CHEMISTRY SYLLABUS

Upper Secondary Express Course

Implementation starting with
2023 Secondary Three Cohort

Ministry of Education
SINGAPORE

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1. INTRODUCTION

1.1 Science Curriculum Framework

The *Science Curriculum Framework* (see **Figure 1.1**) encapsulates the thrust of science education in Singapore, which is to provide students with a strong foundation in science for life, future learning, citizenry and work.

Science for Life and Society at the core of the curriculum framework captures the essence of the goals of science education.

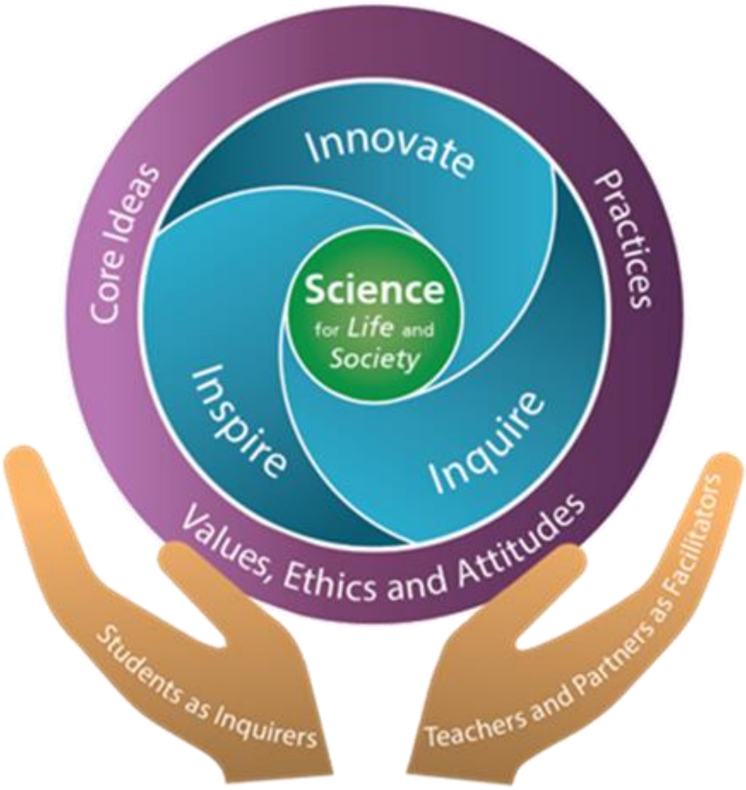

Figure 1.1: Science Curriculum Framework

Our science students are diverse, with different needs, interests and aptitudes for science. Given the diversity of our students and the needs of our country, the twin **goals of science education** are:

- To enthuse and nurture all students to be scientifically literate, which can help them to make informed decisions and take responsible actions in their daily lives.
- To provide strong science foundations for students to innovate and pursue STEM for future learning and work.

Surrounding the core of the framework are the three "IN"s, *inspire*, *inquire* and *innovate,* which represent the **vision of science education**. It encapsulates the desired overall experience of our students in science education:

- INspired by Science. Students enjoy learning science and are fascinated by how everyday phenomena have scientific connections and how science helps solve many of our global challenges. They regard science as relevant and meaningful, and appreciate how science and technology have transformed the world and improved our lives. A good number of students see science-related careers as a viable profession to serve the good of society.

- INquire like scientists. Students have a strong foundation in science, and possess the spirit of scientific inquiry. They are able to engage confidently in the Practices grounded in the knowledge, issues and questions that relate to the roles played by science in daily life, society and the environment. They can discern, weigh alternatives and evaluate claims and ideas critically, based on logical scientific evidence and arguments, and yet be able to suspend judgement where there is lack of evidence.

- INnovate using Science. Students 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. A strong pipeline of students can contribute towards STEM research, innovation and enterprise.

The outer ring represents the domains that make up the strong science fundamentals: *Core Ideas* of science, *Practices of Science*, and *Values, Ethics and Attitudes* in science.

- Core Ideas. Core Ideas are the distilled ideas central to the discipline. The Core Ideas help students see the coherence and conceptual links *across* and *within* the different sub-disciplines of science (i.e. biology, chemistry and physics).

- Practices of Science (POS). The Practices consist of three components:
  (a) Demonstrating Ways of Thinking and Doing in Science;
  (b) Understanding the Nature of Scientific Knowledge; and
  (c) Relating Science, Technology, Society and Environment.

  They represent the set of established procedures and practices associated with scientific inquiry, what scientific knowledge is and how it is generated and established, as well as how science is applied in society. The Practices serve to highlight that the discipline of science is more than the acquisition of a body of knowledge (e.g. scientific facts, concepts, laws, and theories); it is also a *way of thinking and doing*. In particular, it is important to appreciate that the three components representing the cognitive, epistemic and social aspects of the Practices are intricately related.

- Values, Ethics and Attitudes (VEA) in Science. Although science uses objective methods to arrive at evidence-based conclusions, it is in fact a human enterprise conducted in particular social contexts which involves consideration of values and ethics. It is important for our students to be aware of and appreciate the values and ethical implications of the application of science in society. Thus, 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.

The pair of hands in the Science Curriculum Framework represents the roles of students *as inquirers* in their learning and pursuit of science, supported by *teachers and partners as facilitators* of the students' learning experiences, to impart the excitement and value of science to the students. The partnership of learning and teaching goes beyond the students and teachers to include other partners who can facilitate learning in various contexts to help fuel students' sense of inquiry and innovation, to inspire them and to help them appreciate the application of science in their daily lives, society and the environment.

1.2 Developing 21st Century Competencies through Science

To prepare our students for the future, a Framework for 21st Century Competencies (21CC) and Student Outcomes was developed by MOE (see **Figure 1.2**). This 21CC framework guides the purposive development, through the total curriculum, of key competencies and mindsets for students to thrive and contribute in the 21st century.

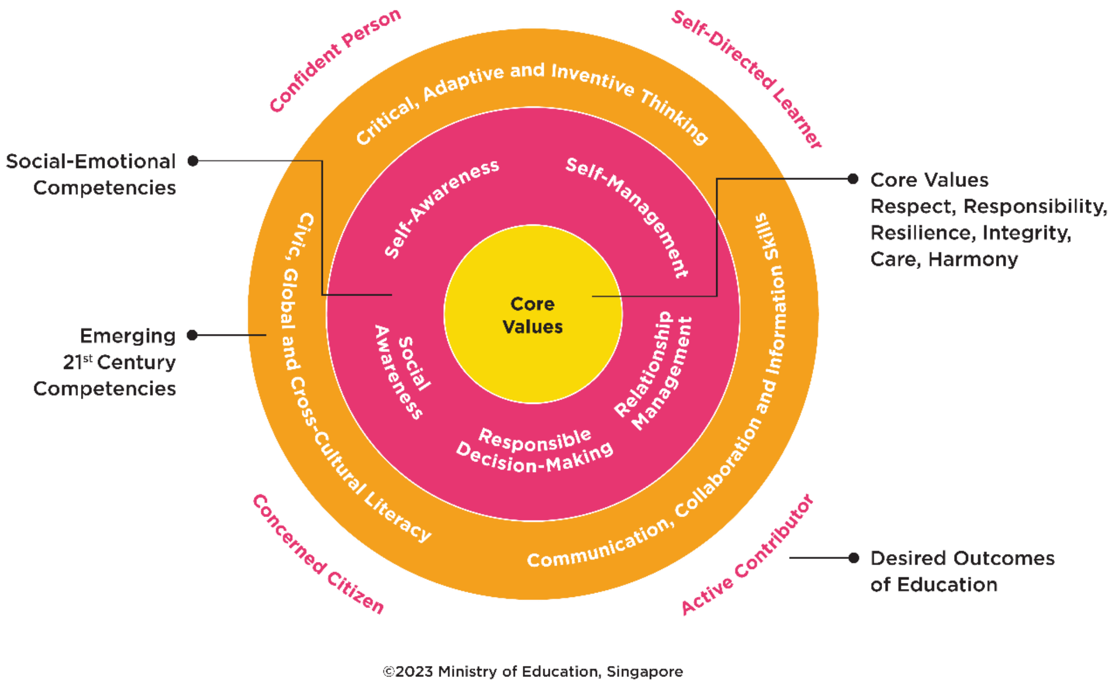

Figure 1.2: Framework for 21st Century Competencies and Student Outcomes

In Singapore, science education plays a crucial role in equipping our students to understand and tackle the myriad of local and global challenges of the 21st century. These challenges include issues such as climate change, technological disruptions (e.g. artificial intelligence), and the sustainable management of resources to support urban development and economic growth. To effectively address these challenges, it is vital to cultivate scientifically literate citizens who:

- Possess the mindset and practical knowledge of science and its applications to make informed decisions and take responsible actions in their daily lives.
- Appreciate science as part of humanity's intellectual and cultural heritage, recognising the beauty and power of its ideas, and engaging in socio-scientific issues ethically and in an informed manner.
- Can apply scientific knowledge and skills, as well as embrace scientific attitudes and mindsets to innovate and explore new frontiers.

In this respect, engaging our students in the Practices of Science (POS) is aligned with the larger goal of developing 21CC in our students. The emerging 21CC that can be most naturally developed through science are **Critical Thinking, Inventive Thinking and Communication**, while the development of the others depends on the context of the lesson. Intentional development of 21CC through science makes learning meaningful and facilitates the transfer of learning (refer to the table below for specific examples).

Critical Thinking

Critical Thinking refers to the ability to exercise sound reasoning and metacognitive thinking to interpret and analyse information and evidence, draw conclusions, make decisions, and solve problems.

Developmental Milestone	Examples of how it could look like in an Upper Secondary Science classroom
• Use evidence and adopt different viewpoints to explain their reasoning and decisions, having considered the implications of the relationship among different viewpoints. • Plan, organise and evaluate their thinking strategies to monitor their learning. Suspend judgement, reassess conclusions and consider alternatives to refine their thoughts, attitudes, behaviour and actions.	Students should be given opportunities to: • draw conclusion(s) from the interpretation of observations and/or experimental data and underlying principles. • compare and assess competing claims in the context of currently accepted explanations, limitations (e.g., trade-offs), constraints, and ethical issues. • identify and analyse a situation, reflecting on the implications of decisions (e.g., weighing risks and benefits) by appreciating and evaluating diverse viewpoints, including scientific/technological, economic, social, environmental, and ethical considerations, using evidence to support their viewpoints.

Inventive Thinking

Inventive Thinking refers to the ability to frame, investigate and explore issues, generate innovative ideas and evaluate them to form novel and useful responses.

Developmental Milestone	Examples of how it could look like in an Upper Secondary Science classroom
• Generate ideas that are unique or modified substantially from existing ones and explore different pathways that lead to solutions. • Evaluate and refine their ideas iteratively, using relevant strategies and based on a set of criteria that is appropriate for the task or context.	Students should be given opportunities to: • design investigations to inquire into specific phenomena or solve issues set in authentic contexts, with consideration for relevance, accuracy, precision, limitations and potential sources of error. • evaluate and refine ideas and solutions in a systematic and iterative manner through applying logic, collection of evidence, experimentation, and applying scientific knowledge. • ensure that their ideas and solutions developed through experimentation are appropriate for the context in which they are developed.

Communication **Effective communication** refers to the ability to convey information and exchange ideas clearly and coherently through multimodal ways for specific purposes, audiences and contexts.	
Developmental Milestone	**Examples of how it could look like in an Upper Secondary Science classroom**
• Convey and critically evaluate knowledge to co-construct new understandings and complex ideas persuasively and with impact, while considering the specific purpose and context of communication. • Respond with respect and empathy. The student is sensitive to the diverse backgrounds that influence the context of communication with others.	Students should be given opportunities to: • communicate and evaluate scientific findings and information using various modes of communication (e.g., written, verbal, pictorial, tabular, or graphical) while employing scientific concepts and ideas. • seek feedback and/or acceptance of explanations or solutions within the class or wider community.

1.3 Purpose and Value of Chemistry Education

Chemistry, as the study of matter and its changes, influences every facet of our lives and shares many essential ties to other science disciplines. While chemistry seeks to understand the nature of matter by relating the study of energy and particles such as atoms and molecules in physical systems to chemical systems, it also provides a basis for studying and understanding molecules and processes in biological systems.

The Upper Secondary Chemistry syllabus is designed to lay a strong foundation in the discipline through developing conceptual understanding, skills and attitudes relevant to the study and practice of chemistry. The syllabus aims to enable students to connect chemical concepts between topics and to transfer learning from one context to another through disciplinary core ideas. The syllabus is conceptualised around overarching ideas of matter and their chemical reactions. Organised in this way, acquisition and mastery of chemical concepts are fostered through a way of thinking and doing involving the use and development of models to explain observable characteristics and changes of matter, and to represent particles and changes of matter through symbols. Chemical concepts learnt in this syllabus should be seen as tools to better understand the world one lives in and means to suggest solutions for global challenges such as those related to energy and the environment.

1.4 Aims

The Upper Secondary Chemistry syllabus seeks to develop in students the understanding, skills, ethics and attitudes relevant to the Practices of Science, enabling them to

a) appreciate practical applications of chemistry in the real world,
b) deepen their interest in chemistry for future learning and work,
c) become scientifically literate citizens who can innovate and seize opportunities in the 21st century, and
d) develop a way of thinking to approach, analyse and solve problems by explaining macroscopic characteristics and changes in chemical systems through the use of sub-microscopic and symbolic representations.

The Disciplinary Ideas of Chemistry, the Practices of Science, and the Values, Ethics and Attitudes elaborated in sections **1.5** to **1.7.**

1.5 Disciplinary Ideas of Chemistry

The disciplinary ideas of chemistry described below represent the overarching ideas which can be applied to explain, analyse and solve a variety of problems that seek to address the broader questions of what matter is and how particles interact with one another. The purpose of equipping students with an understanding of these ideas is to develop in them a coherent view and conceptual framework of scientific knowledge to facilitate the application and transfer of learning. These ideas can be revisited throughout the syllabus, deepened at higher levels of learning and beyond the schooling years.

1. Matter is made up of a variety of chemical elements, each with characteristic properties, and the smallest particle that characterises a chemical element is an atom.

2. The structure of matter and its chemical and physical properties are determined by the arrangement of particles and electrostatic interactions between them.

3. Energy changes across and within systems usually occur during physical and chemical changes, when there is rearrangement of particles.

4. Energy plays a key role in influencing the rate and extent of physical and chemical changes.

5. Matter and energy are conserved in all physical and chemical changes.

1.6 Practices of Science

Teachers are encouraged to provide opportunities for students to develop the Practices of Science. It is important to appreciate that the three components of the Practices are intricately related.

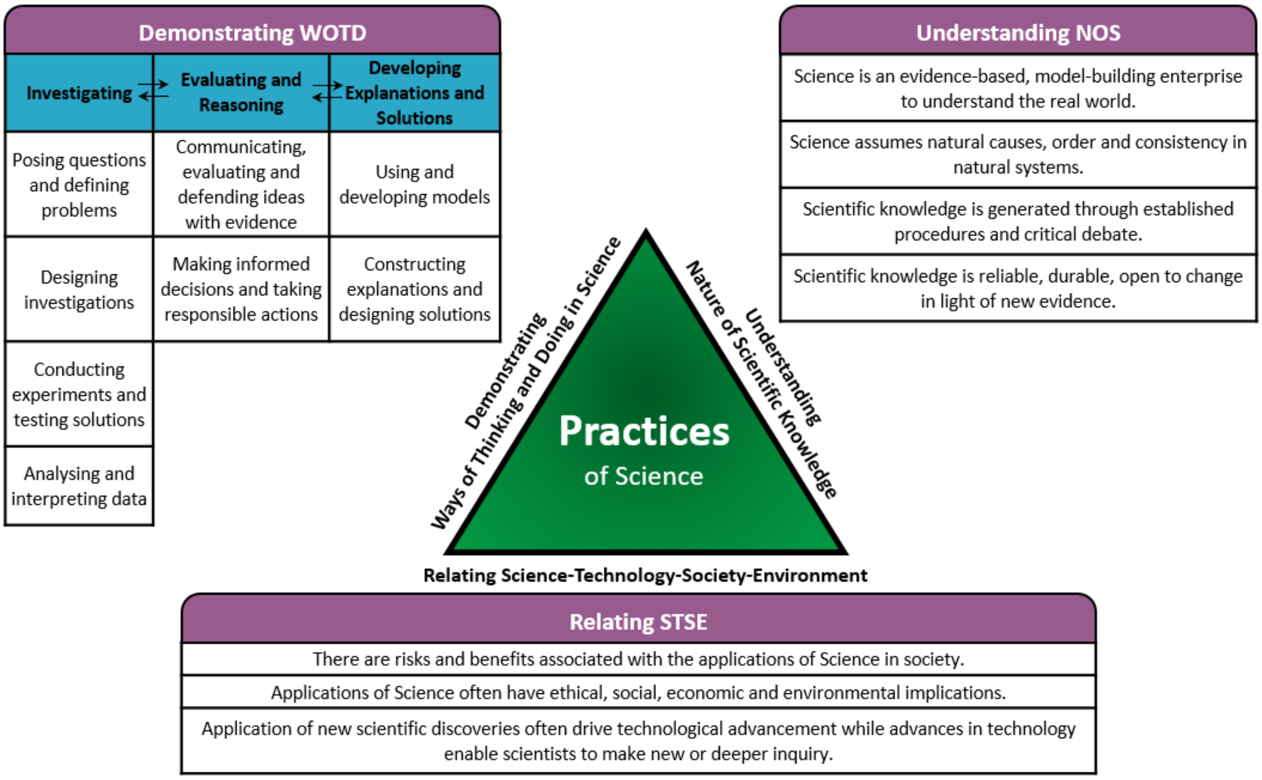

Figure 1.3: Practices of Science

1.7 Values, Ethics and Attitudes

Although science uses objective methods to arrive at evidence-based conclusions, it is in fact a human enterprise conducted in particular social contexts which involves consideration of values and ethics. The intent of fostering an awareness and appreciation of these values in the curriculum is to sensitise our students to the ethical implications of the application of science in society. The challenges that humanity will face in the upcoming centuries will not be overcome by scientific and technological solutions alone. There is a need to consider the impact of these solutions in terms of their benefits to humanity and the ethical issues involved. Thus, science education needs to equip students with the ability to articulate their ethical stance as they participate in discussions about socio-scientific issues[1] that involve ethical dilemmas, with no single right answers.

Values, Ethics and Attitudes	**Description**
Curiosity	Desiring to explore the environment and question what is found.
Creativity	Seeking innovative and relevant ways to solve problems.
Integrity	Handling and communicating data and information with complete honesty.
Objectivity	Seeking data and information to validate observations and explanations without bias.
Open-mindedness	Accepting all knowledge as tentative and suspending judgment. Tolerance for ambiguity. Willingness to change views if the evidence is convincing.
Resilience	Not giving up on the pursuit for answers / solutions. Willingness to take risks and embrace failure as part of the learning process.
Responsibility	Showing care and concern for living things and awareness of our responsibility for the quality of the environment.
Healthy Scepticism	Questioning the observations, methods, processes and data, as well as trying to review one's own ideas.

[1] Examples of socio-scientific issues are genetic engineering (e.g. cloning and gene therapy), reproductive technology, climate change and the adoption of nuclear energy.

SECTION 2: CONTENT

Matter – Structures and Properties
Chemical Reactions
Chemistry in a Sustainable World

2. CONTENT

Content structure

Each of the three sections represents an important aspect of chemistry. In Section 2.1, students explore how the structures at the sub-microscopic level affects the properties exhibited at the macroscopic level. In Section 2.2, students are introduced to different types of chemical reactions and how these reactions can be quantified in terms of the stoichiometric relationship, the energy changes involved and their rates. In the final Section 2.3, students learn how chemistry can be used to make the world a sustainable one.

Sections	Topics
Matter – Structures and Properties	1. Experimental Chemistry
	2. The Particulate Nature of Matter
	3. Chemical Bonding and Structure
Chemical Reactions	4. Chemical Calculations
	5. Acid-Base Chemistry
	6. Qualitative Analysis
	7. Redox Chemistry
	8. Patterns in the Periodic Table
	9. Chemical Energetics
	10. Rate of Reactions
Chemistry in a Sustainable World	11. Organic Chemistry
	12. Maintaining Air Quality

Guide to using this section

This is a brief description of the features in **Sections 2.1- 2.3.**

<u>Section overview</u>

2.1 Matter – Structures and Properties

<u>Overview</u>

Chemistry is the science of matter and the changes it undergoes. To investigate matter, chemists conduct experiments and make measurements. The need for precision and accuracy in measurements, and for safe handling and disposal of chemicals are integral to experimental chemistry.

Pure substances are also important in industries, such as food and medicine. The purity of a substance can be determined by a fixed melting point and boiling point. Over time, chemists have invented different experimental techniques to separate mixtures into pure substances, a process called purification.

Section narrative - highlights the value of learning the concepts covered in each section and the connections among the topics to guide teachers in making learning relevant and coherent.

<u>Topic overview</u>

TOPIC 1. EXPERIMENTAL CHEMISTRY

- Experimental Design
- Methods of Purification and Analysis

Guiding Questions

- What are some considerations that chemists have when selecting the tools to use in their experiments?
- How does one decide on the method of purification?
- Why is it important for us to be able to get a pure substance?

Topic Description

In carrying out experiments, chemists assemble suitable apparatus (with laboratory safety in consideration) and decide on what to look for and measure using appropriate techniques and apparatus. Physical quantities commonly measured include mass, volume, time and temperature. The apparatus used depends on the quantity being measured, and on how accurate and precise the measurement needs to be.

When matter undergoes changes, mixture of substances can be formed. Methods of separation and purification depend on the type of mixtures and the difference in physical properties of the substances in the mixture. Purifying mixtures is important in manufacturing to ensure quality and to separate useful substances from mixtures and waste products. Pure substances are important especially in consumer products such as food and medicine. A pure substance is a single element or compound. To assess the purity of a substance, its melting point or boiling point is measured and matched to reference values. Chromatography is also a method to determine purity of a substance and to identify components in mixtures.

Guiding Questions - highlight the essential takeaways for each topic.

Topic description - highlights the key ideas within each topic and the value of learning them to guide teachers in making learning

<u>Learning Outcomes</u>

Learning Outcomes
1.1 Experimental Design
(a) name appropriate apparatus for the measurement of time, temperature, mass and volume; including burettes, pipettes, measuring cylinders and gas syringes
(b) suggest suitable apparatus, given relevant information, for a variety of simple experiments, including collection of gases

2.1 Matter – Structures and Properties

Overview

Chemistry is the science of matter and the changes it undergoes. To investigate matter, chemists conduct experiments and make measurements. The need for precision and accuracy in measurements, and for safe handling and disposal of chemicals are integral to experimental chemistry.

Pure substances are also important in industries, such as food and medicine. The purity of a substance can be determined by a fixed melting point and boiling point. Over time, chemists have invented different experimental techniques to separate mixtures into pure substances, a process called purification.

Matter is understood in terms of particles, the way they are arranged and the forces that hold them together. Evidence of the particulate nature of matter come from daily observable phenomena such as diffusion and crystal growth. The simplest particle is known as an atom, which consists of sub-atomic particles like proton(s), neutron(s) and electron(s). From atoms in the hundreds of elements, a myriad of molecules with different properties are formed. The physical properties of a substance are determined by how its particles are arranged (i.e. structure) and the strength of the electrostatic forces between them.

This section on the structures and properties of matter forms a basis for an in-depth understanding of matter and its interactions.

TOPIC 1. EXPERIMENTAL CHEMISTRY

- Experimental Design
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Learning Outcomes
1.1 Experimental Design
(a) name appropriate apparatus for the measurement of time, temperature, mass and volume; including burettes, pipettes, measuring cylinders and gas syringes
(b) suggest suitable apparatus, given relevant information, for a variety of simple experiments, including drying and collection of gases and measurement of rates of reaction (drying agents will be limited to calcium oxide, concentrated sulfuric acid and fused calcium chloride)
1.2 Methods of Purification and Analysis
(a) describe methods of separation and purification for the components of mixtures, to include: (i) use of a suitable solvent, filtration and crystallisation or evaporation (ii) sublimation (iii) distillation and fractional distillation (see also **11.1**(b)) (iv) use of a separating funnel (v) paper chromatography
(b) suggest suitable separation and purification methods, given information about the substances involved in the following types of mixtures: (i) solid-solid (ii) solid-liquid (iii) liquid-liquid (miscible and immiscible)
(c) interpret paper chromatograms including comparison with 'known' samples and the use of R_f values
(d) explain the need to use locating agents in the chromatography of colourless compounds (knowledge of specific locating agents is **not** required)
(e) deduce from given melting point and boiling point data the identities of substances and their purity
(f) explain the importance of measuring the purity in substances used in everyday life, e.g. foodstuffs and drugs

TOPIC 2. THE PARTICULATE NATURE OF MATTER

- Kinetic Particle Theory
- Atomic Structure

Guiding Questions

- What does the kinetic particle theory tell us about matter?
- Why is the physical state of a substance affected by temperature?
- What is the structure of an atom?
- What is the significance of having different number of sub-atomic particles?

Topic Description

Models help chemists link macroscopic properties to microscopic behaviour. The kinetic particle theory is a model that describes matter as consisting of particles in constant motion with spaces between them. Forces of attraction of varying strength result in different physical states of a substance. As temperature increases, particles gain energy and move faster. When the particles gain sufficient energy to overcome the attractive forces between them, the substance changes state.

As new evidence become available, models of atomic structure developed. From the simplest model by Dalton, current models describe an atom as a positively charged nucleus containing protons and neutrons, surrounded by negatively charged electrons in discrete energy levels. The number of protons identifies an element while the number of electrons determines how an atom reacts. Contrary to the early model by Dalton which stated that all atoms of an element are identical, mass spectrometry reveal the relative atomic mass of chlorine to be 35.5 although the relative mass of protons and neutrons is 1 respectively. This suggests the presence of isotopes which are atoms of the same element with same number of protons but different number of neutrons.

Learning Outcomes	
2.1 Kinetic Particle Theory	
(a)	describe the solid, liquid and gaseous states of matter and explain their interconversion in terms of the kinetic particle theory and of the energy changes involved
(b)	describe and explain evidence for the movement of particles in liquids and gases (treatment of Brownian motion is **not** required)
(c)	explain everyday effects of diffusion in terms of particles, e.g. the spread of perfumes and cooking aromas; tea and coffee grains in water
(d)	state qualitatively the effect of molecular mass on the rate of diffusion and explain the dependence of rate of diffusion on temperature
2.2 Atomic Structure	
(a)	state the relative charges and approximate relative masses of a proton, a neutron and an electron
(b)	describe, with the aid of diagrams, the structure of an atom as consisting of protons and neutrons (nucleons) in the nucleus and electrons arranged in shells (energy levels) (knowledge of s, p, d and f classification is **not** required; a copy of the Periodic Table will be available in Papers 1 and 2)
(c)	define *proton (atomic) number* and *nucleon (mass) number*
(d)	interpret and use nuclide notations such as $^{12}_{6}C$
(e)	define the term *isotopes*
(f)	deduce the numbers of protons, neutrons and electrons in atoms and ions given proton and nucleon numbers

TOPIC 3. CHEMICAL BONDING AND STRUCTURE

- Ionic Bonding
- Covalent Bonding
- Metallic Bonding
- Structure and Properties of Materials

Guiding Questions

- How does the transfer or sharing of electrons between atoms result in the atoms being attracted to each other?
- Why does the bonding in and structure of a substance affect its physical properties?

Topic Description

This topic builds on the Bohr atomic model. During chemical changes, atoms lose, gain or share electrons to achieve noble gas configuration. While this configuration is used to determine the number of electrons in forming bonds, there are exceptions to this rule like phosphorus pentachloride, boron trihydride and other molecules.

Attractive forces exist between opposite charges when different bond types are formed. The ionic bond is the electrostatic attraction between oppositely charged ions. A covalent bond is formed by the electrostatic attraction between a shared pair of electrons and the nuclei. Metallic bonding involves the electrostatic attraction between a lattice of positive ions and 'sea of electrons'. To describe the bonding in substances, dot and cross diagrams are constructed but they have limitations like the lack of movement of electrons or ions.

The physical properties of a substance depend on the nature and strength of forces between the particles. The nature of the particles involved determine the bonding and structure of the substance.

Learning Outcomes
3.1 Ionic Bonding
(a) describe the formation of ions by electron loss/gain and that these ions usually have the electronic configuration of a noble gas
(b) describe, including the use of 'dot-and-cross' diagrams, the formation of ionic bonds between metals and non-metals, e.g. $NaCl$; $MgCl_2$
(c) state that ionic materials contain a giant lattice in which the ions are held by electrostatic attraction, e.g. $NaCl$ (students will **not** be required to draw diagrams of ionic lattices)
(d) relate the physical properties (including electrical property) of ionic compounds to their lattice structure (see also **3.4**(g))
3.2 Covalent Bonding
(a) describe the formation of a covalent bond by the sharing of a pair of electrons and that the atoms in the molecules usually have the electronic configuration of a noble gas
(b) describe, using 'dot-and-cross' diagrams, the formation of covalent bonds between non-metallic elements, e.g. H_2; O_2; H_2O; CH_4; CO_2
(c) deduce the arrangement of electrons in other covalent molecules
(d) relate the physical properties (including electrical property) of covalent substances to their structure and bonding (see also **3.4**(g))
3.3 Metallic Bonding
(a) describe metals as a lattice of positive ions in a 'sea of electrons'
(b) describe the general physical properties of metals as solids having high melting and boiling points, malleable, good conductors of heat and electricity in terms of their structure (see also **3.4**(g))
3.4 Structure and Properties of Materials
(a) describe the differences between elements, compounds and mixtures
(b) describe an alloy as a mixture of a metal with another element, e.g. brass; stainless steel
(c) identify representations of metals and alloys from diagrams of structures
(d) explain why alloys have different physical properties to their constituent elements
(e) compare the structures of the following substances in order to deduce their properties: (i) simple molecular substances, e.g. methane, iodine (ii) macromolecules, e.g. poly(ethene) (iii) giant covalent substances, e.g. sand (silicon dioxide), diamond, graphite (see also **3.4**(g))
(f) compare the bonding and structures of diamond and graphite in order to deduce their properties such as electrical conductivity, lubricating or cutting action (students will **not** be required to draw the structures)
(g) deduce the physical and chemical properties of substances from their structures and bonding and vice versa (see also **3.1**(d), **3.2**(d), **3.3**(b) and **3.4**(e))

2.2 Chemical Reactions

<u>Overview</u>

Most interactions of matter involve chemical reactions, which are central to any discussion in chemistry. In this section, different types of chemical reactions are delved into. The different chemical reactions lay the foundation for understanding what happens to energy and rate during a chemical change.

To describe chemicals and their reactions, chemists use symbols, formulae and equations. A balanced chemical equation elucidates the study of molar ratios in which substances react and quantifies the amounts of reactants and products in a reaction through performing calculations.

Given the multitude of chemical reactions, it is useful to broadly classify them for understanding. The main classes of reactions include those of acids and bases, and redox reactions. The study of acid-base and redox reactions reveals patterns in the chemical properties of substances, leading to the organisation of elements in the Periodic Table.

During chemical reactions, energy changes occur when bonds are broken and formed. The rate of a reaction is also affected when conditions such as temperature, concentration, pressure and surface area are changed. How and why each of the conditions affect the rate of a reaction can be explained in terms of colliding particles.

TOPIC 4. CHEMICAL CALCULATIONS

- Formulae and Equation Writing
- The Mole Concept and Stoichiometry

Guiding Questions

- What information can be derived from the chemical symbols, formulae and equations?
- Why must a chemical equation be balanced?
- How do the macroscopic quantities (e.g. mass, volume of a gas) relate to the number of particles in a substance?

Topic Description

Chemical symbols are shorthand used by chemists to represent elements. Through the chemical formulae, one is able to tell the type and number of atoms of each element present in the smallest representative unit (e.g. molecule or formula unit) in a substance. Chemical equations can also be constructed using formulae to represent overall changes in reactions. As atoms rearrange to form new substances during reactions, the same atoms are present before and after a reaction. The total mass of reactants is thus equal to the total mass of products and a chemical equation must be balanced to show this conservation of mass.

This topic also introduces the use of moles to count the number of particles, allowing one to deduce the number of particles present in a substance from measurement of physical quantities such as mass and volume. Stoichiometry illustrates the molar amount of reactants and products in a balanced chemical equation, from which a range of calculations can be carried out.

Learning Outcomes
4.1 Formulae and Equation Writing
(a) state the symbols of the elements and formulae of the compounds mentioned in the syllabus
(b) deduce the formulae of simple compounds from the relative numbers of atoms present and vice versa
(c) deduce the formulae of ionic compounds from the charges on the ions present and vice versa
(d) interpret chemical equations with state symbols
(e) construct chemical equations, with state symbols, including ionic equations
4.2 The Mole Concept and Stoichiometry
(a) define relative atomic mass, A_r
(b) define relative molecular mass, Mr, and calculate relative molecular mass (and relative formula mass) as the sum of relative atomic masses
(c) define the term *mole* in terms of the Avogadro constant
(d) calculate the percentage mass of an element in a compound when given appropriate information
(e) calculate empirical and molecular formulae from relevant data
(f) calculate stoichiometric reacting masses and volumes of gases (one mole of gas occupies 24 dm^3 at room temperature and pressure); calculations involving the idea of limiting reactants may be set (knowledge of the gas laws and the calculations of gaseous volumes at different temperatures and pressures are **not** required)
(g) apply the concept of solution concentration (in mol/dm^3 or g/dm^3) to process the results of volumetric experiments (e.g. titration) and to solve simple problems (appropriate guidance will be provided where unfamiliar reactions are involved)
(h) calculate % yield and % purity

TOPIC 5. ACID-BASE CHEMISTRY

- Acids and Bases
- Salts
- Ammonia

Guiding Questions

- What are the key differences between an acidic solution, a neutral solution and an alkaline solution?
- Why are different methods needed to prepare different types of salt?
- How do reversible reactions and irreversible reactions differ?
- How are conditions of industrial processes determined?

Topic Description

Svante Arrhenius, a Swedish chemist, proposed the theory that acids, alkali, and salts in water are composed of ions. Acids form hydrogen ions when they dissolve in water and solutions of alkalis contain hydroxide ions. Salts are formed when the hydrogen ions in an acid are replaced by metal ions or ammonium ions in a reaction. Chemical reactions may be reversible like the ionisation of weak acids and bases. In reversible reactions, the reactions do not go to completion as the products can react to form the original reactants. An irreversible reaction has all the reactants turning into products.

Although most salts are made by reactions of acids, insoluble ones are prepared using a precipitation reaction in which an insoluble solid is formed when two solutions are mixed. Different methods are needed to prepare different types of salts to ensure a good yield and purity of salt. Conditions of industrial processes are selected to give the best yield as quickly and economically as possible in terms of safety, maintaining conditions and equipment and energy use.

Learning Outcomes
5.1 Acids and Bases
(a) describe the meanings of the terms acid and alkali in terms of the ions they produce in aqueous solution and their effects on Universal Indicator
(b) describe neutrality and relative acidity and alkalinity, in terms of (i) relative H^+ and OH^- ion concentrations, (ii) colour in Universal Indicator, and (iii) the pH scale (calculation of pH from hydrogen ion concentration is **not** required)
(c) describe qualitatively the difference between strong and weak acids in terms of the extent of ionisation
(d) describe the characteristic properties of acids as in reactions with metals, bases and carbonates to form salts
(e) describe the reaction between hydrogen ions and hydroxide ions to produce water, $H^+ + OH^- \rightarrow H_2O$, as neutralisation
(f) describe the importance of controlling the pH in soils and how excess acidity can be treated using calcium hydroxide
(g) describe the characteristic properties of bases in reactions with acids and with ammonium salts
(h) classify oxides as acidic, basic, amphoteric or neutral based on metallic/non-metallic character
5.2 Salts
(a) describe the techniques used in the preparation, separation and purification of salts as examples of some of the techniques specified in Section **1.2**(a) (methods for preparation should include precipitation and titration together with reactions of acids with metals, insoluble bases and insoluble carbonates)
(b) describe the general rules of solubility for common salts to include nitrates, chlorides (including those of silver and lead), sulfates (including those of barium, calcium and lead), carbonates, hydroxides, salts of Group 1 cations and ammonium salts
(c) suggest a method of preparing a given salt from suitable starting materials, given appropriate information
5.3 Ammonia
(a) describe the use of nitrogen, from air, and hydrogen, from the cracking of crude oil, in the manufacture of ammonia
(b) state that some chemical reactions are reversible, e.g. manufacture of ammonia
(c) interpret data relating to the conditions used in industry for processes involving reversible reactions, e.g. manufacture of ammonia by the Haber Process (knowledge of Le Chatelier's Principle is **not** required)

TOPIC 6. QUALITATIVE ANALYSIS

Guiding Questions

- What constitutes a good chemical test?

Topic Description

A good chemical test should identify a substance exactly. Some tests identify a substance by eliminating certain substances when a negative result is obtained. In instances like these, additional tests should be carried out to identify a substance completely.

This topic illustrates how acids and bases can be used in some tests to identify ions and gases. For example, acid is used to identify carbonate ions and alkali is used to test for cations. As ions are too small to be seen, they are usually precipitated out of solutions to confirm their presence.

Learning Outcomes
(a) describe the use of aqueous sodium hydroxide and/or aqueous ammonia to identify the following aqueous cations through the formation of precipitates (if any) and their subsequent solubility: aluminium, ammonium (together with evolution of ammonia gas upon warming), calcium, copper(II), iron(II), iron(III) and zinc (formulae of complex ions are **not** required)
(b) describe tests to identify the following anions: carbonate (by the addition of dilute acid and subsequent use of limewater); chloride (by reaction of an aqueous solution with nitric acid and aqueous silver nitrate); iodide (by reaction of an aqueous solution with nitric acid and aqueous silver nitrate); nitrate (by reduction with aluminium in aqueous sodium hydroxide to ammonia and subsequent use of damp red litmus paper) and sulfate (by reaction of an aqueous solution with nitric acid and aqueous barium nitrate)
(c) describe tests to identify the following gases: ammonia (using damp red litmus paper); carbon dioxide (using limewater); chlorine (using damp litmus paper); hydrogen (using a burning splint); oxygen (using a glowing splint) and sulfur dioxide (using acidified potassium manganate(VII))

TOPIC 7. REDOX CHEMISTRY

- Oxidation and Reduction
- Electrochemistry

Guiding Questions

- What happens at the sub-microscopic level during a redox reaction?
- Can oxidation occur without reduction taking place?
- How are electrolytic cells different from simple cells?
- What are the reactions taking place at the electrodes?

Topic Description

In another class of chemical reactions known as redox, reduction and oxidation occur simultaneously in a reaction. Initially defined by Antoine Lavoisier as the loss and gain of oxygen, the meanings of redox have expanded to include electrons and oxidation states as a wider range of chemical reactions are studied. A redox reaction consists of an oxidising agent which oxidises another substance and the substance which is oxidised acts as a reducing agent.

Exemplifying the transfer of electrons, electrochemistry elucidates oxidation and reduction processes at the electrodes when a chemical change is effected by electricity in an electrolytic cell and vice versa in a simple cell.

Learning Outcomes
7.1 Oxidation and Reduction
(a) define *oxidation* and *reduction* (redox) in terms of oxygen/hydrogen gain/loss
(b) define *redox* in terms of electron transfer and changes in oxidation state
(c) identify redox reactions in terms of oxygen/hydrogen gain/loss, electron gain/loss and changes in oxidation state
(d) describe the use of aqueous potassium iodide and acidified potassium manganate(VII) in testing for oxidising and reducing agents from the resulting colour changes
7.2 Electrochemistry
(a) describe electrolysis as the conduction of electricity through an ionic compound (an electrolyte), when molten or dissolved in water, leading to chemical changes (including decomposition) at the electrodes
(b) describe electrolysis as evidence for the existence of ions which are held in a lattice when solid but which are free to move when molten or in solution
(c) describe, in terms of the mobility of ions present and the electrode products, the electrolysis of molten sodium chloride, using inert electrodes
(d) predict the likely products of the electrolysis of a molten binary ionic compound using inert electrodes
(e) apply the idea of selective discharge based on (i) cations: linked to the reactivity series (see also **8.4**) (ii) anions: halides, hydroxides and sulfates (e.g. aqueous copper(II) sulfate and dilute sodium chloride solution (as essentially the electrolysis of water)) (iii) concentration effects (as in the electrolysis of concentrated and dilute aqueous sodium chloride) (in all cases above, **inert** electrodes are used)
(f) predict the likely products of the electrolysis of an aqueous electrolyte, given relevant information
(g) construct ionic equations for the reactions occurring at the electrodes during the electrolysis, given relevant information
(h) describe the electrolysis of aqueous copper(II) sulfate with copper electrodes as a means of purifying copper (**no** technical details are required)
(i) describe the electroplating of metals, e.g. copper plating, and state one use of electroplating
(j) describe the production of electrical energy from simple cells (i.e. two electrodes in an electrolyte) linked to the reactivity series (see also **8.4**) and redox reactions (in terms of electron transfer)
(k) describe hydrogen, derived from water or hydrocarbons, as a potential fuel, reacting with oxygen to generate electricity directly in a hydrogen fuel cell (details of the construction and operation of a fuel cell are **not** required)

TOPIC 8. PATTERNS IN THE PERIODIC TABLE

- Periodic Trends
- Group Properties
- Transition Elements
- Reactivity Series

Guiding Questions

- What are the patterns or trends that can be found in the Periodic Table?
- How and why do chemical/physical properties change across the periods and down the groups?
- What is the usefulness of the reactivity series?

Topic Description

Mendeleev's organisation of elements was refined into the modern Periodic Table which shows the recurring relationship in properties of elements with their atomic numbers. Properties of elements across a period change from metals to non-metals as number of valence electrons increases. Elements in a group have the same number of valence electrons and share similar chemical properties. Transition elements have typical properties such as exhibiting variable oxidation states and forming coloured compounds.

Trends in the Periodic Table allow predictions to be made. The reactivity series, which shows metals in order of their tendency to form positive ions, can be deduced from their group trends. However, metals can come from more than one group. Therefore, redox reactions such as displacement reactions are needed to work out the patterns of reactivity of elements in the series.

Learning Outcomes
8.1 Periodic Trends
(a) describe the Periodic Table as an arrangement of the elements in the order of increasing proton (atomic) number
(b) describe how the position of an element in the Periodic Table is related to proton number and electronic configuration
(c) describe the relationship between number of outer (valence) electrons and the ionic charge of an ion for the first twenty elements
(d) explain the similarities between the elements in the same group of the Periodic Table in terms of their electronic configuration
(e) describe the change from metallic to non-metallic character from left to right across a period of the Periodic Table
(f) describe the relationship between number of outer (valence) electrons and metallic/non-metallic character
(g) predict the properties of elements in Group 1 and Group 17 using the Periodic Table
8.2 Group Properties
(a) describe lithium, sodium and potassium in Group 1 (the alkali metals) as a collection of relatively soft, low density metals showing a trend in melting point and in their reaction with water
(b) describe chlorine, bromine and iodine in Group 17 (the halogens) as a collection of diatomic non-metals showing a trend in colour, state and their displacement reactions with solutions of other halide ions
(c) describe the elements in Group 18 (the noble gases) as a collection of monoatomic elements that are chemically unreactive and hence important in providing an inert environment, e.g. argon and neon in light bulbs; helium in balloons; argon in the manufacture of steel
(d) describe the lack of reactivity of the noble gases in terms of their electronic configurations
8.3 Transition Elements
(a) describe typical transition elements as metals having high melting point, high density, variable oxidation state and forming coloured compounds
(b) state that the elements and/or their compounds are often able to act as catalysts (see also **10**(d))

8.4 Reactivity Series
(a) place in order of reactivity calcium, copper, (hydrogen), iron, lead, magnesium, potassium, silver, sodium and zinc by reference to (i) the reactions, if any, of the metals with water, steam and dilute hydrochloric acid, (ii) the reduction, if any, of their oxides by carbon and/or by hydrogen
(b) describe the reactivity series as related to the tendency of a metal to form its positive ion, illustrated by its reaction with (i) the aqueous ions of the other listed metals (ii) the oxides of the other listed metals
(c) deduce the order of reactivity from a given set of experimental results
(d) describe the action of heat on the carbonates of the listed metals and relate thermal stability to the reactivity series
(e) describe the ease of obtaining metals from their ores by relating the elements to their positions in the reactivity series
(f) describe the essential conditions for the corrosion (rusting) of iron as the presence of oxygen and water; prevention of rusting can be achieved by placing a barrier around the metal, e.g. painting; greasing; plastic coating; galvanising
(g) describe the sacrificial protection of iron by a more reactive metal in terms of the reactivity series where the more reactive metal corrodes preferentially, e.g. underwater pipes have a piece of magnesium attached to them

TOPIC 9. CHEMICAL ENERGETICS

Guiding Questions

- What is the relationship between a system and its surrounding?
- Why are some reactions endothermic while others exothermic?

Topic Description

Accompanying the formation of new substances in chemical reactions are changes in energy and rate. This topic considers the changes in energy for a reaction which usually involves the transfer of heat between the system and the surroundings. For a reaction in a test tube, the system is the reacting chemicals and the surroundings is the environment outside the system. Examples of the surroundings include the solvent in the reaction mixture, the air around the test tube, the test tube itself, thermometer dipping into the test tube.

Energy is absorbed to break bonds and is released during bond formation. The overall energy change is exothermic when energy is released to the surroundings, resulting in a temperature rise. The opposite happens with endothermic reactions. During a chemical reaction, bonds are broken for atoms or ions to collide with one another to form new bonds when the collisions occur with enough energy known as activation energy.

Learning Outcomes
(a) describe the meaning of enthalpy change in terms of exothermic (ΔH negative) and endothermic (ΔH positive) reactions
(b) represent energy changes by energy profile diagrams, including reaction enthalpy changes and activation energies (see also **10**(c), **10**(d))
(c) describe bond breaking as an endothermic process and bond making as an exothermic process
(d) explain qualitatively overall enthalpy changes in terms of the energy changes associated with the breaking and making of covalent bonds

TOPIC 10. RATE OF REACTIONS

Guiding Questions

- What is an effective collision?
- How do each of the factors affect the frequency of effective collision?
- How do chemists alter the rate of reactions?

Topic Description

Reactions proceed at different rates as the amount of reactant changes. The average rate of a reaction determines how fast or slow a reaction is by measuring a change in reactant or product over a period of time. Effective collisions between reacting particles result in chemical reactions. An effective collision occurs only when reacting particles collide with one another and with sufficient energy known as activation energy.

Chemists alter the rate of reactions by changing certain conditions such as concentration of reactants, pressure of reacting gases, temperature, catalyst and surface area of solid reactants. To explain the effect of each condition on rate, a model of colliding particles is used. The rate of a reaction increases when the frequency of effective collisions increases by increasing the concentration of reactants in solution, the pressure of reacting gases and the surface area of solid reactants. Increasing temperature increases the frequency of collisions and makes the collisions more energetic, and so increases the rate of a reaction. A catalyst also speeds up a reaction as it provides an alternative route with a lower activation energy.

Learning Outcomes
(a) describe the effect of concentration, pressure, particle size and temperature on the rates of reactions and explain these effects in terms of collisions between reacting particles
(b) define the term *catalyst* and describe the effect of catalysts (including enzymes) on the rates of reactions
(c) explain how pathways with lower activation energies account for the increase in rates of reactions (see also **9**(b))
(d) state that some compounds act as catalysts in a range of industrial processes and that enzymes are biological catalysts (see also **8.3**(b), **9**(b), **10**(c), and **12**(d))
(e) suggest a suitable method for investigating the effect of a given variable on the rate of a reaction
(f) interpret data obtained from experiments concerned with rate of reaction

2.3 Chemistry in a Sustainable World

Overview

Ubiquitous in modern life, organic compounds range from the fuels we burn, the materials we use such as plastics to the food we eat. Urbanisation, industrialisation, increasing population and economic development have created a huge demand for consumption of materials and energy. These activities affect environmental sustainability which aims to meet the resource needs of present and future generations while preserving the health of the ecosystems that provides them.

Although crude oil is one of the most important raw materials in the world, it is non-renewable and finite. Besides providing us with fuels to generate energy, crude oil is also an important chemical feedstock for the production of useful materials such as plastics. To conserve this important resource for sustainable development, innovations by chemistry include alternative fuels such as biofuels and recycling of plastics. In addition, the uses of crude oil and plastics have their resulting environmental side-effects on the quality of air. Reactions used in solutions to maintain air quality are developed through understanding the sources of common air pollutants.

This section provides an avenue for students to apply their learning from other topics within the syllabus to assess the impacts of the consumption of organic compounds like fuels and plastics, the environmental issues related to their uses and the solutions afforded by chemistry.

TOPIC 11. ORGANIC CHEMISTRY

- Fuels and Crude Oil
- Hydrocarbons
- Alcohols, Carboxylic Acids and Esters
- Polymers

Guiding Questions

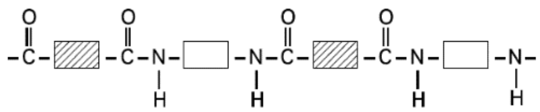
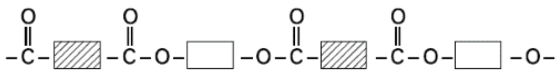
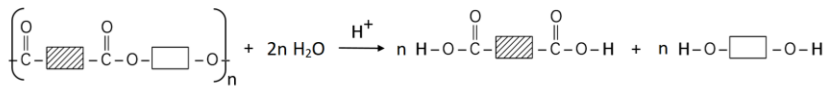
- Why are natural gas and crude oil important in our lives?
- How do chemists classify organic compounds into homologous series?
- Why is the systematic naming of organic compounds useful?
- How and why do organic compounds in different homologous series behave differently?
- What are the similarities and differences between addition polymers and condensation polymers?
- How does chemistry contribute to sustainable development, particularly in the area of plastics recycling?

Topic Description

As important sources of energy and raw materials, natural gas and crude oil consists of organic compounds. The creation of urea by Friedrich Wohler in 1828 dispelled the belief that organic compounds was from living organisms. His work led other chemists to attempt the synthesis of other organic compounds. The plethora of organic molecules are classified into homologous series such as alkanes, alkenes, alcohols and carboxylic acids.

Members in the same homologous series share characteristics like same functional group and general formula, and a gradual change in physical properties as one molecule differs from the next by a $-CH_2$ group. From these characteristics, predictions of physical and chemical properties of organic molecules in the same homologous series can be made. Polymers are large useful organic molecules formed by either addition or condensation reactions and they are non-biodegradable. Recycling plastic waste through physical and chemical means contribute to sustainability by turning it to chemical feedstock and fuel.

Learning Outcomes	
11.1 Fuels and Crude Oil	
(a)	name natural gas, mainly methane, and crude oil as non-renewable sources of energy
(b)	describe crude oil as a mixture of hydrocarbons and its separation by fractional distillation to yield fractions which have competing uses as fuels and as a source of chemicals (see also **1.2**(a))
(c)	describe biofuel (exemplified by bioethanol from sugarcane) as a renewable alternative to natural gas and crude oil
(d)	describe how biofuel, when compared to fossil fuels, can be more environmentally sustainable in terms of carbon dioxide emission (see also **12**(g))
11.2 Hydrocarbons	
(a)	describe a homologous series as a group of compounds with a general formula, similar chemical properties and showing a gradation in physical properties as a result of increase in the size and mass of the molecules, e.g. melting and boiling points; viscosity
(b)	describe the alkanes as a homologous series of saturated hydrocarbons with the general formula C_nH_{2n+2}
(c)	draw the structures of branched and unbranched alkanes, C_1 to C_4, and name the unbranched alkanes methane to butane
(d)	define *isomerism* and identify isomers
(e)	describe alkanes (exemplified by methane) as being generally unreactive except in terms of combustion and substitution by chlorine
(f)	describe the alkenes as a homologous series of unsaturated hydrocarbons with the general formula C_nH_{2n}
(g)	draw the structures of branched and unbranched alkenes, C_2 to C_4, and name the unbranched alkenes ethene to butene
(h)	describe the manufacture of alkenes and hydrogen by cracking hydrocarbons and recognise that cracking is essential to match the demand for fractions containing smaller molecules from the refinery process
(i)	describe the difference between saturated and unsaturated hydrocarbons from their molecular structures and by using aqueous bromine
(j)	describe the reactions of alkenes (exemplified by ethene) in terms of combustion, polymerisation (see also **11.4**(b)) and the addition with bromine, steam and hydrogen
(k)	state the meaning of *polyunsaturated* when applied to food products
(l)	describe the manufacture of margarine by the addition of hydrogen to unsaturated vegetable oils to form a solid product
11.3 Alcohols, Carboxylic Acids and Esters	
(a)	describe the alcohols as a homologous series containing the –OH group
(b)	draw the structures of branched and unbranched alcohols, C_1 to C_4, and name the unbranched alcohols methanol to butanol
(c)	describe the reactions of alcohols in terms of combustion and oxidation to carboxylic acids
(d)	describe the formation of ethanol by the catalysed addition of steam to ethene and by fermentation of glucose

Learning Outcomes
(e) describe the carboxylic acids as a homologous series containing the $-CO_2H$ group
(f) draw the structures of carboxylic acids, C_1 to C_4, and name the unbranched acids methanoic acid to butanoic acid
(g) describe the carboxylic acids as weak acids, reacting with carbonates, bases and some metals
(h) describe the formation of ethanoic acid by the oxidation of ethanol by atmospheric oxygen or acidified potassium manganate(VII)
(i) describe the reaction of a carboxylic acid with an alcohol to form an ester, e.g. ethyl ethanoate
(j) deduce the name and formula of an ester from the unbranched carboxylic acid, C_1 to C_4, and alcohol, C_1 to C_4, and vice versa
11.4 Polymers
(a) describe polymers as large molecules built up from small units (monomers), different polymers having different units and/or different linkages
(b) describe the formation of poly(ethene) as an example of addition polymerisation of ethene as the monomer (see also **11.2**(j))
(c) state some uses of poly(ethene) as a typical plastic, e.g. plastic bags; clingfilm
(d) deduce the structure of the polymer product from a given monomer and vice versa
(e) describe nylon, a polyamide, and *Terylene*, a polyester, as condensation polymers, the partial structure of nylon being represented as  and the partial structure of *Terylene* as  (details of manufacture and mechanisms of these polymerisations are **not** required.)
(f) state some typical uses of man-made fibres such as nylon and *Terylene*, e.g. clothing; curtain materials; fishing line; parachutes; sleeping bags
(g) describe the pollution problems caused by the disposal of non-biodegradable plastics
(h) describe two methods of recycling plastics as (i) physical method (exemplified by melting small pieces of poly(ethene) waste into pellets) (ii) chemical method (exemplified by depolymerisation and cracking of plastic waste into chemical feedstock and fuel respectively)
(i) describe depolymerisation as a process in which polymers are broken down into their monomers, exemplified by hydrolysis of polyesters using acid as a catalyst  (details of mechanisms are **not** required)
(j) discuss the social, economic and environmental issues of recycling plastics

TOPIC 12. MAINTAINING AIR QUALITY

Guiding Questions

- How does human activity impact the environment?
- What can we do to minimise the negative impacts of human activity on the environment?

Topic Description

A useful material, plastics are produced in large quantities generating a lot of waste and polluting the air when they are disposed of by burning. Atmospheric pollutants such as nitrogen oxides fall to Earth as acid rain and pollute land and water. Discarded waste when washed into rivers and seas pollutes them. Human activity at the individual and societal levels has impact on the environment.

The impact on the environment can be reduced by recycling some of the substances we use: recycling metals to conserve metal ores and recycling plastics to conserve the petroleum from which they are made. Focusing on an area of the environment, this topic discusses the sources and effects of air pollutants, and possible solutions to the problems they cause. These include several chemistry innovations like catalytic converters to reduce harmful exhaust emissions and flue gas desulfurization to mitigate the effect of acidic gases.

Learning Outcomes
(a) describe the volume composition of gases present in dry air as being approximately 78% nitrogen, 21% oxygen and the remainder being noble gases (with argon as the main constituent) and carbon dioxide
(b) name some common atmospheric pollutants, e.g. carbon monoxide; methane; nitrogen oxides (NO and NO_2); ozone; sulfur dioxide; unburned hydrocarbons
(c) state the sources of these pollutants as (i) carbon monoxide from incomplete combustion of carbon-containing substances (ii) nitrogen oxides from lightning activity and internal combustion engines (iii) sulfur dioxide from volcanoes and combustion of fossil fuels
(d) describe the reactions used in possible solutions to the problems arising from some of the pollutants named in (b) (i) the redox reactions in catalytic converters to remove combustion pollutants (see also **10**(d)) (ii) the use of calcium carbonate to reduce the effect of 'acid rain' and in flue gas desulfurisation
(e) discuss some of the effects of these pollutants on health and on the environment (i) the toxic nature of carbon monoxide (ii) the role of nitrogen dioxide and sulfur dioxide in the formation of 'acid rain' and its effects on respiration and buildings
(f) discuss the importance of the ozone layer and the problems involved with the depletion of ozone by reaction with chlorine-containing compounds, chlorofluorocarbons (CFCs)
(g) describe the carbon cycle in simple terms, to include (i) the processes of combustion, respiration and photosynthesis (ii) how the carbon cycle regulates the amount of carbon dioxide in the atmosphere (see also **11.1**(d))
(h) state that carbon dioxide and methane are greenhouse gases and may contribute to global warming; give the sources of these gases and describe the potential effects of increased levels of these greenhouse gases, including more extreme weather events and melting of polar ice

SECTION 3: PEDAGOGY

Teaching and Learning of Upper Secondary Chemistry
Students as Inquirers
Blended Learning
Teachers as Facilitators
Practical Work
Use of ICT
Designing STEM Learning Experiences in Science

3. PEDAGOGY

3.1 Teaching and Learning of Upper Secondary Chemistry

We believe that all students are curious and want to explore and learn about things around them. The curriculum seeks to nurture students as inquirers by providing opportunities for them to explore and to appreciate the role of *Science for Life and Society*.

To nurture students as inquirers, teachers are key in facilitating a variety of learning experiences to support students in understanding *Core Ideas*, developing *Practices* and cultivating *Values, Ethics and Attitudes*.

These learning experiences can be situated in various authentic contexts in both formal and informal settings and should inspire students to inquire and innovate. In designing purposeful and engaging learning experiences, teachers should consider amongst others, profile of students, resources available and relevant pedagogical approaches. Students should also be provided with opportunities to reflect on their own learning progress and act on feedback as part of Assessment for Learning (AfL).

Learning of science will not be complete without the incorporation of practical work, which develops in students the ways of thinking and doing while supporting their development of scientific knowledge and knowledge about science.

3.2 Students as Inquirers

For students to be inquirers, their thinking skills and dispositions should be developed as part of their learning experiences. To engage students as inquirers, they can be provided with learning experiences centred on authentic contexts that allow them to pose questions, be involved in discussions on socio-scientific issues, or be engaged in problem solving. Through these learning experiences, students are likely to

- ask questions as they engage with an event, phenomenon, problem or issue. They learn to be objective, ask questions which they are curious about and identify key variables of their questions. The questions and variables can guide the design of investigations, from which they draw valid conclusions.

- gather evidence to respond to their questions. They gather evidence through observations and collect qualitative or quantitative data using simple instruments. In the process, they have to make appropriate decisions about measurements or observations, which should be made with appropriate degree of precision and good details respectively.

- formulate explanations based on the evidences gathered. They explain their findings with integrity, based on evidence gathered (e.g. qualitative descriptions of observations or quantitative data collected over a time interval), conclusion(s) from the interpretation of experimental data or observations and underlying principles. They practise healthy scepticism towards the evidence gathered and observations made, and are aware of the effect of significant sources of errors on the reliability and validity of the explanations and conclusions reached.

- connect their explanations to various contexts. They explain how the concepts are related to or applied in various examples and contexts around them. This helps them to appreciate how science is relevant and universally applicable in everyday life and unfamiliar situations.

- communicate and justify their explanations. After data collection, they present and communicate the evidence in appropriate forms (e.g. tables, charts, graphs, with all quantitative data to an appropriate number of decimal places/significant figures) to facilitate the analysis of patterns and relationships. For example, they can use texts, drawings, charts, tables, graphs, equations or a combination of representations to support their explanations.

- reflect on their learning and progress. They can reflect on their learning (e.g. what they have learnt, how they would like to improve, what they are curious about) in different ways (e.g. ask questions, write journals). For laboratory-based learning experiences, students can propose how significant errors may be overcome or reduced, as appropriate, including how experimental procedures may be improved. These reflections help them take greater ownership of their own learning and develop deeper conceptual understanding.

3.3 Blended Learning

3.3.1 Why Blended Learning

Blended Learning in MOE's context transforms our students' educational experience by providing them with a more seamless blending of different modes of learning. The key intended student outcomes are to nurture (i) self-directed and independent learners; and (ii) passionate and intrinsically motivated learners.

An aspect of Blended Learning is the integration of home-based learning (HBL) as a regular feature of the schooling experience. HBL can be a valuable complement to in-person schooling. Regular HBL can equip students with stronger abilities, dispositions and habits for independent and lifelong learning, in line with MOE's Learn for Life movement.

Blended Learning presents an opportunity to re-think curriculum and assessment design and innovate pedagogies for a more effective and student-centric educational experience. It involves giving students more ownership and agency over how they learn, at a pace they are comfortable with. It also offers scope for teachers to tap the advantages of both in-person learning and distance learning to plan lessons best suited to each mode of learning opportunity.

3.3.2 What is Blended Learning

Blended Learning provides students with a broad range of learning experiences (see **Figure 3.1**).

Figure 3.1: Examples of Blended Learning experiences

Possible Blended Learning Experiences	What this means
Structured/Unstructured learning	A combination of structured time for students to learn within a given time frame and unstructured time for students to learn at their own pace and exercise self-management
Synchronous/Asynchronous learning	A combination of in-person schooling, live online lessons and online/offline learning where students learn remotely and at their own pace.
Within-curriculum/Out-of-curriculum learning	Opportunities for students to learn from and beyond the formal curriculum
Distance/In-person learning	Opportunities for students to learn during face-to-face lessons with teachers and peers in school, complemented by out-of-school learning activities
ICT-mediated/Non-ICT-mediated learning	Opportunities for students to learn through a combination of ICT-mediated and non-ICT-mediated learning experiences

Table 3.1: Elaboration of possible Blended Learning experiences

3.4 Teachers as Facilitators

In the teaching and learning process, teachers play an important role in stimulating students' curiosity, as well as encouraging students to see the value of science and its applications in their everyday lives.

To do these, teachers should ensure that the learning experiences provided for students go beyond learning facts and outcomes of scientific investigations. Teachers should play the role of facilitators to support students as inquirers.

As facilitators, teachers should:

- provide students with opportunities to ask questions about events/ phenomenon/problems/issues that are related to their daily lives, society and environment;

- support students in gathering and using evidence;
- encourage students to formulate and communicate explanations based on evidences gathered;
- encourage students to apply concepts learnt in understanding daily events/phenomenon, finding solutions to problems/issues and creating products; and
- provide students with opportunities to reflect on their own learning progress and act on feedback provided through formative assessment.

The *Pedagogical Practices* in the *STP*, as shown in **Figure 3.2**, comprise four core *Teaching Processes* which lie at the heart of good teaching. Teachers can refer to the Teaching Processes and relevant Teaching Areas under each process to guide them in the design and enactment of students' learning experiences. To design student-centred learning experiences, teachers will need to consider student profiles, readiness and needs as they transit from lower to upper secondary, as well as understand the interest and aspirations of these students as they progress to the next stage of studies and the future workplace.

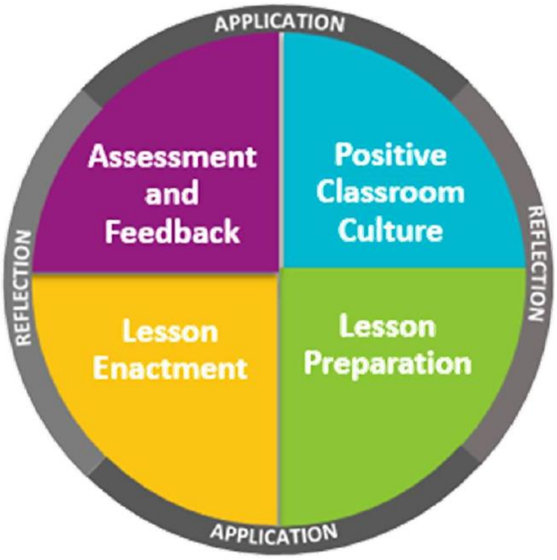


Figure 3.2: The four core *Teaching Processes* within the *Pedagogical Practices* in *STP*

3.5 Practical Work

Practical work is an essential component of science teaching and learning, both for the aim of developing students' scientific knowledge and that of developing students' knowledge about science.

Good quality science practical work supports the teaching and learning of science in the following ways:

- Developing science inquiry skills
- Developing experimental techniques and practical manipulative skills
- Understanding of the nature of scientific knowledge
- Enhancing conceptual understanding
- Cultivating interest in science and in learning science

3.6 Use of ICT

Integrating ICT can enhance teaching and learning practices in the science classroom.
Teachers are encouraged to harness:

- e-Pedagogy principles for lesson design;
- technology for active learning; and
- technology for assessment and feedback.

3.6.1 e-Pedagogy Principles for Lesson Design

<u>What is e-Pedagogy?</u>
e-Pedagogy is the practice of teaching with technology for active learning that creates a participatory, connected, and reflective classroom to nurture the future-ready learner.

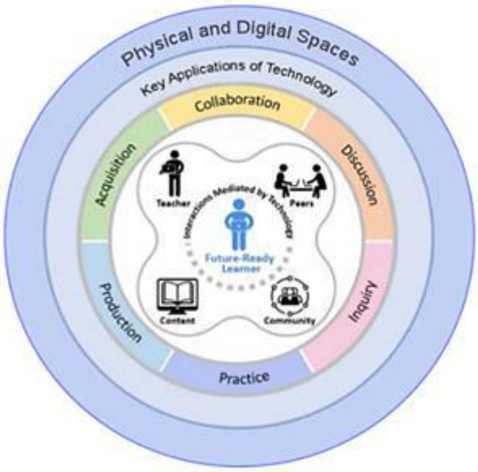


Figure 3.3: Overview of e-Pedagogy

Teachers can be guided by the Key Applications of Technology (see **Figure 3.3**) in designing different learning experience types to achieve the intended learning outcomes of the Science syllabus and the Science Curriculum Framework. The following are the LE types that teachers could design with technology: Acquisition, Collaboration, Discussion, Inquiry, Practice and Production. These learning experience types, occurring in the physical and/or digital spaces, capitalise on the role of technology in mediating learning interactions between the learner and the teacher, peers, content, and community.

3.6.2 Technology for Active Learning

Beyond the use of digital resources, there is a need to evaluate and select appropriate technological tools based on their pedagogical affordances and apply technologies to support active learning in science. For example, online collaboration tools can be used by teachers to facilitate students' co-construction of knowledge through scientific experimentation/investigations (inquiry-based learning) or discussion of science-related issues (socio-scientific issues-based learning).

In the Upper Secondary Chemistry syllabus, students can be acquainted with the use of basic digital tools (e.g. data loggers, simulations etc). Apart from better preparing students for the technologically-driven world, using digital tools in the classroom supports the development of the practices of science. For instance, when students are given opportunities to collect experimental data using these tools, competencies such as understanding experimental design can be strengthened. Digital tools such as simulations or virtual molecular models allow student to explore and visualise abstract concepts better.

3.6.3 Technology for Assessment and Feedback

Meaningful integration of technology also supports teacher-student interactions. When students are given opportunities to demonstrate their understanding in multi-modal ways, supported by technology (e.g. designing a digital artefact to illustrate the pollution problems caused by the disposal of plastics and the methods for recycling plastics, creating graphic organisers to evaluate the pros and cons of using biofuels), rich learning data is available for assessment and feedback. In designing AfL items in SLS, teachers should invite a range of different response strategies in order to assess students' learning, and use the monitoring features to understand students' learning gaps, provide timely feedback and track their learning progress.

3.7 Designing STEM Learning Experiences in Science

STEM education seeks to strengthen the interest and capabilities of our students in STEM to prepare them for an increasingly complex and uncertain world. We want our students to be curious about the world around them, to think creatively and critically in solving problems, and be concerned citizens who make a difference in society. These are in line with the goals of Science Education.

When designing STEM learning experiences, consider two aspects: 1) level of integration and 2) level of application. These two aspects lie on a continuum as illustrated in **Figure 3.4**.

Level of integration	***Disciplinary*** • Learning is anchored within a discipline.	⟵⟶	***Integrative*** • Learning involves integration of concepts/skills across two or more STEM disciplines.
Level of application	***Learning knowledge and skills through real-world examples*** • Use of real-world examples to illustrate concepts. • Involves application of knowledge/skills to solve simplified/routine problems set in real-world contexts.	⟵⟶	***Creative application of knowledge and skills in real-world contexts*** • Creative application of knowledge and skills (e.g. in ideating and making) to address real-world issues. • Involves application of knowledge/skills to solve complex real-world problems.

Figure 3.4: Design considerations for STEM Learning

SECTION 4: ASSESSMENT

4. ASSESSMENT

4.1 Purposes of Assessment

Assessment is the process of gathering and analysing evidence about student learning to make appropriate decisions and enhance learning. Assessment is integral to the teaching and learning process. In designing assessments, we need to have **clarity of purpose**. Assessment measures the extent to which desired knowledge, skills and attitudes are attained by students. It should produce both quantitative and qualitative descriptions of a learner's progress and development that can be analysed and used to provide feedback for improving future practices.

- Assessment provides feedback to **students**. It allows them to understand their strengths and weaknesses. Through assessment, students can monitor their own performance and progress. It also points them in the direction they should go to improve further. The use of feedback in this way helps students work towards mastering their 21CC.

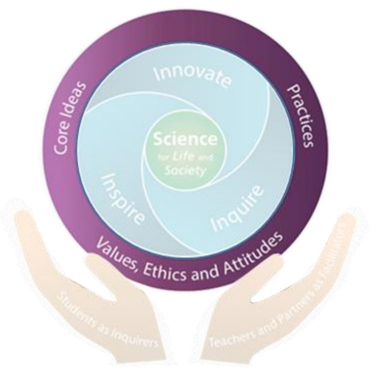
- Assessment provides feedback to **teachers**. It enables them to understand the strengths and weaknesses of their students. It provides information about students' attainment of learning outcomes (which includes 21CC development) as well as the effectiveness of their teaching.

- Assessment provides feedback to **schools**. The information gathered facilitates the placement of students in the appropriate course, and the promotion of students from one level to the next. It can also help to inform the review of the instructional programmes in schools.

- Assessment provides feedback to **parents**. It allows them to monitor their children's learning attainment and progress through the information obtained.

4.2 Scope of Assessment

Besides knowing the reasons for assessment, it is important to be clear about what is being assessed. If the assessment objectives are not clear, then the information obtained from the assessment process will not help improve student learning; neither will the information be meaningful for making decisions about student progression.



The *Science Curriculum Framework* shares that students should be provided with strong grounding in the three fundamentals:

- Core Ideas of Science
- Practices of Science
- Values, Ethics and Attitudes (VEA) in Science

These broad goals are translated into more specific learning objectives under the Subject Content section.

While VEA are usually not assessed formally, informal assessment is encouraged.

4.3 Designing Assessment for Learning (AfL)

Assessment for Learning (AfL) is assessment conducted constantly during classroom instruction to support teaching and learning. The critical feature about AfL is that information gathered from the assessment is used to adjust and improve the teacher's teaching strategies, as well as surface students' learning progress and difficulties.

4.4 Designing Assessment of Learning (AoL)

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 Preliminary and O/N-Level examinations are examples of AoL. To ensure content validity, the assessment should be designed to cover a representative sample of the syllabus. The assessment content should reflect the scope of the syllabus and be pitched at the appropriate demand.

For more information on the scheme of assessment for the national examinations, please refer to the Singapore Examinations and Assessment Board.

SECTION 5: ACKNOWLEDGEMENTS

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