-based learning in science 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. Learning science in a real-life context accessible to students can increase their interest and enhance their awareness of the interconnections among science, technology, society and the environment.

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.

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 summarize 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.

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.

4.1.1 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.*

C *Experimental skills and investigations*

Candidates should be able to:

1. follow a detailed set or sequence of instructions and use techniques, apparatus and materials safely and effectively;
2. make, record and present observations and measurements with due regard for precision and accuracy;
3. interpret and evaluate observations and experimental data;
4. identify a problem, devise and plan investigations, select techniques, apparatus and materials;
5. evaluate methods and techniques, and suggest possible improvements.

4.1.2 SCHEME OF ASSESSMENT

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

Paper	Type of Paper	Duration	Weighting (%)	Marks
1	**Multiple Choice**	1 h	15	30
2	**Structured Questions**	2 h	30	75
3	**Free Response Questions**	2 h	35	80
4	**Practical Paper**	2 h 30 min	20	55

Paper 1 (1 h, 30 marks)

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

All questions will include 4 options.

Paper 2 (2 h, 75 marks)

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

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

Paper 3 (2 h, 80 marks)

This paper consists of two sections:
- Section A worth 60 marks consisting 3–4 free response questions, all compulsory. Each question constitutes 15–25 marks.
- Section B worth 20 marks consisting *two* questions, each of 20 marks. Candidates are to answer any one question.

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

Paper 4 (2 h 30 min, 55 marks)

This paper will assess appropriate aspects of objectives C1 to C5 in the following skill areas:
- Planning (P)
- Manipulation, measurement and observation (MMO)

- Presentation of data and observations (PDO)
- Analysis, conclusions and evaluation (ACE)

The assessment of Planning (P) will have a weighting of 5%. The assessment of skill areas MMO, PDO and ACE will have a weighting of 15%.

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

Weighting of Assessment Objectives

Assessment Objectives		Weighting (%)	Assessment Components
A	**Knowledge with understanding**	32	Papers 1, 2, 3
B	**Handling, applying and evaluating information**	48	Papers 1, 2, 3
C	**Experimental skills and investigations**	20	Paper 4

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

5. TEXTBOOKS AND REFERENCES

Students 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 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