Appendix II

Updated Chemistry (Secondary 4-6) Curriculum and Assessment Framework

(Consultation Draft)

Curriculum Development Council
June 2026

Preamble

The Updated Chemistry (Secondary 4-6) Curriculum and Assessment Framework (Consultation Draft) sets out the proposed update of the Chemistry Curriculum for Senior Secondary Level. This curriculum document presents the proposed curriculum rationale, curriculum framework and assessment framework of Chemistry (Secondary 4 – 6), including the learning targets, curriculum emphases, curriculum contents and public assessment. It also includes two Annexes, namely "The Use of Digital Educational Tools and Artificial Intelligence for Learning, Teaching and Assessment of Chemistry" and "Connections across Learning of Senior Secondary Science Subjects", which provide further guidance on promoting effective pedagogical use of digital and AI tools, as well as strengthening curriculum connection among the science subjects. The views collected from this consultation will be taken into consideration in the development of *Science Education Key Learning Area Chemistry Curriculum and Assessment Guide (Secondary 4-6)*.

Views and suggestions on this document may be sent to:

Chief Curriculum Development Officer (Science)
Science Education Section, Innovation Technology Education Division
Education Bureau
Room E232, 2/F, East Block
Education Bureau Kowloon Tong Education Services Centre
19 Suffolk Road, Kowloon Tong, Hong Kong
Fax: 2194 0670
E-mail: science@edb.gov.hk

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Chapter 1 Introduction

1.1 Background

Science education cultivates students' curiosity about the world and enhances their scientific thinking. Through systematic inquiry, students will develop scientific knowledge and skills to help them evaluate the impact of scientific and technological developments. This will prepare them to become lifelong learners in science and technology and responsible citizens, and contributors to the advancement of scientific and technological society.

Building on the Science Education curriculum across primary and junior secondary education, Chemistry, along with Physics and Biology, is offered as an elective subject under Science Education Key Learning Area in the senior secondary curriculum. The *Chemistry Curriculum and Assessment Guide (Secondary 4-6)* was first published in 2007. It was then updated in January 2014, November 2015 and June 2018 in response to the recommendations made in the Short-term Review and the Medium-term Review in 2012 and 2014 respectively as well as the Ongoing Renewal of the School Curriculum thereafter to fine-tune the senior secondary Chemistry curriculum and assessment.

Following the recommendations from the Task Force on Review of School Curriculum and the corresponding optimisation of the four senior secondary core subjects in 2021, the curriculum and assessment of the elective subjects, including Chemistry, were also reviewed along the same directions to formulate measures to create space for students and cater for learner diversity. A working group was established under the CDC-HKEAA Committee on Chemistry in April 2023 to kickstart the review and revision of the Chemistry curriculum. On top of creating space and catering for learner diversity, this review also aims to strengthen the articulation with the updated Science (Secondary 1-3) curriculum for further developing students' scientific literacy, enabling them to understand the impact and application of science for life and society, and fostering their science foundations for innovation and future pathways. The review also considered the directions set out in the report by the Task Force entitled "Optimise the curriculum for the future, foster whole-person development and diverse talents", and the related guidelines of the Curriculum Development Council's Secondary Education Curriculum Guide (CDC, 2017), the Science Education Key Learning Area Curriculum Guide (Primary 1 – Secondary 6) (CDC, 2017), and the Supplement to the Science Education Key Learning Area Curriculum Guide – Science (Secondary 1 to 3) Curriculum Framework (CDC, 2025).

1.2 Curriculum Rationale

The Chemistry Curriculum is designed to stimulate and cultivate students' interest in science, and to enhance their scientific literacy. Meanwhile, it also provides a strong foundation in science that nurtures their capacity to innovate and equips them to pursue further studies and professional careers in science and technology. It emphasises the cultivation of students' curiosity about the natural and material world, the strengthening of their scientific thinking, and the development of their understanding of how chemical knowledge is generated, communicated and applied.

Building on these directions, the Chemistry Curriculum articulates two closely linked core rationales: (i) **strengthening scientific literacy through chemistry learning**, enabling students to understand and flexibly apply chemical ideas, scientific thinking and scientific inquiry skills to analyse and solve real-world problems; and (ii) **providing strong science foundations for innovation and future pathways**, by equipping students with essential chemical knowledge and practical scientific skills needed to progress to innovation and technology-related studies and careers. The curriculum integrates core chemical ideas, scientific inquiry processes, and positive values and attitudes. Through coherent learning experiences, it guides students in mastering the abilities to explain scientific phenomena, solve problems and make evidence-based judgements. At the same time, it helps prepare them to contribute constructively to an increasingly innovation-driven and sustainability-focused world.

1.2.1 Strengthening scientific literacy through chemistry learning

The Chemistry Curriculum aims to develop students' scientific literacy by integrating scientific knowledge, inquiry practices, and positive values and attitudes through meaningful learning experiences. By engaging in various learning activities, such as science experiments, conceptual learning on chemistry ideas, scientific inquiry, data analysis, use of chemical language and conventions, and socio-scientific exploration, students gradually acquire the abilities to apply scientific thinking to explain phenomena, to solve real-life problems, and to evaluate science-related issues in personal, societal and global contexts.

Through this curriculum, students will gain an understanding of how chemical knowledge is generated, tested and refined, and learn to construct evidence-based explanations using appropriate chemical language and representations. They will also be guided to examine the ethical, social, economic and environmental impacts of chemical and technological developments. This strengthens their critical minds and ability to make informed decisions, recognise the values and limitations of science, and take responsible actions as citizens in a society shaped by scientific advancement and sustainable development.

1.2.2 Providing strong science foundations for innovation and future pathways

Chemistry explores the composition, structure and properties of matter, the interactions between substances, and the relationship between matter and energy. As the central science, it bridges the physical and life sciences, providing essential theoretical frameworks for explaining natural phenomena and technological applications.

This curriculum aims to equip students with a solid foundation in theoretical knowledge, practical competencies, and scientific reasoning skills. Through inquiry-based learning and application of concepts in authentic contexts, students develop quantitative reasoning and data analysis skills, critical thinking, and a deeper understanding of the nature of science and the connections of science with technology, society and the environment.

When students take Physics and/or Biology together with Chemistry at the senior secondary level, the coherence across science subjects further strengthens their conceptual understanding and transferable competencies. Shared scientific principles and inquiry methods reinforce learning effectiveness, promote interdisciplinary thinking, and enhance students' capacity to flexibly apply knowledge across domains. Such integrated preparation supports progression to tertiary studies in science, engineering, health sciences and other innovation-driven fields, enabling students to contribute to scientific advancement and sustainable development in a knowledge-based economy in the future.

1.3 Curriculum Aims

The overarching aim of the Chemistry Curriculum is to provide students with chemistry-related learning experiences that develop scientific literacy, enabling them to participate actively in a rapidly changing knowledge-based society, prepare for further studies or careers in chemistry- and STEAM-related fields, and become lifelong learners in science and technology.

The aims of the Chemistry Curriculum are to enable students to:

- develop interest and maintain a sense of wonder and curiosity about chemistry and science;
- construct and apply chemical knowledge to explain and solve problems using macroscopic, sub-microscopic and symbolic representations, and appreciate the relationship between chemistry and other disciplines;

- understand the nature of science, including the usefulness, limitations and evolving nature of scientific knowledge;
- acquire scientific knowledge, inquiry skills and scientific reasoning to investigate chemical phenomena and address unfamiliar situations with creativity and resilience;
- think, communicate and collaborate scientifically, and discuss, evaluate and make informed judgements on chemistry-related issues using the language of chemistry;
- recognise the social, ethical, economic, environmental and technological implications of chemistry and develop a commitment to act as responsible citizens in promoting sustainable development; and
- become lifelong learners in science, and be prepared for further studies and future careers in science, technology and engineering-related fields.

Chapter 2 Curriculum Framework

The Chemistry Curriculum framework embodies the key knowledge, skills, and values and attitudes that students are to develop at senior secondary level. Meanwhile, at the heart of the curriculum are two key emphases: “scientific inquiry as practice” and “STSE[1] connections and sustainability”. These emphases, which stem from the curriculum rationale, guide the holistic design and implementation of the curriculum, aiming to develop students’ scientific literacy and strengthen their capacity to integrate and apply knowledge and skills across disciplines to address various real-world challenges effectively and creatively.

Organised into fourteen topics, the curriculum provides both breadth and depth, ensuring a solid grasp of fundamental chemical principles and process skills while allowing for extended learning or in-depth exploration in selected areas. This curriculum framework serves as the solid foundation and clear guidelines for teachers to design a school-based chemistry curriculum and to plan effective learning, teaching, and assessment activities.

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[1] STSE refers to science, technology, society and the environment.

2.1 Learning Targets

The learning targets of the curriculum are categorised into three domains: knowledge and understanding, skills and processes, and values and attitudes.

2.1.1 Knowledge and understanding

Students are expected to:

- understand phenomena, facts and patterns, principles, concepts, laws and theories in chemistry;
- acquire and apply chemical vocabulary, terminology and conventions;
- appreciate the applications and relevance of chemistry in daily life and society; and
- understand the methods, processes and limitations of scientific investigations.

2.1.2 Skills and processes

(1) Scientific thinking

Students are expected to:

- identify patterns and changes in the natural and material world, and predict trends from them;
- recognise the role of models in exploring phenomena and that models evolve as evidence changes;
- examine evidence and apply logical reasoning to draw valid conclusions;
- analyse and evaluate theories and concepts using reasoning and experimentation; and
- integrate new concepts into existing knowledge framework and apply them to novel situations.

(2) Scientific method, investigations and problem solving

Students are expected to:

- identify scientific, technological, social and environmental problems, and ask relevant questions;
- identify assumptions, concepts and theories related to a problem posed;
- propose hypotheses, identify variables, and devise methods to test them;
- plan, carry out and manage investigations safely and effectively;
- record, analyse and interpret experimental observations accurately and honestly;
- analyse data gathered from experiments or other sources;

- draw conclusions, make predictions and evaluate suggested solutions from multiple perspectives;
- use appropriate techniques to present findings and to convey concepts;
- assess the validity, reliability and limitations of findings;
- propose further investigations or refinements if appropriate;
- apply knowledge and understanding to solve problems in unfamiliar situations; and
- recognise the usefulness and limitations of scientific methods.

(3) Decision making

Students are expected to:

- make decisions based on evidence, arguments and scientific principles;
- support judgements with reasoning, relevant chemical knowledge and appropriate scientific principles; and
- justify choices among alternatives using evidence-based reasoning.

(4) Practical work

Students are expected to:

- select appropriate apparatus and materials for an experiment;
- handle chemicals safely and apparatus in a proper way;
- carry out experiments and record observations accurately;
- interpret observations and experimental data;
- devise and plan experiments;
- evaluate experimental methods and suggest possible improvements; and
- use models to aid understanding of chemical phenomena.

(5) Information handling

Students are expected to:

- search, retrieve, reorganise, analyse and interpret scientific information from a variety of sources;
- use information technology to manage and present information and data;
- evaluate the accuracy, credibility and relevance of information from secondary sources; and
- distinguish between fact, opinion and value judgement when processing scientific information.

(6) Communication

Students are expected to:

- use symbols, formulae, equations and conventions accurately;
- interpret scientific information in verbal, diagrammatic, numerical, tabular and graphical forms;
- organise and present ideas and arguments clearly and logically; and
- communicate scientific ideas and values effectively and creatively.

(7) Collaboration

Students are expected to:

- participate actively and contribute ideas in group discussions;
- negotiate, liaise and compromise to achieve group goals;
- define roles and responsibilities among team members and work effectively as part of a team; and
- employ strategies to collaborate productively.

(8) Learning and self-directed learning

Students are expected to:

- develop study and self-directed learning skills to enhance the effectiveness and efficiency of learning; and
- cultivate the habits, attitudes and competencies essential for lifelong learning.

(9) Use of digital tools and artificial intelligence (AI)

Students are expected to:

- use a range of digital tools, including AI, to search for, select and organise information for chemistry learning and scientific investigations;
- use appropriate digital tools (e.g. data-loggers and sensors, spreadsheets, graphing software, computer simulations and AI) to process, present and interpret experimental data and scientific information;
- evaluate the reliability, limitations and possible biases of information, explanations and visualisations produced by digital tools and AI, by comparing them with trusted scientific information sources; and
- demonstrate ethical and responsible use of digital tools and AI in science contexts, including protecting data privacy, acknowledging AI and digital assistance appropriately, and avoiding plagiarism.

2.1.3 Values and attitudes

Students are expected to:

- develop curiosity and interest in scientific investigation;
- demonstrate integrity through objective observation and honest recording of data;
- communicate and make decisions on chemistry-related issues with an open-minded attitude;
- appreciate that chemistry is a developing science with inherent limitations;
- recognise the interrelationship of chemistry with other disciplines and its contribution to societal and cultural values;
- commit to safe laboratory practices;
- understand the social, economic, industrial, environmental and technological impacts of chemistry;
- reflect on the ethical and societal implications of using digital technologies and AI in chemistry-related fields; and
- commit to lifelong learning, including the effective and responsible use of digital technologies and AI, to adapt to a rapidly changing knowledge-based society.

Figure 2.1 summarises some important learning targets of the curriculum.

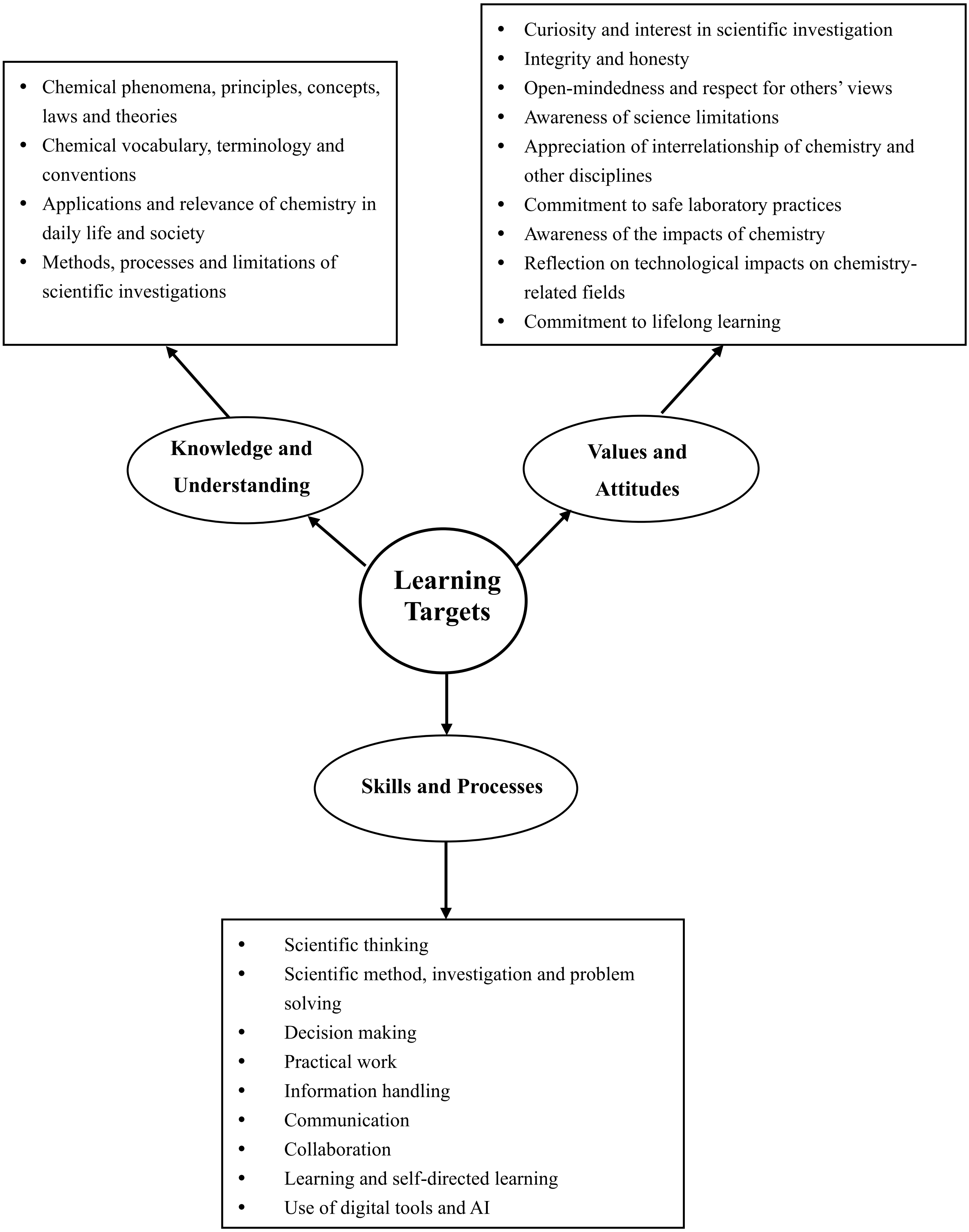


Figure 2.1 Learning Targets of the Chemistry Curriculum.

2.2 Curriculum Emphases

The following curriculum emphases are intended to provide teachers with clear guidance for the implementation of the curriculum, focusing not only on the core chemical knowledge and practical skills that students are expected to acquire but, more importantly, on providing the meaningful learning experiences to develop students' scientific literacy and lay a solid science foundation for their future studies and career development in the innovation and technology area.

2.2.1 Scientific inquiry as practice

Scientific Inquiry as a Core Learning Experience

As an experimental science, Chemistry learning emphasises not only theoretical understanding and experimental practices, but also an understanding of the construction and refinement processes of chemical knowledge. The Chemistry Curriculum emphasises scientific inquiry as a core learning experience, enabling students to practise investigation skills while cultivating scientific values, ethical awareness and responsible attitudes. Through experiments and inquiry-based activities across curriculum topics, students can develop competence in exploring phenomena, generating evidence, and constructing data-based explanations and solutions.

Hands-on and Minds-on Engagement in Practical Work

Practical work in Chemistry goes beyond procedural execution. More emphasis is placed on "minds-on" engagement, encouraging students to think critically about the validity of the experimental design, the underlying chemical principles, the sources of error, and the interpretation of results. Teachers are encouraged to incorporate higher-order thinking questions that prompt students to analyse patterns, explain observations using chemical principles, evaluate limitations of experiments, and propose improvements. This integrated hands-on and minds-on approach will help students develop logical reasoning, problem-solving and reflective thinking skills, reinforcing that scientific investigation requires intellectual engagement rather than mechanical procedures.

Scientific Values and Ethics

This curriculum also places importance on the cultivation of scientific integrity and ethical practice. Students are expected to demonstrate honesty in data recording and report writing, rational skepticism towards unsupported claims, openness to alternative explanations, and respect for empirical results. Emphasis is also placed on experimental risk assessment, laboratory safety practices and responsible behaviour when handling chemicals, fostering students' responsibility and care for themselves, others and the environment.

Progressive Development of Inquiry Skills

Students should build upon foundations laid in the science learning at junior secondary level to enhance their inquiry skills progressively from S4 to S6 through diverse practical and inquiry-based activities. Teachers are encouraged to incorporate inquiry elements systematically into their teaching design so that the development of scientific inquiry skills and the related values and attitudes becomes a key integrated component of daily learning and teaching.

Key learning components related to scientific inquiry include:

- Identifying investigable questions and making predictions
- Conducting risk assessments and adopting safe laboratory practices
- Planning and carrying out investigations to collect valid and reliable data
- Analysing data and communicating findings clearly and honestly
- Evaluating the validity, reliability and limitations of experimental results
- Suggesting improvements to enhance feasibility, validity and reliability

Topic XIV Scientific Inquiry in Chemistry provides details on the learning objectives and suggestions on planning and arranging inquiry-based practical activities to help students acquire the essential skills of scientific inquiry.

2.2.2 STSE connections and sustainability

Chemistry in Context: Science, Technology, Society and the Environment

The Chemistry Curriculum emphasises the interconnections of science, technology, society and the environment (STSE) and upholds the principles of sustainability to ensure that students do not learn chemical knowledge in isolation, but understand chemistry as an effective tool for explaining, evaluating and responding to real-world issues. Through this curriculum, students can appreciate how chemical knowledge contributes to improvements in quality of life, while also evaluating the ethical, social, economic and environmental implications of chemical and technological developments.

Sustainability and Responsible Application of Chemistry

Sustainability is a core theme woven throughout the Chemistry Curriculum. Students will recognise that while chemistry brings advancements and convenience to humanity, it also comes with environmental and social challenges. Therefore, they must make responsible decisions that balance long-term environmental, social, and economic benefits. The learning outcomes across topics require students to evaluate issues like metal recycling, the environmental impact of industrial processes (e.g. electroplating), the need for alternative energy, and the role of green chemistry. These learning experiences help cultivate students' sense of environmental responsibility and deepen their understanding of the close relationship between chemistry and sustainable development.

<u>Chemistry as a Foundation for Innovation and Technological Development</u>

Another key aspect of STSE connections in the Chemistry Curriculum is to guide students in recognising that chemistry serves as the foundation for driving major technological innovations in modern society. Chemical principles are not merely abstract knowledge but are the core driving force behind advanced materials, modern energy technologies, and the optimisation of industrial processes. Through exploring topics such as electrochemistry, organic synthesis, and analytical chemistry, students will appreciate how chemical knowledge drives technological innovation. Students should not only be able to state the applications of chemistry but also understand how chemical principles influence technological choices and evaluate their efficiency, sustainability, and ethical implications. They will also recognise that chemical technologies evolve over time in response to scientific advancement, societal demands, and environmental constraints.

<u>Socio-scientific Issues as a Platform for Cultivating Positive Values and Attitudes</u>

The curriculum also provides a platform for students to explore Socio-scientific Issues (SSI), such as evaluation of energy choices, the environmental impact of plastics, or the costs and benefits of industrial processes like the Haber process. These issues are often complex, open-ended and controversial, involving multiple stakeholders and value judgements rather than a single "correct" answer. Through discussion, students apply chemical knowledge and scientific reasoning while considering the interaction between ethical, social, economic, and environmental dimensions. They will also learn to distinguish evidence from opinion, construct arguments using chemical knowledge and data, articulate ethical positions, understand the limitations of science when addressing complex societal issues, and appreciate that real-world decision-making often requires balancing conflicting values and constraints.

2.3 Curriculum Structure

2.3.1 Time allocations

The table shows the topics and suggested time allocation for the Chemistry Curriculum.

Topic	Suggested lesson time (hours)
I. Microscopic world I	22
II. Metals	20
III. Acids and bases	28
IV. Microscopic world II	8
V. Redox reactions, chemical cells and electrolysis	25
VI. Fossil fuels and carbon compounds	19
VII. Chemical reactions and energy	9
VIII. Rate of reaction	20
IX. Chemical equilibrium	18
X. Chemistry of carbon compounds	20
XI. Important organic synthetic products	8
XII. Patterns in the chemical world	9
XIII. Analytical chemistry	24
XIV. Scientific inquiry in chemistry	20
Total	**250**

Remarks:
The lesson time for each elective subject is 250 hours (or 10% of the total allocation time) for planning purpose, and schools have the flexibility to allocate lesson time at their discretion in order to enhance learning and teaching effectiveness and cater for students' needs.

2.3.2 Curriculum contents

Topic I Microscopic World I (22 hours)

Overview

The study of chemistry involves the linkage between phenomena in the macroscopic world and the interaction of atoms, molecules and ions in the microscopic world. Through studying the structures of atoms, molecules and ions, and the bonding in elements and compounds, students will acquire knowledge of some basic chemical principles. These can serve to further illustrate the macroscopic level of chemistry, such as patterns of change, observations in various chemical reactions, the rates of reactions and chemical equilibria. In addition, students should be able to perform calculations related to chemical formulae, which are the basis of mole calculations to be studied in later topics.

Students should also be able to appreciate the interrelation between bonding, structures and properties of substances by learning the properties of metals, giant ionic substances, simple molecular substances and giant covalent substances. With the knowledge of various structures, students should be able to differentiate the properties of substances with different structures, and to appreciate that knowing the structure of a substance can help us decide its applications. This topic provides the basic knowledge for further study of the development of functional materials, e.g. polymers, in modern society.

Through activities such as gathering and analysing information about atomic structure and the Periodic Table, students should appreciate the impact of the discoveries of atomic structure and the development of the Periodic Table on modern chemistry. Students should also be able to appreciate that symbols and chemical formulae constitute part of the common language used by scientists to communicate chemical concepts.

Students should learn	Students should be able to
a. Atomic structure • elements, atoms and symbols • classification of elements into metals, non-metals and metalloids • electrons, neutrons and protons as subatomic particles • simple model of atom • atomic number (Z) and mass number (A) • isotopes • isotopic masses and relative atomic masses based on $^{12}C=12.00$ • electronic arrangement of atoms (up to Z=20) • stability of noble gases related to their electronic arrangements	• state the relationship between element and atom • use symbols to represent elements • classify elements as metals or non-metals on the basis of their properties • be aware that some elements possess characteristics of both metals and non-metals • state and compare the relative charges and the relative masses of a proton, a neutron and an electron • describe the structure of an atom in terms of protons, neutrons and electrons • interpret and use symbols such as $^{23}_{11}Na$ • deduce the numbers of protons, neutrons and electrons in atoms and ions with given atomic numbers and mass numbers • identify isotopes among elements with relevant information • perform calculations related to isotopic masses and relative atomic masses • understand and deduce the electronic arrangements of atoms • represent the electronic arrangements of atoms using electron diagrams • relate the stability of noble gases to the octet rule
b. The Periodic Table • the position of the elements in the Periodic Table related to their electronic arrangements • similarities in chemical properties among elements in Groups I, II, VII and 0	• understand that elements in the Periodic Table are arranged in order of ascending atomic number • appreciate the Periodic Table as a systematic way to arrange elements • define the group number and period number of an element in the Periodic Table • relate the position of an element in the Periodic Table to its electronic structure and vice versa • relate the electronic arrangements to the chemical properties of the Group I, II, VII and 0 elements

Students should learn	Students should be able to
	• describe differences in reactivity of Group I, II and VII elements • predict chemical properties of unfamiliar elements in a group of the Periodic Table
c. Bonding, structures and properties of metals • metallic bonding • giant metallic structures • properties of metals • differences in properties between metals and alloys	• describe the simple model of metallic bond • describe the general properties of metals • recognise that there are close-packed structures and open structures for metals (N.B.: The structures of specific metallic crystals (e.g. hexagonal close-packed structure and body-centered cubic structure) are not expected.) • relate the properties of metals to their giant metallic structures • recognise that alloys are formed by the introduction of other elements into metals • explain the differences in properties (e.g. hardness and conductivity) between metals and alloys (N.B.: The structures of specific alloys are not expected.)
d. Ionic and covalent bond • transfer of electrons in the formation of ionic bond • cations and anions • electron diagrams of simple ionic compounds • names and formulae of ionic compounds • ionic structure as illustrated by sodium chloride • sharing of electrons in the formation of covalent bond • single, double and triple bonds • electron diagrams of simple covalent	• describe the formation of ions and ionic bonds using electron diagrams • draw the electron diagrams of cations and anions • predict the ions formed by atoms of metals and non-metals by using information in the Periodic Table • identify polyatomic ions • name some common cations and anions according to the chemical formulae of ions • name ionic compounds based on the component ions • describe the colours of some common ions in aqueous solutions • interpret chemical formulae of ionic compounds in terms of the ions present and their ratios • construct formulae of ionic compounds based on their names or component ions

Students should learn	Students should be able to
molecules • names and formulae of covalent compounds • formula masses and relative molecular masses	• describe the structure of an ionic crystal • describe the formation of a covalent bond • describe the formation of single, double and triple bonds using electron diagrams • describe the formation of the dative covalent bond by means of electron diagram using H_3O^+ and NH_4^+ as examples • interpret chemical formulae of covalent compounds in terms of the elements present and the ratios of their atoms • write the names and formulae of covalent compounds based on their component atoms • communicate scientific ideas with appropriate use of chemical symbols and formulae • define and distinguish the terms: formula mass and relative molecular mass • perform calculations related to formula masses and relative molecular masses of compounds
e. Structures and properties of giant ionic substances	• describe giant ionic structures of substances such as sodium chloride and caesium chloride • state and explain the properties of ionic compounds in terms of their structures and bonding
f. Structures and properties of simple molecular substances	• describe simple molecular structures of substances such as carbon dioxide and iodine • recognise that van der Waals' forces exist between molecules • state and explain the properties of simple molecular substances in terms of their structures and bonding
g. Structures and properties of giant covalent substances	• describe giant covalent structures of substances such as diamond, graphite and quartz • state and explain the properties of giant covalent substances in terms of their structures and bonding

Students should learn	Students should be able to
h. Comparison of structures and properties of important types of substances	• compare the structures and properties of substances with giant ionic, giant covalent, simple molecular and giant metallic structures • deduce the properties of substances from their structures and bonding, and vice versa • explain applications of substances according to their structures

(Remark: The underlined text represents the extension component of the curriculum.)

Suggested Learning and Teaching Activities

A variety of learning and teaching activities, especially *practical activities*, should be arranged for students to develop the knowledge and skills listed in learning objectives (students should learn) and learning outcomes (students should be able to). Some related examples are:

Sub-topics	Learning and teaching activities	Key practical tasks
a. Atomic structure	• search for and present information on the discoveries related to the structure of an atom	
b. The Periodic Table	• search for and present information on elements and the development of the Periodic Table • investigate chemical similarities of elements in the same group of the Periodic Table • predict chemical properties of unfamiliar elements in a group of the Periodic Table	• perform experiments to investigate chemical similarities of elements in the same group of the Periodic Table (e.g. group II elements with dilute hydrochloric acid and group VII elements with sodium sulphite solution)

Sub-topics	Learning and teaching activities	Key practical tasks
c. Bonding, structures and properties of metals	• build models or study computer simulations of metallic crystals • compare the appearance, hardness, melting point and corrosion resistance of (a) brass and copper, (b) steel and iron, (c) solder and tin, (d) coinage metal and nickel, and (e) gold of different carats and pure gold	
d. Ionic and covalent bond	• predicting colours of ions from a group of aqueous solutions (e.g. predicting colour of K^+(aq), $Cr_2O_7^{2-}$(aq) and Cl^-(aq) from aqueous solutions of potassium chloride and potassium dichromate) • build models of three-dimensional ionic crystals and covalent molecules	• perform experiments to investigate the migration of ions of aqueous solutions, e.g. copper(II) dichromate and potassium permanganate, towards oppositely charged electrodes
h. Comparison of structures and properties of important types of substances	• study three-dimensional images of ionic crystals, simple molecular substances and giant covalent substances with the use of computer programmes • build models of diamond, graphite, quartz and iodine • predict the structures of substances from their properties, and vice versa • justify some particular applications of substances in terms of their structures • read articles or write essays on the applications of materials such as graphite and aluminium in relation to their structures	

Values and Attitudes

Students are expected to develop, in particular, the following *values and attitudes*:

- to appreciate that scientific evidence is the foundation for generalisations and explanations about matter.
- to appreciate the usefulness of models and theories in helping explain the structures and behaviours of matter.
- to appreciate the perseverance of scientists in developing the Periodic Table and hence to envisage that scientific knowledge changes and accumulates over time.
- to appreciate the restrictive nature of evidence when interpreting observed phenomena.

STSE Connection

Students are encouraged to appreciate and comprehend issues which reflect the interconnections of science, technology, society and the environment. Related examples are:

- Using the universal conventions of chemical symbols and formulae facilitates communication among people in different parts of the world.
- Some specialised new materials have been created on the basis of the findings of research on the structure, chemical bonding, and other properties of matter (e.g. bullet-proof fabric, superconductors and superglue).
- Among three natural isotopes of uranium, uranium-235 (U-235) is used as fuels of nuclear energy. However, its relative abundance is very low. Uranium enrichment is a process that uses physical properties to separate isotopes of uranium which can increase the isotopic proportion of U-235 from below 1 percent to over 90 percent.
- Graphene, due to its unique structure and properties, is being studied for use in high-performance applications such as gas-free water filtration system, graphene-enhanced sports equipment, and graphene super capacitors.

Topic II Metals (20 hours)

Overview

Metals have a wide range of uses in daily life. Therefore, the extraction of metals from their ores has been an important activity of human beings since prehistoric times. This topic provides opportunities for students to develop an understanding of how metals are extracted from their ores and how they react with other substances. Students are expected to establish a reactivity series of metals based on experimental evidence.

The corrosion of metals poses a socioeconomic problem to human beings. It is therefore necessary to develop methods to preserve the limited reserve of metals. An investigation of factors leading to corrosion and of methods to prevent metals from corroding is a valuable problem-solving exercise and can help students develop a positive attitude towards the use of resources on our planet.

A chemical equation is a concise and universally adopted way to represent a chemical reaction. Students should be able to transcribe word equations into chemical equations and appreciate that a chemical equation shows a quantitative relationship between reactants and products in a reaction. Students should also be able to perform calculations involving the mole and chemical equations. The mole concepts acquired from this topic prepare students for learning calculations involving concentration of solutions, molar volume of gases and equilibrium constant of reaction in other topics of the curriculum.

Students should learn	Students should be able to
a. Occurrence and extraction of metals • occurrence of metals in nature in free state and in combined forms • obtaining metals by heating metal oxides or by heating metal oxides with carbon	 • state the sources of metals and their occurrence in nature • explain why extraction of metals is needed • understand that the extraction of metals involves reduction of their ores • describe and explain the major methods of extraction of metals from their ores

Students should learn	**Students should be able to**
• extraction of metals by electrolysis • relation of the discovery of metals with the ease of extraction of metals and the availability of raw materials • limited reserves of metals and their conservations	• relate the ease of obtaining metals from their ores to the reactivity of the metals • deduce the order of discovery of some metals from their relative ease of extraction • write word equations for the extraction of metals • describe metal ores as a finite resource and hence the need to recycle metals • evaluate the recycling of metals from social, economic and environmental perspectives
b. Reactivity of metals • reactions of some common metals (sodium, calcium, magnesium, zinc, iron, lead, copper, etc.) with oxygen/air, water, dilute hydrochloric acid and dilute sulphuric acid • metal reactivity series and the tendency of metals to form positive ions • displacement reactions and their interpretations based on the reactivity series • prediction of the occurrence of reactions involving metals using the reactivity series • relation between the extraction method of a metal and its position in the metal reactivity series	• describe and compare the reactions of some common metals with oxygen/air, water and dilute acids • write the word equations for the reactions of metals with oxygen/air, water and dilute acids • construct a metal reactivity series with reference to their reactions, if any, with oxygen/air, water and dilute acids • write balanced chemical equations to describe various reactions • use the state symbols (*s*), (*l*), (*g*) and (*aq*) to write chemical equations • relate the reactivity of metals to the tendency of metals to form positive ions • describe and explain the displacement reactions involving various metals and metal compounds in aqueous solutions • deduce the order of reactivity of metals from given information • write balanced ionic equations • predict the feasibility of metal reactions based on the metal reactivity series • relate the extraction method of a metal to its position in the metal reactivity series
c. Reacting masses • quantitative relationship of the reactants and the products in a reaction as revealed by a	• understand and use the quantitative information provided by a balanced chemical equation • perform calculations related to moles, Avogadro's constant and molar masses

Students should learn	Students should be able to
chemical equation • the mole, Avogadro's constant and molar mass • reacting masses from chemical equations	• calculate masses of reactants and products in a reaction from the relevant equation and state the interrelationship between them • solve problems involving limiting reagents
d. Corrosion of metals and their protection • factors that influence the rusting of iron • methods used to prevent rusting of iron • socioeconomic implications of rusting of iron • corrosion resistance of aluminium • anodisation as a method to enhance corrosion resistance of aluminium	• describe the nature of iron rust • describe the essential conditions for the rusting of iron • describe and explain factors that influence the speed of rusting of iron • describe the observations when a rust indicator (a mixture of potassium hexacyanoferrate(III) and phenolphthalein) is used in an experiment that investigates rusting of iron • describe and explain the methods of rusting prevention as exemplified by i. coating with paint, oil or plastic ii. galvanising iii. tin-plating iv. electroplating v. cathodic protection vi. sacrificial protection vii. alloying • recognise the socio-economic impact of rusting • understand why aluminium is less reactive and more corrosion-resistant than expected • describe how the corrosion resistance of aluminium can be enhanced by anodisation

Suggested Learning and Teaching Activities

A variety of learning and teaching activities, especially *practical activities*, should be arranged for students to develop the knowledge and skills listed in learning objectives (students should learn) and learning outcomes (students should be able to). Some related examples are:

Sub-topics	**Learning and teaching activities**	**Key practical tasks**
a. Occurrence and extraction of metals	• search for and present information about the occurrence of metals and their uses in daily life • analyse information to relate the reactivity of metals to the chronology of the Bronze Age, the Iron Age and the modern era • decide on appropriate methods for the extraction of metals from their ores • perform experiments to extract metals from metal oxides (e.g. silver oxide, copper(II) oxide, lead(II) oxide, iron(III) oxide) • search for and present information about the metal-recycling industry of Hong Kong and the measures for conserving metal resources in the world	
b. Reactivity of metals	• write balanced chemical equations with the aid of computer simulations • construct a metal reactivity series based on experimental evidence • view a chemical demonstration of the displacement reaction between zinc and copper(II) oxide solid and interpret the observations	• perform experiments to investigate reactions of metals with oxygen/air, water and dilute acids • perform experiments to investigate displacement reactions of metals with aqueous metal ions

Sub-topics	Learning and teaching activities	Key practical tasks
c. Reacting masses	• perform an experiment to study the thermal decomposition of baking soda / sodium hydrogencarbonate and solving the related stoichiometric problems • perform calculations related to moles and reacting masses • practice writing chemical symbols and formulae, balancing chemical equations and solving stoichiometric problems using an AI-assisted self-learning platform	
d. Corrosion of metals and their protection	• perform experiments to study methods that can be used to prevent rusting • decide on appropriate methods to prevent metal corrosion based on social, economic and technological considerations	• perform experiments to investigate factors that influence rusting

Values and Attitudes

Students are expected to develop, in particular, the following *values and attitudes*:

- to appreciate the contribution of science and technology in providing us with useful materials.
- to appreciate the importance of making fair comparisons in scientific investigations.
- to value the need for adopting safety measures when performing experiments involving potentially dangerous chemicals and violent reactions.
- to show concern for the limited reserve of metals and realise the need for conserving and using these resources wisely.
- to appreciate the contribution of chemistry in developing methods of rust prevention and hence its socio-economic benefit.
- to understand the significance of different metal resources on the development of our country and recognise the necessity of safeguarding resource security.

STSE Connections

Students are encouraged to appreciate and to comprehend issues which reflect the interconnections of science, technology, society and the environment. Related examples are:

- Critical minerals are resources of metals that have essential applications in various industries and technologies, such as energy, aerospace, electronics, defense, and healthcare. Our country, like other countries and regions, has implemented strategies to secure the availability of these critical minerals with a view to supporting the national sustainable development.
- New technologies are being applied to increase the efficiency of the metal extraction process and at the same time to limit its impact on the environment.
- The development of new alloys to replace pure metals is needed in order to enhance the performance of some products, such as vehicles, aircrafts, window frames and spectacles frames. New alloys are also used to cope with the latest development of innovation and technology. For instance, titanium alloys have been used extensively in biomedical implants due to their resistance to corrosion in human body environment, high strength, low toxicity, and high capacity to join with bone or other tissues.
- Corrosion of metals can pose significant devastating impact on economy in many industries, and, even worse, cause injuries and loss of lives from related infrastructure and industrial incidents. Thus, engineers and scientists specialised on corrosion protection technology strive hard to study and understand the fundamentals, mechanisms and potential consequences of corrosion with a view to controlling it effectively.

Topic III Acids and Bases (28 hours)

Overview

Acids and bases/alkalis are involved in numerous chemical processes that occur around us, from industrial processes to biological ones, and from reactions in the laboratory to those in our environment. Students have encountered acids and alkalis in their junior science courses. In this topic, they will further study the properties and reactions of acids and bases/alkalis, and the concept of molarity. Students should also be able to develop an awareness of the potential hazards associated with the handling of acids and alkalis. In addition, building on the mole concepts acquired from Topic II, students will learn the calculations involving molar volume of gases at room temperature and pressure.

Students will learn to use an instrumental method of pH measurement, to prepare salts by different methods, and to perform volumetric analysis involving acids and alkalis. Through these experimental practices students should be able to demonstrate essential experimental techniques, to analyse data and to interpret experimental results. On completion of this topic, students are expected to have acquired the essential skills for conducting inquiry-based experiments, as well as some basic knowledge for carrying out more complicated quantitative analyses in chemistry.

Students should learn	Students should be able to
a. Introduction to acids and alkalis • common acids and alkalis in daily life and in the laboratory • characteristics and chemical reactions of acids as illustrated by dilute hydrochloric acid and dilute sulphuric acid • acidic properties and hydrogen ions ($H^+(aq)$) • role of water in exhibiting properties of acid • basicity of acid	• recognise that some household substances are acidic • state the common acids found in laboratory • describe the characteristics of acids and their typical reactions • write chemical and ionic equations for the reactions of acids • relate acidic properties to the presence of hydrogen ions ($H^+(aq)$) • describe the role of water for acids to exhibit their properties • state the basicity of different acids such as HCl, H_2SO_4, H_3PO_4, CH_3COOH • define bases and alkalis in terms of their reactions with acids

Students should learn	Students should be able to
• characteristics and chemical reactions of alkalis as illustrated by sodium hydroxide and aqueous ammonia • alkaline properties and hydroxide ions ($OH^-(aq)$) • corrosive nature of concentrated acids and concentrated alkalis	• recognise that some household substances are alkaline • state the common alkalis found in the laboratory • describe the characteristics of alkalis and their typical reactions • write chemical and ionic equations for the reactions of alkalis • relate alkaline properties to the presence of hydroxide ions ($OH^-(aq)$) • describe the corrosive nature of acids and alkalis and the safety precautions in handling them
b. Molar volume of gases • calculations involving molar volume of gases	• recognise that equal numbers of moles of gases occupy equal volumes at the same temperature and pressure (Avogadro's Law) • perform stoichiometric calculations involving molar volume of gases at room temperature and pressure (r.t.p.) (e.g. reactions of acids with metals and carbonates)
c. Concentration of solutions • concentration of solutions in mol dm^{-3} (molarity)	• convert the molar concentration of solutions to g dm^{-3} • perform calculations related to the concentration of solutions • recognise different ways in which concentrations of solutions and amount of substances are expressed in the contexts like chemistry laboratories, household products and environmental studies (N.B.: With sufficient information given, students should be able to interconvert different concentration units.)
d. Indicators and pH • acid-base indicators as exemplified by litmus, methyl orange and phenolphthalein • pH scale as a measure of acidity and alkalinity	• state the colours produced by litmus, methyl orange and phenolphthalein in acidic solutions and alkaline solutions • describe how to test for acidity and alkalinity using suitable indicators • relate the pH scale to the acidity or alkalinity of substances

Students should learn	Students should be able to
pH = - log[H⁺(aq)] • use of universal indicator and an appropriate instrument to measure the pH of solutions	• perform calculations related to the concentration of H^+(aq) and the pH value of a strong acid solution • suggest and demonstrate appropriate ways to determine pH values of substances
e. Strength of acids and alkalis • meaning of strong and weak acids as well as strong and weak alkalis in terms of their extent of dissociation in aqueous solutions • methods to compare the strength of acids/alkalis	• describe the dissociation of acids and alkalis • relate the strength of acids and alkalis to their extent of dissociation • describe acids and alkalis with the appropriate terms: strong and weak, concentrated and dilute • suggest and perform experiments to compare the strength of acids or alkalis
f. Salts and neutralisation • bases as chemical opposites of acids • neutralisation as the reaction between acid and base/alkali to form water and salt only • exothermic nature of neutralisation • preparation of soluble and insoluble salts • naming of common salts • applications of neutralisation	• write chemical and ionic equations for neutralisation • state the general rules of solubility for common salts in water • <u>describe the techniques used in the preparation, separation and purification of soluble and insoluble salts</u> • <u>suggest a method for preparing a particular salt</u> • name the common salts formed from the reaction of acids and alkalis • explain some applications of neutralisation
g. Volumetric analysis involving acids and alkalis • standard solutions • acid-alkali titrations	• describe and demonstrate how to prepare solutions of a required concentration by dissolving a solid or diluting a concentrated solution • calculate the concentration of the solutions prepared • describe and demonstrate the techniques of performing acid-alkali titration • apply the concepts of concentration of solution and use the results of acid-alkali titrations to solve stoichiometric problems

Students should learn	Students should be able to
	(N.B.: With sufficient information given, students should be able to solve problems involving back titration.) • communicate the procedures and results of a volumetric analysis experiment by writing a laboratory report

(Remark: The underlined text represents the extension component of the curriculum.)

Suggested Learning and Teaching Activities

A variety of learning and teaching activities, especially *practical activities*, should be arranged for students to develop the knowledge and skills listed in learning objectives (students should learn) and learning outcomes (students should be able to). Some related examples are:

Sub-topics	Learning and teaching activities [Inquiry-based experiments are marked with #]	Key practical tasks
a. Introduction to acids and alkalis	• search for examples of naturally occurring acids and bases, and their chemical composition • design and perform experiments to study the role of water in exhibiting properties of acids • search for information about the hazardous nature of acids/alkalis • investigate the action of dilute alkalis on ammonium compounds to give ammonia gas	• perform experiments to investigate the reactions of dilute acids with metals, carbonates, hydrogencarbonates, metal oxides and metal hydroxides • perform experiments to investigate the reactions of dilute alkalis with aqueous metal ions to form metal hydroxide precipitates

Sub-topics	Learning and teaching activities [Inquiry-based experiments are marked with #]	Key practical tasks
b. Molar volume of gases	• perform experiments to determine the molar volume of a gas	
c. Concentration of solutions	• perform calculations to convert concentrations in different units • perform calculations involving molarity	
d. Indicators and pH	• search for information about the nature of common acid-base indicators • perform experiments to find the pH values of some domestic substances • measure pH values of substances by using data-logger or pH meter	
e. Strength of acids and alkalis	• perform experiments for distinguishing a strong acid and a weak acid having the same pH value	• design and perform experiments to compare the strengths of acids/alkalis
f. Salts and neutralisation	• investigate the temperature change in a neutralisation process • search for and present information on applications of neutralisation	• prepare and isolate soluble and insoluble salts
g. Volumetric analysis involving acids and alkalis	• perform calculations on titration • perform experiments to determine the concentration of acetic acid in vinegar or the concentration of sodium hydroxide in drain cleaner # • perform experiments to extract useful substances from	• prepare a standard solution for volumetric analysis • perform acid-alkali titrations using suitable indicators

Sub-topics	Learning and teaching activities [Inquiry-based experiments are marked with #]	Key practical tasks
	plant materials and test their use as indicators for acid-base titrations # • write a detailed report for an experiment involving volumetric analysis • design an experiment with assistance of GenAI to determine the concentration of hydrogencarbonate ions in a household cleaner that also contains hydroxide ions, and evaluate the feasibility and safety of the proposed experimental procedures	

Values and Attitudes

Students are expected to develop, in particular, the following *values and attitudes*:

- to develop a positive attitude towards the safe handling, storage and disposal of chemicals, and hence adopt safe practices.
- to appreciate the importance of proper laboratory techniques and precise calculations for obtaining accurate results.
- to develop personal integrity through objective observation and honest recording of experimental data.

STSE Connections

Students are encouraged to appreciate and comprehend issues which reflect the interconnections of science, technology, society and the environment. Related examples are:

- Measures involving neutralisation have been implemented to control the emission of nitrogen oxides and sulphur dioxide from factories and power stations.

- Caustic soda is manufactured by the chloroalkali industry which is a traditional chemical raw materials industry.
- Volumetric analysis, as an essential technique in analytical chemistry, is applied in testing laboratories and forensic science.
- Antacid is a common drug which contains base(s) for neutralising stomach acid and therefore relieving stomach ache.
- There are many industrial processes and products in our daily-life that involve the applications of acid and base chemistry, e.g. food preparation and preservation, the pulp and paper industry, cleaning products, lead-acid batteries in cars, and treatment for accidental acid or base spills.

Topic IV Microscopic World II (8 hours)

Overview

This topic builds on Topic I and aims at broadening students' knowledge and concepts of bonding and structures of substances. Students will learn more about simple molecular substances such as the shapes and the non-octet structures of some covalent molecules. In addition, by learning the concept of electronegativity difference between atoms in covalent bonds, students should be able to identify the polar bonds and their partial charges. With reference to polarity of bonds and molecular shape, students should be able to explain the polarity of a molecule. The knowledge of polarity of molecules will in turn assist students in understanding the different natures of intermolecular forces. Students should also be able to understand the origin, nature and strength of hydrogen bonding, and differentiate van der Waals' forces in non-polar and polar covalent substances. With the knowledge of various intermolecular forces, they will be able to explain the properties of ice in terms of its structure.

Students should learn	**Students should be able to**
a. Simple molecular substances with non-octet structures	• recognise the existence of covalent molecules with non-octet structures • draw the electron diagrams of some non-octet molecules such as BF_3, PCl_5 and SF_6
b. Shapes of simple molecules	• predict and draw three-dimensional diagrams to represent shapes of (i) molecules with central atoms obeying octet rule; and (ii) molecules with central atoms not obeying octet rule and with no lone pair of electrons (such as BF_3, PCl_5 and SF_6) (N.B.: - Students are not expected to explain shapes of molecules and predict the shapes of polyatomic ions or molecules with more than one central atom. - Stating bond angles for the molecules is not expected.)
c. Polarity of bond and molecules	• define the electronegativity of an atom • describe the general trends in the electronegativities of the main group elements down a group

Students should learn	Students should be able to
	and across a period in the Periodic Table (N.B.: Students are not expected to memorise the electronegativity scales. But they should be able to describe the general trend in electronegativity of elements in the Periodic Table.) • explain how the sharing of electrons in covalent bonds leads to non-polar and polar bonds • explain the polar nature of molecules (such as HF, H_2O, NH_3 and $CHCl_3$) and the non-polar nature of molecules (such as CH_4 and BF_3) with reference to electronegativity, polarity of bonds and molecular shape (N.B.: Dipole moment (i.e. the magnitude of the separated charge x the distance between the charges) is not expected.)
d. Intermolecular forces • van der Waals' forces • hydrogen bonding	• explain the existence of van der Waals' forces in non-polar and polar covalent substances • state the factors affecting the strength of van der Waals' forces between molecules (N.B.: Classifying van der Waals' forces into "dipole-dipole forces", "dispersion forces", "permanent dipole-permanent dipole attractions", "permanent dipole-induced dipole attractions", "instantaneous dipole-induced dipole attractions" etc. is not expected.) • compare the strength of van der Waals' forces with that of covalent bonds • describe the formation of hydrogen bonding as exemplified by HF, H_2O and NH_3 • compare the strength of van der Waals' forces with that of hydrogen bonding • understand the effect of hydrogen bonding on properties of substances such as water and ethanol
e. Structure and properties of ice	• describe the structure of ice • state and explain the properties of ice in terms of its structure and bonding

Suggested Learning and Teaching Activities

A variety of learning and teaching activities, especially *practical activities*, should be arranged for students to develop the knowledge and skills listed in learning objectives (students should learn) and learning outcomes (students should be able to). Some related examples are:

Sub-topics	Learning and teaching activities	Key practical tasks
b. Shapes of simple molecules	• read articles on how Valence Shell Electron Pair Repulsion (VSEPR) theory can be used to predict the shapes of molecules and its limitations • investigate the shapes of some selected molecules with the aid of computer simulations and/or AI	
c. Polarity of bond and molecule	• investigate polarity of molecules with the aid of computer simulations	• perform an experiment to investigate the effect of a non-uniform electrostatic field on a jet of polar and non-polar liquid

Sub-topics	Learning and teaching activities	Key practical tasks
d. Intermolecular forces	• investigate the effect of hydrogen bonding on liquid flow (e.g. comparing the viscosity of alcohols possessing different numbers of hydroxyl groups) • determine the strength of the hydrogen bonding formed between ethanol molecules • compare the boiling points of propane, methoxymethane and ethanol in terms of van der Waals' forces and hydrogen bonding • investigate the evaporation rates of substances with different intermolecular forces • investigate the surface tension and viscosity of water • search for and present information on the important role of hydrogen bonding in macromolecules such as DNA and proteins • investigate the properties of graphite in terms of its structure and bonding	
e. Structure and properties of ice	• build model of ice • view and manipulate three-dimensional images of crystal structures using a computer programme	

Values and Attitudes

Students are expected to develop, in particular, the following *values and attitudes*:

- to recognise that general rules in chemistry, such as the octet rule, often have exceptions.
- to appreciate the usefulness of models and theories in helping explain the structures and behaviours of matter.
- to appreciate the usefulness of models in helping us visualise the structure of substances.
- to appreciate that knowledge about bonding may advance and have to be revised as new evidence arises

STSE Connections

Students are encouraged to appreciate and comprehend issues which reflect the interconnections of science, technology, society and the environment. Related examples are:

- Understanding of intermolecular forces is essential for scientists and engineers to study physical properties and working principles of various daily-life substances, e.g. glues, detergents, non-stick coating, plastics, nanomaterials, etc.
- Intermolecular forces are crucial for the proper functioning of biological systems, including protein folding, biological catalysis, and DNA replication.
- Hydrogen bonding has a significant influence on the specific heat capacity of water, making it much higher than that of other substances. The high specific heat capacity of water allows it to be used as a coolant in nuclear power plants and a thermal energy storage medium in solar power plants.

Topic V Redox Reactions, Chemical Cells and Electrolysis (25 hours)

Overview

Chemical reactions involve the release or absorption of energy, which often appear in the form of heat, light or electrical energy. In a chemical cell, chemical energy is converted to electrical energy. The flow of electrons in an external circuit indicates the occurrence of reduction and oxidation (redox) at the electrodes. To help students understand the chemistry involved in a chemical cell, the concept of redox reactions is introduced in this topic. Students will carry out investigations involving common oxidising and reducing agents. They will also learn how to write chemical equations for redox reactions.

With the concepts related to redox reactions, students should be able to understand the reactions occurring in more complicated chemical cells and the processes involved in electrolysis. Students should also appreciate that the feasibility of a redox reaction can be predicted by comparing the different positions of the species in the electrochemical series. In addition, students should be able to predict products in electrolysis according to the different factors affecting the preferential discharge of ions.

The concepts of redox reactions have a number of applications in industrial chemistry and daily life. Students should appreciate the contribution of electrochemistry to technological innovations, which in turn improve our quality of life. Students should also be able to assess the environmental impact and safety issues associated with these technologies.

Students should learn	**Students should be able to**
a. Chemical cells in daily life • primary cells and secondary cells	• distinguish between primary and secondary cells • select and justify the uses of common primary and secondary cells according to their characteristics: i. zinc-carbon cell

Students should learn	Students should be able to
	ii. alkaline manganese cell iii. silver oxide cell iv. lead-acid accumulator v. nickel metal hydride (NiMH) cell vi. lithium ion cell (N.B.: Describing structures and working principles of zinc-carbon cell, alkaline manganese cell, silver oxide cell, lead-acid accumulator, nickel metal hydride (NiMH) cell and lithium ion cell are not expected.) • understand the environmental impact of using dry cells • recognise the need of recycling rechargeable batteries
b. Reactions in simple chemical cells • chemical cells consisting of: i. two metal electrodes and an electrolyte ii. metal-metal ion half cells and salt bridge/porous device • changes occurring at the electrodes and electron flow in the external circuit • half equations and overall cell equations	• describe and demonstrate how to build simple chemical cells using metal electrodes and electrolytes • measure the voltage produced by a chemical cell • explain the problems associated with a simple chemical cell consisting of two metal electrodes and an electrolyte • explain the functions of a salt bridge/porous device • describe and demonstrate how to build simple chemical cells using metal-metal ion half cells and salt bridges/porous devices • explain the differences in voltages produced in chemical cells when different metal couples are used as electrodes • write a half equation representing the reaction at each half cell of a simple chemical cell • write overall equations for simple chemical cells • predict the electron flow in the external circuit and the chemical changes in the simple chemical cells

Students should learn	Students should be able to
c. Redox reactions • oxidation and reduction • oxidation numbers • common oxidising agents (e.g. $MnO_4^-(aq)/H^+(aq)$, $Cr_2O_7^{2-}(aq)/H^+(aq)$, $Fe^{3+}(aq)$, $Cl_2(aq)$, $HNO_3(aq)$ of different concentrations and conc. $H_2SO_4(l)$) • common reducing agents (e.g. $SO_3^{2-}(aq)$, $I^-(aq)$, $Fe^{2+}(aq)$, $Zn(s)$) • balancing equations for redox reactions	• identify redox reactions, oxidising agents and reducing agents on the basis of i. gain or loss of oxygen/hydrogen atom(s) ii. gain or loss of electron(s) iii. changes in oxidation numbers • assign oxidation numbers to the atoms of elements and compounds • construct a general trend of the reducing power of metals and the oxidising power of metal ions • describe the chemical changes of some common oxidising agents and reducing agents • relate the trends of the reducing power and oxidising power of chemical species to their positions in a given electrochemical series • balance half equations of reduction and oxidation • balance redox equations by using half equations or changes in oxidation numbers
d. Redox reactions in chemical cells • chemical cells with inert electrodes • fuel cell	• describe and construct chemical cells with inert electrodes • predict the chemical changes at each half cell of the chemical cells with inert electrodes • write a half equation for reaction occurring at each half cell and the overall ionic equation for reaction in the chemical cells with inert electrodes (N.B.: With sufficient information given, students are expected to apply the concepts of electrochemistry to solve problems involving more complicated chemical cells.) • <u>understand the principles of hydrogen-oxygen fuel cell</u> • <u>write the half equation for reaction occurring at each electrode and the overall equation for reaction in a hydrogen-oxygen fuel cell</u> • <u>state the pros and cons of a hydrogen-oxygen fuel cell</u> • <u>recognise the benefits and the challenges of using hydrogen fuel cells for transportation</u>

<table>
<tr><th>Students should learn</th><th>Students should be able to</th></tr>
<tr><td>e. Electrolysis
• electrolysis as the decomposition of substances by electricity as exemplified by electrolysis of
i. dilute sulphuric acid
ii. sodium chloride solutions of different concentrations
iii. copper(II) sulphate solution
• anodic and cathodic reactions
• preferential discharge of ions in relation to the electrochemical series, concentration of ions and nature of electrodes
• industrial applications of electrolysis:
i. electroplating
ii. chloroalkali industry</td><td>• describe the materials needed to construct an electrolytic cell
• predict products at each electrode of an electrolytic cell with reference to the factors affecting the preferential discharge of ions
• describe the anodic and cathodic reactions, overall reaction and observable changes of the electrolyte in electrolytic cells
• <u>understand the principles of electroplating</u>
• <u>describe the anodic and cathodic reactions, overall reaction and observable changes of electrolyte in electroplating</u>
• <u>describe the importance of the chloroalkali industry</u>
• <u>explain the underlying chemical principles involved in flowing mercury cell process and membrane cell process of the chloroalkali industry</u>
• <u>understand the environmental impact of the electroplating industry and the chloroalkali industry</u></td></tr>
</table>

(Remark: The underlined text represents the extension component of the curriculum.)

Suggested Learning and Teaching Activities

A variety of learning and teaching activities, especially *practical activities*, should be arranged for students to develop the knowledge and skills listed in learning objectives (students should learn) and learning outcomes (students should be able to). Some related examples are:

Sub-topics	**Learning and teaching activities** **[Inquiry-based experiments are marked with #]**	**Key practical tasks**
a. Chemical cells in daily life	• make decisions on the choice of chemical cells in daily life based on available information • searching for and presenting information about the recycling of rechargeable batteries	
b. Reactions in simple chemical cells	• predict changes in chemical cells based on given information	• make simple chemical cells and measure their voltages
c. Redox reactions	• balance redox equation by using ionic half equations or using oxidation numbers • investigate redox reactions of concentrated sulphuric acid with metals • investigate redox reactions of nitric acid of different concentrations with metals • investigate the chemistry involved in oxygen absorbers of packaged food	• perform experiments to investigate redox reactions with common oxidising and reducing agents

Sub-topics	Learning and teaching activities **[Inquiry-based experiments are marked with #]**	Key practical tasks
d. Redox reactions in chemical cells	• search for and present information about the applications of fuel cells • investigate the working principles of a fuel cell car • discuss the pros and cons of using hydrogen fuel cells in vehicles • read scientific articles on cutting-edge research on hydrogen fuel technology using AI-assisted tools • perform experiments to investigate the working principles of a lead-acid accumulator • view computer simulations illustrating the reactions in chemical cells • design and construct a chemical cell using given materials and equipment and testing its performance #	
e. Electrolysis	• perform microscale experiments to study electrolysis of tin(II) chloride solution or dilute sodium chloride solution • extract copper metal from a given copper ore sample, e.g. $CuCO_3 \cdot Cu(OH)_2 \cdot H_2O(s)$ # • search for and present information about the possible adverse impact of the electroplating industry on the environment • design and perform electroplating experiments # • reading articles about the industrial processes involved in the extraction of aluminium from aluminium ore	• perform experiments to investigate changes in electrolysis • perform experiments to investigate factors affecting preferential discharge of ions during electrolysis

Values and Attitudes

Students are expected to develop, in particular, the following *values and attitudes*:

- to value the contribution of technological innovations to the quality of life and the sustainability of the environment.
- to develop a positive attitude towards the safe handling, storage and disposal of chemicals, and hence adopt safe practices.
- to appreciate the endeavour of scientists in the discovery and development of new battery innovations
- to be aware of the impact of chemistry in social, economic, industrial, environmental and technological contexts.

STSE Connections

Students are encouraged to appreciate and comprehend issues which reflect the interconnections of science, technology, society and the environment. Related examples are:

- Fuel cells are being used for some areas like space missions and transportation. For instance, the use of hydrogen fuel cell vehicles is one of the major strategies in our country to reduce air pollution and greenhouse gas emissions.
- While lithium-ion batteries for electric vehicles are widely used as a dominant fossil-free technology in transportation, there is a risk of supply of the raw materials for manufacturing lithium-ion batteries to meet the demand. Therefore, researchers look for alternative battery technologies with lower risk of running out of raw materials, such as sodium-ion batteries.
- Redox reactions are utilised in wastewater treatment to break down organic pollutants such as pharmaceuticals, pesticides, and dyes into harmless end-products like carbon dioxide and water.
- Many electrolytic processes are involved in industrial processes, e.g. refining of metals, the chloroalkali industry and the aluminium production from ore (bauxite).
- The development of electrolysis in extracting reactive metals is closely related to human history.

Topic VI Fossil Fuels and Carbon Compounds (19 hours)

Overview

Carbon compounds play an important role in industry and in daily life. Coal and petroleum are two major sources of carbon compounds. In this topic, the main focus is placed on the use of petroleum fractions as fuel and as a source of hydrocarbons. Students should appreciate that the use of fossil fuels has brought us benefits and convenience, such as providing us with domestic and transportation fuels, alongside environmental problems such as air pollution, acid rain, and the global warming. Eventually, they should realise that human activities can have a significant impact on our environment.

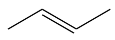
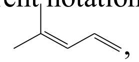
This topic also introduces some basic concepts of organic chemistry such as homologous series, functional group, general formula and structural formula. Students should be able to give systematic names of alkanes, alkenes, alkanols and alkanoic acids with carbon chains containing not more than eight carbon atoms. In addition, they are expected to learn the chemical reactions of alkanes, alkenes and alkanols.

Polymers can be synthesised by reacting small organic molecules (monomer) together in a chemical reaction. This process is called polymerisation. Students should understand the formation of addition polymers. Also, they should realise that the uses of some common addition polymers can be related to their physical properties which are, in turn, related to their structures.

Building on the mole concepts acquired from previous topics, this topic further introduces concepts related to percentage by mass of an element in a compound, empirical formulae and molecular formulae for a complete stoichiometric treatment of chemical equations at this level of study.

Students should learn	**Students should be able to**
a. Hydrocarbons from fossil fuels	
• coal, petroleum and natural gas as sources of fossil fuels and carbon compounds	• describe the origin of fossil fuels • describe petroleum as a mixture of hydrocarbons and its industrial separation into useful fractions

Students should learn	Students should be able to
• composition of petroleum and its separation • gradation in properties of the various fractions of petroleum • heat change during combustion of hydrocarbons • major uses of distilled fractions of petroleum • consequences of using fossil fuels	by fractional distillation • recognise the economic importance of petroleum as a source of aliphatic and aromatic hydrocarbons (e.g. benzene) • relate the gradation in properties (e.g. colour, viscosity, volatility and burning characteristics) with the number of carbon atoms in the molecules of the various fractions • explain the demand for the various distilled fractions of petroleum • recognise combustion of hydrocarbons as an exothermic chemical reaction • relate some common air pollutants (e.g. carbon monoxide, nitrogen oxides, sulphur dioxide, unburnt hydrocarbons) with the combustion of fossil fuels • describe the effects of the pollutants arising from the combustion of fossil fuels on health and the environment • describe how the following methods are used to minimise air pollutants from the combustion of fossil fuels: i. catalytic converters in car exhaust system ii. scrubbers in industry iii. using fuels of low sulphur content in vehicles and industry • recognise the need for alternative sources of energy
b. Homologous series, structural formulae and naming of carbon compounds • unique nature of carbon • homologous series as illustrated by alkanes, alkenes, alkanols and alkanoic acids • structural formulae and systematic naming of alkanes, alkenes, alkanols and alkanoic acids • percentage by mass of an element in a compound	 • explain the large number and diversity of carbon compounds with reference to carbon's unique combination power and ability to form different bonds • explain the meaning of a homologous series • understand that members of a homologous series show a gradation in physical properties and similarity in chemical properties • write structural formulae of alkanes • give systematic names of alkanes

Students should learn	Students should be able to
• empirical formulae and molecular formulae derived from experimental data	• extend the knowledge of naming carbon compounds and writing structural formulae to alkenes, alkanols and alkanoic acids (N.B.: - Students should be able to give systematic names of alkanes, alkenes, alkanols and alkanoic acids with up to eight carbon atoms in their carbon chains. - Students should be able to use different notations in drawing/writing structural formulae of organic compounds (e.g.  , , $CH_3CH{=}CHCH_3$, $CH_3(CH_2)_2CH{=}CH_2$).) • calculate the percentage by mass of an element in a compound • determine empirical formulae and molecular formulae from compositions by mass and molar masses
c. Alkanes and alkenes • petroleum as a source of alkanes • alkanes • cracking and its industrial importance • alkenes	 • distinguish saturated and unsaturated hydrocarbons from the structural formulae • describe the following reactions of alkanes: i. combustion ii. substitution reactions with chlorine and bromine, as exemplified by the reaction of methane and chlorine (or bromine) • recognise that cracking is a means to obtain smaller molecules including alkanes and alkenes • describe how to carry out laboratory cracking of a petroleum fraction • explain the importance of cracking in the petroleum industry • describe the reactions of alkenes with the following reagents: i. bromine ii. potassium permanganate solution • demonstrate how to carry out chemical tests for unsaturated hydrocarbons
d. Addition polymers • monomers, polymers and repeating units	 • recognise that synthetic polymers are built up from small molecules called monomers

Students should learn	Students should be able to
• addition polymerisation • structures, properties and uses of addition polymers as illustrated by polyethene, polypropene, polyvinyl chloride and polystyrene	• recognise that alkenes, unsaturated compounds obtainable from cracking of petroleum fractions, can undergo addition reactions • understand that alkenes and unsaturated compounds can undergo addition polymerisation (N.B.: - Students should be reminded that carbon-carbon double bonds in benzene and phenyl group of the aromatic compounds cannot undergo addition polymerisation. - Students are not expected to explain the stability of benzene and aromatic compounds.) • write structural formulae of addition polymers based on given monomers: polyethene, polypropene, polyvinyl chloride, polystyrene • deduce the repeating unit of an addition polymer obtained from a given monomer • describe addition polymerisation using chemical equations • deduce the monomer from a given section of a formula of an addition polymer (N.B: Recall of structural formulae of specific polymers is not expected.)

Suggested Learning and Teaching Activities

A variety of learning and teaching activities, especially *practical activities*, should be arranged for students to develop the knowledge and skills listed in learning objectives (students should learn) and learning outcomes (students should be able to). Some related examples are:

Sub-topics	**Learning and teaching activities**	**Key practical tasks**
a. Hydrocarbons from fossil fuels	• search for and present information about the locations of deposits of coal, petroleum and natural gases in the nation and other countries • investigate colour, viscosity, volatility and burning characteristics of petroleum fractions • search for and present information about petroleum fractions regarding their major uses and the relation between their uses and properties • search for information and presenting arguments on the risks and benefits of using fossil fuels to the society and the environment • discuss the relationship between global warming and the use of fossil fuels • search for and present information about the international treaty on climate change – the Paris Agreement • read articles about the components and sources of the main greenhouse gases and their impact to the global warming • discuss the pros and cons of using alternative sources of energy in Hong Kong	

Sub-topics	**Learning and teaching activities**	**Key practical tasks**
b. Homologous series, structural formulae and naming of carbon compounds	• build molecular models of simple alkanes, alkenes, alkanols and alkanoic acids • perform calculations to determine the empirical formula and molecular formula of an organic compound containing carbon, hydrogen and oxygen • perform an experiment to determine the empirical formula of copper(II) oxide	
c. Alkanes and alkenes	• perform an experiment on cracking of a petroleum fraction and testing the products	• perform experiments to investigate the typical reactions of alkanes and alkenes • select and carry out suitable chemical tests for unsaturated hydrocarbons
d. Addition polymers	• search for information or read articles about the discovery of polyethene and the development of addition polymers • build physical or computer models of addition polymers • perform an experiment to prepare polystyrene	

Values and Attitudes

Students are expected to develop, in particular, the following *values and attitudes*:

- to appreciate the importance of organising scientific information in a systematic way.
- to recognise the benefits and impacts of the application of science and technology.
- to value the need for the conservation of the Earth's resources.
- to appreciate the need for alternative sources of energy for sustainable development of our society.
- to recognise the need for the safe use and storage of fuels.
- to show concern for the environmental issues and develop a sense of shared responsibility for sustainable development of Hong Kong, our country and the world, and to recognise the necessity of safeguarding the nation's ecological and resource security.

STSE Connections

Students are encouraged to appreciate and comprehend issues which reflect the interconnections of science, technology, society and the environment. Related examples are:

- The petroleum industry provides us with many useful products that have improved our standard of living. However, there are risks associated with the production, transportation, storage and usage of fossil fuels.
- Emissions produced from the burning of fossil fuels are polluting the environment and are contributing to long-term and perhaps irreversible changes in the climate. In this connection, our country has been taking an active role in developing and adopting low-carbon fuels and technologies to meet the target of carbon neutrality.
- Science and technology have both intended and unintended consequences for humans and the environment. For instance, the use of leaded petrol and diesel for enhancing vehicle performance has caused pollution problems to our environment as well as health problems. Therefore, it is essential to carefully assess the risks and benefits to society and the environment before actually using applications of science and technology in daily life.

Topic VII Chemical Reactions and Energy (9 hours)

Overview

Chemical reactions are accompanied by energy changes, which often appear in the form of heat. In fact, energy absorbed or released by a chemical system may take different forms. Basic concepts of chemical energetics and enthalpy terms are introduced in this topic. Besides, practical work on the simple calorimetric method and quantitative treatment of Hess's law can help students to better understand the concepts of energetics. However, the use of equipment such as the bomb calorimeter is not expected at this level of study.

Students should learn	Students should be able to
a. Energy changes in chemical reactions • conservation of energy • endothermic and exothermic reactions and their relationship to the breaking and forming of bonds	• explain energy changes in chemical reactions in terms of the concept of conservation of energy • recognise enthalpy change, ΔH, as heat change at constant pressure (N.B.: Deriving the relation between enthalpy change and heat change at constant pressure is not expected.) • explain diagrammatically the nature of exothermic and endothermic reactions in terms of enthalpy change • explain the nature of exothermic and endothermic reactions in terms of the breaking and forming of chemical bonds
b. Standard enthalpy changes of reactions	• explain and use the terms: enthalpy change of reaction and standard conditions, with particular reference to neutralisation, formation and combustion • carry out experimental determination of enthalpy changes using simple calorimetric method • calculate enthalpy changes from experimental results

Students should learn	Students should be able to
c. Hess's law • use of Hess's law to determine enthalpy changes which cannot be easily determined by experiment directly • calculations involving enthalpy changes of reactions	• apply Hess's law to construct simple enthalpy change cycles • perform calculations involving such cycles and relevant energy terms, with particular reference to determining enthalpy change that cannot be found directly by experiment

(Remark: The underlined text represents the extension component of the curriculum.)

Suggested Learning and Teaching Activities

A variety of learning and teaching activities, especially *practical activities*, should be arranged for students to develop the knowledge and skills listed in learning objectives (students should learn) and learning outcomes (students should be able to). Some related examples are:

Sub-topics	Learning and teaching activities [Inquiry-based experiments are marked with #]	Key practical tasks
b. Standard enthalpy changes of reactions	• discuss the limitations of simple calorimetric methods as opposed to other more sophisticated techniques • perform calculations involving (a) standard enthalpy change of formation, (b) standard enthalpy change of combustion and (c) other standard enthalpy terms • investigate the chemistry involved in hand-warmers or cold-packs • design a self-heating package using calcium oxide and water and testing its performance #	• perform experiments to determine standard enthalpy change of (a) acid-base neutralisation and (b) combustion of alcohols

Sub-topics	Learning and teaching activities **[Inquiry-based experiments are marked with #]**	Key practical tasks
c. Hess's law	• perform experiments to determine the enthalpy change of formation of metal oxides or metal carbonates • find out different approaches to solving problems of standard enthalpy changes in chemical reactions	

Values and Attitudes

Students are expected to develop, in particular, the following *values and attitudes*:

- to value the need to understand heat changes in chemical reactions in a systematic way.
- to appreciate the usefulness of laws and theories in helping explain the energy changes in chemical reactions.
- to appreciate the importance of interdisciplinary relevance, e.g. knowledge of quantitative treatment in thermal physics is involved in enthalpy change calculations.
- to accept quantitative experimental results within tolerance limits.

STSE Connections

Students are encouraged to appreciate and comprehend issues which reflect the interconnections of science, technology, society and the environment. Related examples are:

- The principles of chemical energetics, including the concept of conservation of energy, are essential for the development of efficient energy storage technologies, such as batteries, fuel cells and thermal energy storage systems.
- The ever-increasing use of thermal energy from chemical reactions, especially the combustion of fossil fuels, has impacts on our society and the environment, e.g. energy crisis and global warming.
- Energy changes in chemical reactions have been utilised in many daily life products, e.g. hand-warmers, physiotherapy heat-packs, cold-packs, and self-heating coffee and lunchboxes.

Topic VIII Rate of Reaction (20 hours)

Overview

Rate of reaction is a fundamental concept in the study of chemistry and in daily life. Students have had a lot of experience of different rates of reactions in their previous learning. For example, students should know that rusting is a slow process but the reaction of hydrogen and oxygen can be extremely rapid. Furthermore, there is always a strong need for ways to control the rates of reactions. In short, this topic attempts to help students to build up concepts related to rate of reaction.

Students will learn different methods that can be used to follow the progress of a reaction and the factors that affect the rate of reaction. Equipment and apparatus in the school laboratory should be able to provide students with such experience. With the use of more sophisticated instruments such as suitable sensors and data-logging system, investigations or practical work can be performed in a more accurate and efficient manner.

Catalysis plays an important role in both research and chemical industries. Students are expected to have a more in-depth understanding of chemical kinetics including activation energy and catalysis. Students should be aware of the fact that practically all chemical reactions in large-scale chemical plants involve the use of catalysts and that reactions occurring in living systems are catalysed by enzymes. Students are also expected to develop skills related to quantitative chemistry by constructing and interpreting graphs, and performing calculations.

Students should learn	Students should be able to
a. Rate of chemical reaction • methods of following the progress of a chemical reaction • instantaneous and average rate	• select and justify the following techniques to follow the progress of a reaction: i. titrimetric analysis ii. measurement of the changes in: volume / pressure of gases, mass of a mixture and colour intensity of a mixture (N.B.: Calculation and instrumentation details of different techniques to follow reaction

Students should learn	Students should be able to
	progress are not expected.) • interpret a graph showing the progress of a reaction • determine instantaneous and average rate from a suitable graph • recognise that initial rate equals instantaneous rate at time t = 0
b. Factors affecting rate of reaction • concentration • temperature • surface area • catalyst	• design and perform experiments to study the effects of the following factors on rate of reaction: i. concentration ii. temperature iii. surface area iv. catalyst • interpret results (e.g. graphs) collected through first-hand investigations on factors affecting rate of reaction: changes in volume / pressure of gases, mass of a mixture, colour intensity of a mixture and turbidity of a mixture • explain qualitatively the effect of changes in concentration, surface area and temperature on the rate of reaction
c. Rate equation • rate equation determined from experimental results	• <u>understand the interrelationship between reaction rate, rate constant, concentration of reactants and order of reaction</u> • <u>determine the rate equation of a chemical reaction by method of initial rate</u>
d. Activation energy • energy profile • explanation of the effect of temperature	• <u>draw an energy profile of a reaction</u> (N.B.: Students should be able to label intermediate(s) in an energy profile. However,

Students should learn	Students should be able to
change on reaction rate in terms of activation energy	labelling for transition state/activated complex is not expected.) • explain the relationship between temperature and reaction rate using Maxwell-Boltzmann distribution curve • determine the activation energy of a chemical reaction with Arrhenius equation provided: $log\ k = constant - \frac{E_a}{2.3RT}$
e. Catalysis • meaning and characteristics of catalyst • relation between activation energy and catalysis	• describe the characteristics of catalysts using suitable examples • understand that catalysts work by providing an alternative reaction route • describe the applications of catalysis in industrial processes with examples such as iron in the Haber process and enzymes in the production of alcoholic drinks

(Remark: The underlined text represents the extension component of the curriculum.)

Suggested Learning and Teaching Activities

A variety of learning and teaching activities, especially *practical activities*, should be arranged for students to develop the knowledge and skills listed in learning objectives (students should learn) and learning outcomes (students should be able to). Some related examples are:

Sub-topics	**Learning and teaching activities** **[Inquiry-based experiments are marked with #]**	**Key practical tasks**
a. Rate of chemical reaction	• select and explain the appropriateness of using different techniques to follow the progress of the chemical reactions such as: (a) base hydrolysis of esters (b) reaction of $CaCO_3(s)$ or $Mg(s)$ with dilute acids (c) oxidation of $C_2O_4^{2-}(aq)$ ion by acidified $KMnO_4(aq)$ • perform an experiment to follow the progress of a catalysed decomposition of $H_2O_2(aq)$ through measuring the change in height of foam in the presence of a dish detergent • discuss the nature of rate studies with respect to methods of “quenching” and “on-going” • study the progress of a reaction using appropriate methods, skills and techniques (such as the micro-scale chemistry technique and data-loggers) • search for information on accidents caused by the failure to control reaction rate • search for information or read articles on airbags of vehicles	
b. Factors affecting rate of reaction	• investigate the relationship between the concentration of sodium hydroxide solution and the rate of decolourisation of phenolphthalein in alkaline medium using datalogger	• perform experiments to investigate the effect of changes in concentration of reactant, temperature, surface area, or the use of

Sub-topics	**Learning and teaching activities** **[Inquiry-based experiments are marked with #]**	**Key practical tasks**
		catalyst on reaction rate
c. Rate equation	• determine the rate equation of the reaction between sodium thiosulphate and dilute hydrochloric acid by using initial rate method	
d. Activation energy	• perform calculations related to activation energy of chemical reactions	• perform experiments to determine the activation energy of a chemical reaction
e. Catalysis	• design and perform experiments to investigate ways to change the rate of a reaction with a suitable catalyst #	

Values and Attitudes

Students are expected to develop, in particular, the following *values and attitudes*:

- to value the need to control reaction rates for human advancement.
- to show curiosity about the factors and the underlying mechanisms that influence the rate of chemical reactions.
- to appreciate the importance of detailed and precise measurements in quantitative chemistry.
- to recognise the need to consider multiple variables and perspectives when approaching scientific problems

STSE Connections

Students are encouraged to appreciate and comprehend issues which reflect the interconnections of science, technology, society and the environment. Related examples are:

- Understanding the factors that affect the rate of chemical reactions, such as temperature, pressure, and the use of catalysts, is crucial in the design and optimisation of industrial processes like manufacturing, pharmaceutical, and energy production.
- Combustion becomes faster and more vigorous when the combustible materials are in a finely divided form. These combustible dust particles in workplaces and industries, such as wood, light metals, coal, flour, starch, spice, sugar, are a deadly hazard as they can cause dust explosion and subsequently serious injuries and damages.
- At the nanoscale, the rate of chemical reactions can be significantly different from those observed at the macroscale, due to factors like surface area-to-volume ratios. Understanding the nanoscale reaction kinetics is crucial in the applications in areas like energy storage, electronics and medicine.

Topic IX Chemical Equilibrium (18 hours)

Overview

In general, chemical reactions are either reversible or irreversible. The concept of a state of equilibrium for the majority of reversible reactions is fundamental in chemistry. Students should appreciate the dynamic nature of chemical equilibrium, in particular the shifting of equilibrium position when a system at equilibrium is subjected to a change. It is therefore important to control variables such as pressure, concentration and temperature in an industrial process so as to establish the optimal reaction conditions. Students should be able to apply the concept of chemical equilibria to understand the operating conditions used in the Haber process, which illustrates the importance of an understanding of chemical equilibrium in the chemical industry. Moreover, students should be able to develop concepts and understanding of green chemistry for the management and control of the impact of chemical industrial processes on our environment.

The equilibrium law provides a quantitative relationship between the concentrations of the reactants and products in systems which are existing in a state of equilibrium. Students should understand the equilibrium constant K_c and its mathematical treatment in relation to the stoichiometry of reactions. Students should also be able to predict the effect of changes in either concentration or temperature on the position of chemical equilibrium in a homogeneous reaction. However, the effect on the position of equilibrium of introducing species which have no reaction with reactants and products is not required.

The concept of chemical equilibrium has a number of applications in daily life. Information search and reading on related topics can help students to build up their understanding of the concepts involved as well as the relationship between different types of equilibria.

Students should learn	Students should be able to
a. Dynamic equilibrium • characteristics of dynamic equilibrium	• describe reversible and irreversible reactions by using suitable examples • describe characteristics of a system existing in dynamic equilibrium
b. Equilibrium constant • equilibrium constant expressed in terms of concentrations (K_c)	• express the mathematical relationship between concentrations of reactants and products at equilibrium and K_c • <u>perform calculations involving K_c</u> • <u>perform practical work on the determination of K_c</u> • <u>understand that K_c for the dissociation of an acid is expressed in terms of K_a</u> • <u>compare strength of acids using pK_a</u> (N.B.: - $pH = pK_a + log \frac{[A^-]}{[HA]}$ is not expected. - K_w and K_b are not expected.)

Students should learn	Students should be able to
c. The effect of concentration, temperature and catalyst on chemical equilibria in homogenous reactions	• recognise that the value of K_c for an equilibrium system is a constant at constant temperature irrespective of changes in concentration of reactants and products • predict qualitatively the effect of changes in concentration on the position of equilibrium using Le Chatelier's Principle • deduce the effect of changes in concentration on the position of chemical equilibrium using reaction quotient • derive inductively the relation of temperature and the value of K_c from given data sets • predict qualitatively the effect of changes in temperature on the position of equilibrium from the sign of ΔH for the forward reaction using Le Chatelier's Principle (N.B.: $\ell n\, K = constant - \frac{\Delta H}{RT}$ and $log\, K = constant - \frac{\Delta H}{2.3RT}$ are not expected.) • describe the effect of catalyst on reversible reactions
d. Chemical industry • consideration of operation conditions for industrial processes using principles of chemical equilibrium and rates of reaction • principles and practices of green chemistry	• describe feedstock, principles, reaction conditions, procedures and products for processes involved in the production of ammonia in the Haber process • explain how industrial processes involve a compromise between rate, yield and economic consideration as exemplified by the Haber process • recognise the importance of the Haber process • discuss social, economic and environmental considerations of industrial processes as illustrated by the Haber process • describe the principles of green chemistry • describe the relation between sustainable development and green chemistry • calculate the atom economy of a chemical reaction • evaluate industrial processes using principles of green chemistry (N.B. Students are not expected to memorise details of industrial processes that are not specified in this curriculum.)

Students should learn	Students should be able to

(Remark: The underlined text represents the extension component of the curriculum.)

Suggested Learning and Teaching Activities

A variety of learning and teaching activities, especially *practical activities*, should be arranged for students to develop the knowledge and skills listed in learning objectives (students should learn) and learning outcomes (students should be able to). Some related examples are:

Sub-topics	Learning and teaching activities	Key practical tasks
a. Dynamic equilibrium	• design and perform experiments to investigate the qualitative effects of pH on chemical equilibrium systems such as $Br_2(aq) + H_2O(l) \rightleftharpoons HOBr(aq) + H^+(aq) + Br^-(aq)$ $Cr_2O_7^{2-}(aq) + H_2O(l) \rightleftharpoons 2CrO_4^{2-}(aq) + 2H^+(aq)$	
b. Equilibrium constant	• perform calculations related to equation stoichiometry and the equilibrium constant K_c by either finding K_c from equilibrium concentrations or vice versa • perform an experiment to determine K_c of a chemical equilibrium system such as esterification of alcohol and carboxylic acid	

Sub-topics	Learning and teaching activities	Key practical tasks
c. The effect of concentration, temperature and catalyst on chemical equilibria	• investigate the effect of changes in concentration or temperature on chemical equilibria using a computer simulation. • investigate the relationship of temperature and the value of K_c from given data sets • explore how Le Chatelier's Principle can be used for predicting the shift in equilibrium position and recognising its limitations	• perform experiments to study the shift of equilibrium positions of chemical reactions upon changing concentration or temperature, e.g. $SCN^-(aq) + Fe^{3+}(aq) \rightleftharpoons Fe(SCN)^{2+}(aq)$ or $Co^{2+}(aq) + 4Cl^-(aq) \rightleftharpoons CoCl_4^{2-}(aq)$
d. Chemical industry	• read articles on the importance of nitrogen fixation. • search for and present information on the discovery of the Haber process and its significance to the world • analyse an industrial process from scientific, social, economic and environmental perspectives • discuss the feasibility of using the principles of green chemistry for daily-life applications of chemistry • review industrial processes using green chemistry principles	

Values and Attitudes

Students are expected to develop, in particular, the following *values and attitudes*:

- to appreciate the advantages of qualitative treatment and quantitative treatment in solving different problems.
- to appreciate the human endeavour in searching for means to increase the efficiency of industrial processes.
- to be aware of the impact of chemistry in social, economic, industrial, environmental and technological contexts.
- to show concern for the environmental issues and develop a sense of shared responsibility for sustainable development of Hong Kong, our country and the world.
- to show willingness to adopt green chemistry practices.

STSE Connections

Students are encouraged to appreciate and comprehend issues which reflect the interconnections of science, technology, society and the environment. Related examples are:

- The Haber process has been regarded as one of the most important chemical reactions for human as it facilitated mass production of fertilisers to relieve problems related to inadequate supply of food. However, the Haber process also had a large impact on weaponry in wars.
- Green chemistry involves the employment of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products. In order to encourage business leaders to choose responsibly between traditional options and green solutions, more environmentally benign alternatives to current materials and technologies must be developed and promoted.
- The fundamental challenge for the chemical industry is to maintain the benefits to the society without overburdening or causing damage to the environment, and this must be done at an acceptable cost.

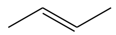
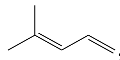
Topic X Chemistry of Carbon Compounds (20 hours)

Overview

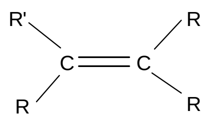
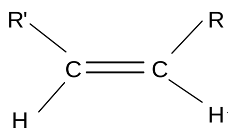
Organic chemistry is a very important branch of Chemistry as judged by the uniqueness of carbon and ubiquitousness of carbon compounds. Together with the basic concepts and knowledge acquired in the junior secondary course, and Topics IV and VI in this curriculum, students build up concepts related to the structural characteristics of some common carbon compounds. Students are also expected to be able to use the systematic and common trivial names of carbon compounds to communicate knowledge and understanding in study and in daily life.

In this topic, basic concepts of isomerism including structural isomerism, *cis-trans* isomerism and enantiomerism are introduced. Students will also learn about the chemistry of a number of functional groups. They should be able to give systematic names of alkanes, alkenes, haloalkanes, alcohols, aldehydes and ketones, carboxylic acids, esters, unsubstituted amides and primary amines, with no more than eight carbon atoms in their carbon chains. Through studying the reactions of the functional groups (including the reagents, reaction conditions, products and observations), students will be able to make use of some chemical methods to distinguish different functional groups and to identify unknown carbon compounds. In addition, they should be able to describe the mechanism of addition reactions of alkenes with hydrogen halides and predict major products of reactions between unsymmetrical alkenes and hydrogen halides using Markovnikov's rule.

Students should also recognise the relationship between different functional groups and be aware of the most important application of organic chemistry, i.e. the synthesis of useful carbon compounds through inter-conversions between different functional groups. To further consolidate their understanding of the reactions included in this topic, students should carry out experiments on synthesising simple organic substances.

Students should learn	Students should be able to
a. Introduction to selected homologous series • homologous series • structural formulae and systematic naming	• give systematic names, general formulae, condensed formulae and structural formulae for: alkanes, alkenes, haloalkanes, alcohols, aldehydes and ketones, carboxylic acids, esters, unsubstituted amides and primary amines (N.B.: - Students should be able to give systematic names for organic compounds of the above functional groups with up to eight carbon atoms in their carbon chains, and with unsaturated carbon-carbon bonds and/or halogen substituents, e.g. 3,3-dichloropropene and 2-bromopent-3-en-1-ol. - Students should be able to give systematic names for organic compounds with multiple of the above functional groups of the same type, e.g. propane-1,2,3-triol.) • draw the structures of the compounds based on their systematic names (N.B.: Students should be able to use different notations in drawing/writing structural formulae of organic compounds (e.g.  , , $CH_3CH{=}CHCH_3$, $CH_3(CH_2)_2CH{=}CH_2$).) • understand the effects of functional groups and the length of carbon chains on physical properties of carbon compounds • identify common trivial names of some carbon compounds (e.g. formaldehyde, chloroform, acetone, isopropyl alcohol, acetic acid)
b. Isomerism • structural isomerism • *cis-trans* isomerism as exemplified by acyclic carbon compounds containing one C=C bond	• understand that isomerism occurs when two or more compounds have the same molecular formula but different structures • recognise and predict the existence of structural isomerism which includes isomers containing the same functional group and isomers containing different functional groups

Students should learn	Students should be able to
• enantiomerism as exemplified by compounds containing one chiral carbon	• recognise the existence of *cis-trans* isomerism in acyclic carbon compounds resulting from restricted rotation about a C=C bond (N.B.: Describing and explaining properties of specific examples of *cis-trans* isomers such as butenedioic acid are not expected. However, students are expected to apply their knowledge acquired in Topic IV to relate structures of *cis-trans* isomers to their properties.) • show an understanding of structural and cis-trans isomerism by predicting structures of the isomers of some given carbon compounds • recognise the existence of enantiomerism in compounds with only one chiral carbon • use structural formulae and molecular models to demonstrate the arrangement of atoms in isomers of carbon compounds • recognise that enantiomers of a chiral compound exhibit optical activity and rotate the plane of plane-polarised light by the same extent but in opposite directions (N.B.: Details of polarimetry and concepts related to racemic mixture are not expected.)
c. Typical reactions of various functional groups • alkanes • alkenes • haloalkanes • alcohols • aldehydes • ketones • carboxylic acids • esters • amides	• describe the following reactions, in terms of reagents, reaction conditions and observations, and write the relevant chemical equations: i. alkanes: substitution with halogens ii. alkenes: addition of hydrogen, halogens and hydrogen halides iii. haloalkanes: substitution with $OH^-(aq)$ (N.B.: Comparing the reactivity of haloalkanes in their substitution with hydroxide ions is not expected.) iv. alcohols: substitution with halides using hydrogen halides (HX) or phosphorus trihalides (PX_3); dehydration to alkenes; oxidation of primary alcohols to aldehydes and carboxylic acids; oxidation of secondary alcohols to ketones (N.B.: For substitution of alcohols with halides, experimental details of how to produce

Students should learn	Students should be able to
	HX and PX_3 for the reactions are not expected.) v. aldehydes and ketones: oxidation using $Cr_2O_7^{2-}$(aq); reduction using $LiAlH_4$ or $NaBH_4$ vi. carboxylic acids: esterification; formation of unsubstituted amide; reduction using $LiAlH_4$ vii. esters: hydrolysis viii. unsubstituted amides: hydrolysis • predict and name the products of the above reactions • describe an appropriate chemical test to detect the presence of the functional groups: C=C, –OH and –COOH • state the reaction conditions and observations of the tests for the presence of aldehydes using Tollens' reagent • describe the mechanism of addition reactions of alkenes with hydrogen halides, using the reaction between hydrogen bromide gas and propene as an example • recognise that the order of stability for alkyl substituted carbocations: tertiary > secondary > primary > methyl • apply Markovnikov's rule to predict major products of addition reactions of unsymmetrical alkenes and hydrogen halides (N.B.: - Prediction of major products of reactions involving alkenes with the same degree of substitution on both double-bonded carbon atoms (e.g.  or ) is not expected. - Students should realise that carbocation stability increases with the number of adjacent alkyl groups. However, justifications on the order of stability for alkyl substituted

Students should learn	Students should be able to
	carbocations are not expected.) • relate the typical reactions of functional groups to applications in industrial processes: i. hardening of unsaturated fats ii. <u>saponification</u> iii. <u>synthesis of artificial flavouring</u> (N.B.: - For saponification and hardening of unsaturated fats, students are not expected to memorise molecular formulae of specific oils/fats. - For synthesis of artificial flavourings, students are not expected to memorise molecular formulae of specific esters and their corresponding flavours.)
d. Inter-conversions of carbon compounds • inter-conversions between the functional groups • laboratory preparations of simple carbon compounds	• <u>suggest routes to convert one functional group into another by using the reactions described in (c)</u> • <u>state the reagents and conditions to accomplish conversions of carbon compounds using the reactions described in (c)</u> • <u>predict the major organic products of reactions, with given starting materials, reagents and reaction conditions</u> • <u>describe how to carry out laboratory preparations and purification of simple carbon compounds such as ethanoic acid and ester</u> • <u>calculate the percentage yield of a product obtained from a reaction</u>

(Remark: The underlined text represents the extension component of the curriculum.)

Suggested Learning and Teaching Activities

A variety of learning and teaching activities, especially *practical activities*, should be arranged for students to develop the knowledge and skills listed in learning objectives (students should learn) and learning outcomes (students should be able to). Some related examples are:

Sub-topics	**Learning and teaching activities** **[Inquiry-based experiments are marked with #]**	**Key practical tasks**
a. Introduction to selected homologous series	• build molecular models of compounds with different functional groups • compare physical properties of the following compounds: propane, butane, pentane, ethanol, propan-1-ol and butan-1-ol • search for common trivial names of common carbon compounds • practice writing systematic names, general formulae, condensed formulae and structural formulae of different functional groups with the assistance of AI tools or using an AI-assisted self-learning platform	
b. Isomerism	• build molecular models of but-2-ene • build molecular models of butan-2-ol or 2-hydroxypropanoic acid (lactic acid) • search and present information on ‘chiral drug’ • study three-dimensional models of compounds with chiral carbons using a computer programme	

Sub-topics	**Learning and teaching activities** **[Inquiry-based experiments are marked with #]**	**Key practical tasks**
c. Typical reactions of various functional groups	• search for and present information on the principles and applications of the alcohol breathalyser • design and make a portable alcohol breathalyser and testing its effectiveness # • perform an experiment to study the reduction of vanillin to vanillyl alcohol using sodium borohydride as reducing agent • perform an experiment to prepare 2-chloro-2-methylpropane from 2-methylpropan-2-ol	• perform experiments to study esterification with different carboxylic acids and alcohols • perform experiments to identify carbon compounds with different functional groups
d. Inter-conversions of carbon compounds	• plan synthetic routes of simple carbon compounds from precursors that are readily available by analysing the structures of the target molecules • practice constructing synthetic routes for selected organic compounds with the assistance of AI tools or using an AI-assisted self-learning platform • search for and present information about the synthetic routes of some important organic substances commonly found in daily life	• prepare benzoic acid by alkaline hydrolysis of ethyl benzoate

Values and Attitudes

Students are expected to develop, in particular, the following *values and attitudes*:

- to appreciate that science and technology provide us with useful products.
- to develop a positive attitude towards the safe handling, storage and disposal of chemicals, and hence adopt safe practices.
- to be aware of the hazards associated with the use and disposal of carbon compounds in the laboratory (e.g. their combustibility and toxicity) and the precautions to be taken.

STSE Connections

Students are encouraged to appreciate and comprehend issues which reflect the interconnections of science, technology, society and the environment. Related examples are:

- Often more than one synthetic route may be available to prepare a particular carbon compound. However, some synthetic routes may have undesirable effects on our health and our environment. The best synthetic route may not be the one with the fewest steps or the lowest cost. It is, therefore, essential to apply our knowledge of organic chemistry so that useful organic products are developed and manufactured by safe, economic and environmentally acceptable routes.
- The search for new carbon compounds in drug discovery often requires the synthesis of hundreds of compounds which are variations of their basic structures. Some compounds which have been synthesised may have certain useful aspects, but also dangerous side-effects which prohibit their general use. It is often necessary to look for other compounds with similar structures but without the side-effects.

Topic XI Important Organic Synthetic Products (8 hours)

Overview

This topic builds upon Topics VI and X and aims to allow students to appreciate the significant impact of organic chemistry on various industries and our everyday lives by learning about some important organic products.

Important organic substances such as aspirin, paracetamol and detergents are discussed in this topic. Aspirin and paracetamol stand as widely used medication worldwide, serving as prime examples of how organic chemistry contributes to pharmaceutical development. Detergents, on the other hand, play a crucial role in cleaning and personal hygiene maintenance. In this topic, students should recognise the structures of these substances. In particular, they should appreciate that the hydrophobic and hydrophilic parts of detergents render the emulsifying and wetting properties of detergents. They should also understand the relation between the cleansing action of soaps and soapless detergents and their structures.

Students should also recognise that there are natural polymers and synthetic polymers. Natural polymers (e.g. cellulose, chitin, starch and proteins) occur in nature, while synthetic polymers are produced through chemical reactions. Building on the knowledge of addition polymerisation, in this topic, students further learn the formation of condensation polymers, and how their structures relate to the physical properties and uses. However, the details of structures and properties of naturally occurring polymers are not expected at this level of study.

Students should learn	Students should be able to
a. Common over-the-counter drugs • structure and applications of acetylsalicylic acid (aspirin) and acetaminophen (paracetamol)	• identify the functional groups of the acetylsalicylic acid and acetaminophen molecules • recognise that aspirin is used as a drug to relieve pain, reduce inflammation and fever, and the risk of heart attack • recognise that paracetamol is used as a drug to relieve pain and reduce fever • recognise that there are potential side effects in taking aspirin and paracetamol

Students should learn	Students should be able to
b. Soaps and soapless detergents • structures and properties of soaps and soapless detergents	• describe the structures of soaps and soapless detergents • recognise that detergents can be made from chemicals derived from petroleum • explain the wetting and emulsifying properties of detergents in relation to their structures • relate the cleansing action of soaps and soapless detergents to their structures • compare the cleaning abilities of soaps and soapless detergents in hard water (N.B.: Recall of chemical formulae of scum is not expected.) • discuss the environmental problems associated with the use of detergents
c. Condensation polymers • natural polymers and synthetic polymers • condensation polymerisation • structures, properties and uses of condensation polymers as illustrated by nylon, poly(ethylene terephthalate) (PET) and urea-methanal	• recognise that there are natural polymers and synthetic polymers (N.B.: Details of structures and properties of naturally occurring polymers are not expected.) • deduce the type of polymerisation reaction for a given monomer or a given pair of monomers • write structural formulae of condensation polymers based on given monomers: nylon, poly(ethylene terephthalate) (PET) and urea-methanal • deduce the repeating unit of a polymer obtained from a given monomer or a pair of monomers • deduce the monomer or the pair of monomers from a given section of a formula of a polymer • describe condensation polymerisation using chemical equations (N.B.: Recall of structural formulae of specific polymers is not expected.) • state the similarities and differences between addition polymerisation and condensation polymerisation • explain the terms “thermoplastics” and “thermosetting plastics” • explain the properties of polymers in terms of their structures • state the advantages and disadvantages of biodegradable plastics as exemplified by polylactide (PLA) • discuss the importance of recycling plastics and the difficulties encountered in its

Students should learn	Students should be able to
	implementation • discuss the environmental impact of the use of plastics

(Remark: The underlined text represents the extension component of the curriculum.)

Suggested Learning and Teaching Activities

A variety of learning and teaching activities, especially *practical activities*, should be arranged for students to develop the knowledge and skills listed in learning objectives (students should learn) and learning outcomes (students should be able to). Some related examples are:

Sub-topics	**Learning and teaching activities** **[Inquiry-based experiments are marked with #]**	**Key practical tasks**
a. Common over-the-counter drugs	• search for and present information on the discovery of aspirin and its applications • perform an experiment to analyse commercial aspirin tablets using back titration • search for information and discuss about the uses and side effects of aspirin and paracetamol • search for and present information on the application of AI in drug discovery	

Sub-topics	**Learning and teaching activities** [Inquiry-based experiments are marked with #]	**Key practical tasks**
b. Soaps and soapless detergents	• search for and present information on the historical development of detergents • prepare soap from a fat or an oil and test its properties • design and conduct experiments to compare the cleansing abilities of soaps and soapless detergents # • search for and present information on environmental issues related to the use of detergents	• perform experiments to investigate the wetting ability and emulsifying action of detergents
c. Condensation polymers	• search for information about structures and properties of naturally occurring polymers such as chitin and cellulose • investigate properties such as the strength and the ease of softening upon heating of different addition and condensation polymers • build physical or computer models of condensation polymers • search for and present information about microplastic pollution and its impact on our environment • search for and present information on the application of AI in the discovery of new materials	• perform experiment to prepare nylon

Values and Attitudes

Students are expected to develop, in particular, the following *values and attitudes*:

- to appreciate that science and technology provide us with useful products.
- to appreciate the versatility of synthetic materials and the limitations of their use.
- to recognise that material resources are finite and the importance of their recycling processes.
- to recognise the need for alternative sources of the compounds presently obtained from the petroleum industry.
- to show concern for the environmental issues and develop a sense of shared responsibility for sustainable development of Hong Kong, our country and the world.

STSE Connections

Students are encouraged to appreciate and comprehend issues which reflect the interconnections of science, technology, society and the environment. Related examples are:

- Many of the daily products, such as cosmetics, personal care products, cleaning agents, and textiles, are based on organic compounds and their properties. Organic chemistry plays a significant role on the formulation and improvement of these consumer products to enhance their functionality, safety and environmental compatibility.
- The environmental impact of synthetic polymers, in particular their durability and non-biodegradability, has led to increased research and development of more sustainable, biodegradable, and recyclable polymer alternatives.
- To address the environmental concerns arising from the use of detergents, manufacturers have developed more eco-friendly detergent formulations that use biodegradable surfactants, reduce or eliminate phosphates, and minimize the use of toxic ingredients. Consumers can also contribute by selecting environmentally-conscious detergent products and properly disposing of wastewater to reduce the impact on the environment.

Topic XII Patterns in the Chemical World (9 hours)

Overview

Through the study of this topic, students can develop an understanding of the importance of the Periodic Table in chemistry. Students are expected to develop knowledge and concepts about the periodic trends of physical properties of some elements and the periodic relationship of acid-base properties of selected oxides.

Students can also develop knowledge and concepts of the properties of selected transition metals and their compounds. The importance of the use of transition metals in industries and other applications will be discussed.

Students should learn	Students should be able to
a. Periodic variation in physical properties of the elements from Li to Ar • variation in the nature of bonding • variations in melting point and electrical conductivity	• describe the nature of bonding and structures of elements of Group I through Group 0 of the Periodic Table • describe the periodic variations of melting point and electrical conductivity of the elements • interpret the variations in melting point and in electrical conductivity in terms of the bonding and structures of the elements, viz. the presence of metallic structures, covalent structures and molecular structures
b. Bonding, stoichiometric composition and acid-base properties of the oxides of elements from Na to Cl	• describe the nature of bonding and stoichiometric composition of the oxides of elements from Na to Cl • describe the variation in behaviour of the following oxides in water: Na_2O, MgO, Al_2O_3, SiO_2, P_4O_{10}, SO_2 and Cl_2O • recognise the variations of acid-base properties of the oxides of elements from Na to Cl as

Students should learn	Students should be able to
	exemplified by Na_2O, Al_2O_3 and SO_2
c. General properties of transition metals • coloured ions • variable oxidation states • catalytic properties • transition metal complexes	• identify positions of the transition metals in the Periodic Table • recognise that most aqueous ions of transition metals are coloured • describe the colours of some transition metal ions such as $Fe^{3+}(aq)$, $Cr^{3+}(aq)$, $Cu^{2+}(aq)$ • describe that transition metals can exist in more than one oxidation state in their compounds, e.g. Fe^{2+} and Fe^{3+}; Mn^{2+}, MnO_2 and MnO_4^- • describe that transition metals and their compounds can be used as catalysts • describe the importance of transition metals • recognise that transition metal ions form complexes by forming dative covalent bonds with ligands as illustrated by $[Cu(H_2O)_6]^{2+}$ • describe the ligand exchange and the colour changes in the formation of $[Cu(NH_3)_4(H_2O)_2]^{2+}$ from $[Cu(H_2O)_6]^{2+}$ via $Cu(OH)_2(H_2O)_4$ (N.B.: Other than copper(II) complexes stated in the above learning outcome, students are not expected to memorise molecular formulae of specific transition metal complexes.)

(Remark: The underlined text represents the extension component of the curriculum.)

Suggested Learning and Teaching Activities

A variety of learning and teaching activities, especially *practical activities*, should be arranged for students to develop the knowledge and skills listed in learning objectives (students should learn) and learning outcomes (students should be able to). Some related examples are:

Sub-topics	**Learning and teaching activities**	**Key practical tasks**
a. Periodic variation in physical properties of the elements from Li to Ar	• search for information and interpret the trends of physical properties of elements, e.g. density and solubility in water, in Periods 2, 3, and 4 • investigate the trends of the melting point and the electrical conductivity of elements across a period	
b. Bonding, stoichiometric composition and acid-base properties of the oxides of elements from Na to Cl	• investigate the behaviour of oxides of the elements Na to Cl in water and their corresponding acid-base properties • plan and write experimental procedures for identifying unknown samples of sodium oxide, aluminium oxide, silicon dioxide and phosphorus pentoxide	
c. General properties of transition metals	• perform an experiment to investigate the equilibrium system involving $[Cu(H_2O)_6]^{2+}$, $Cu(OH)_2(H_2O)_4$ and $[Cu(NH_3)_4(H_2O)_2]^{2+}$ with the use of copper(II) sulphate solution and ammonia solution • explore relationship of colour and composition of some gem stones • search for information on the importance of transition metals and their compounds	• prepare a copper complex using hydrated copper(II) sulphate and ammonia solution

Values and Attitudes

Students are expected to develop, in particular, the following *values and attitudes*:

- to appreciate the pattern-wise variations that occur in nature.
- to appreciate that scientific evidence is the foundation for generalisations and explanations about matter.
- to appreciate the usefulness of models and theories in helping explain the structures and behaviours of matter.
- to appreciate the human endeavour in searching for means to increase the efficiency of industrial processes.

STSE Connections

Students are encouraged to appreciate and comprehend issues which reflect the interconnections of science, technology, society and the environment. Related examples are:

- Transition metals are used as catalysts in the fields of technology, medical research and industry.
- Transition metal ions have been playing an important role in maintaining our health. For example, some transition metal complexes have been developed as effective therapeutic agents, including anticancer drugs (e.g. platinum-based compounds), anti-inflammatory drugs (e.g. gold-based compounds) and antimicrobial agents (e.g. silver-based compounds).
- Myoglobin and haemoglobin are physiologically important in terms of their ability to bind molecular oxygen. The ability to bind oxygen is related to the deep red iron-containing prosthetic group in the molecule.

Topic XIII Analytical Chemistry (24 hours)

Overview

At the beginning of this topic, students are expected to apply the knowledge and skills they have acquired in previous topics to plan and carry out appropriate tests for the detection of some common chemical species. In addition to the common separation methods learned in earlier topics, students should know that liquid-liquid extraction and chromatographic methods can be used to separate a mixture of substances. Students are also expected to understand that the determination of melting point and boiling point is an important way to indicate the purity of a substance.

In addition, this topic stresses quantitative methods of analysis. Students should be provided with the opportunity to solve problems related to estimating quantities of substances, if possible, in authentic situations. In this connection, investigations using different types of volumetric methods, which may involve acid-base reactions and redox reactions, are conducted. On completion of this topic, students are expected to acquire skills related to quantitative chemistry, such as performing calculations and describing ways to minimise possible sources of error.

Modern instruments play a key role in chemical analysis nowadays. Students are expected to acquire a basic understanding of instrumental methods such as colorimetry for determining the quantity of coloured substances, infrared (IR) spectroscopy for identifying functional groups and mass spectrometry for determining molecular structures. Students should be aware of the limitations inherent in the use of conventional chemical tests for the detection of chemical species and, therefore, appreciate the application of modern instruments in chemical analysis. However, in-depth understanding of the principles and detailed operation procedure of the instruments are not expected at this level of study.

Instead of learning a number of tests and analytical methods, students can select the most appropriate means to solve problems in different situations and justify their choices. Together with the hands-on experience of investigating the nature and the quantity of chemicals, students are expected to understand the important role of analytical chemistry in daily life.

<table>
<tr><th>Students should learn</th><th>Students should be able to</th></tr>
<tr><td>a. Detecting the presence of chemical species
• detecting the presence of calcium, copper, potassium and sodium in substances by the flame test
• application of appropriate tests for detecting the presence of
i. molecules: hydrogen, oxygen, chlorine, carbon dioxide, water, ammonia, sulphur dioxide and hydrogen chloride
ii. cations: aluminium, ammonium, calcium, magnesium, copper(II), iron(II), iron(III) and zinc
iii. anions: chloride, bromide, iodide, carbonate, hypochlorite and sulphite</td><td>• select appropriate tools and apparatus for chemical tests
• gather empirical information using chemical tests
• record observations accurately and systematically
• decide on and carry out an appropriate chemical test to detect the presence of a chemical species
• justify the conclusion of the presence of a chemical species either orally or in written form
• assess possible risks associated with chemical tests
• devise a scheme to separate a mixture of known substances</td></tr>
<tr><td>b. Separation and purification methods
• crystallisation
• distillation / fractional distillation
• liquid-liquid extraction
• paper, thin layer or column chromatography</td><td>• describe various separation and purification methods
• separate and purify substances by the following methods:
i. crystallisation
ii. distillation / fractional distillation
iii. liquid-liquid extraction
iv. chromatographic methods
• determine the R_f values of substances in a chromatogram
• determine the melting point or boiling point of a substance
• examine the purity of a substance by measuring its melting or boiling point
• justify the choice of an appropriate method used for the separation of substances in a mixture</td></tr>
</table>

Students should learn	Students should be able to
c. Quantitative method of analysis • volumetric analysis	• <u>gather data with appropriate instruments and apparatus in quantitative analysis</u> • <u>record observations and data accurately and systematically</u> • <u>be aware of and take necessary steps to minimise possible sources of error</u> • <u>perform calculations on data obtained to draw evidence-based conclusions</u> • <u>present observations, data, results, conclusions and sources of error either orally or in written form</u> • <u>justify the choice of an appropriate quantitative method for the determination of the quantity of a substance</u> • <u>assess possible risks associated with quantitative analysis</u> (N.B.: - With sufficient information given, students should be able to apply the concepts of volumetric analysis to solve problems involving different titrations. - Students are not expected to memorise the details of experimental procedures involved in specific volumetric analyses that are not covered in the previous topics of this curriculum.)

Students should learn	Students should be able to
d. Instrumental analytical methods • basic principles and applications of colorimetry • identification of functional groups of carbon compounds using IR spectroscopy • basic principles and applications of mass spectrometry, including simple fragmentation pattern	• <u>understand the basic principles deployed in the instrumental analytical methods, viz. colorimetry, IR spectroscopy and mass spectrometry</u> • <u>construct a calibration curve by measuring absorbance of standard solutions</u> • <u>determine the concentration of a solution using a calibration curve</u> • <u>identify the following groups from an IR spectrum and a given correlation table: C–H, O–H, N–H, C=C, C≡C, C=O and C≡N</u> • <u>identify the following groups from a mass spectrum: R^+, RCO^+ and $C_6H_5CH_2^+$</u> • <u>analyse data from primary sources and draw evidence-based conclusions</u> • <u>analyse data from secondary sources, including textual and graphical information, and draw evidence-based conclusions</u> • <u>communicate information, and justify and defend evidence-based conclusions in both written and oral forms</u>
e. Contribution of analytical chemistry to our society • analysis of food and drugs • environmental protection • chemistry aspects of forensic science • clinical diagnoses	• recognise the use of modern instrumentation for analysis in daily life • discuss the role of analytical chemistry in modern ways of living such as gauging levels of atmospheric pollutants like CO, volatile organic compounds, fine suspended particulates ($PM_{2.5}$) and dioxins, and indoor air pollutants like formaldehyde and ozone • describe the role of forensic chemistry in providing legal evidence • discuss the role of analytical chemistry in the diagnosis, treatment and prevention of diseases

(Remark: The underlined text represents the extension component of the curriculum.)

Suggested Learning and Teaching Activities

A variety of learning and teaching activities, especially *practical activities*, should be arranged for students to develop the knowledge and skills listed in learning objectives (students should learn) and learning outcomes (students should be able to). Some related examples are:

<u>**Sub-topics**</u>	<u>**Learning and teaching activities**</u> **[Inquiry-based experiments are marked with #]**	<u>**Key practical tasks**</u>
a. Detecting the presence of chemical species	• perform experiments to detect the presence of certain chemical species in a sample • watch videos on various chemical experimental techniques of qualitative analysis • design and perform experiments to identify a number of unlabelled white solids: citric acid, sodium sulphate, sodium hydrogencarbonate, ammonium chloride #	
b. Separation and purification methods	• perform an experiment to analyse a mixture by paper chromatography, column chromatography or thin layer chromatography • watch videos about the working principles and applications of gas chromatography and liquid chromatography	• perform experiments to separate and identify the major components of the selected over-the-counter analgesics by thin layer chromatography
c. Quantitative method of analysis	• perform titrimetric analysis of chloride using silver nitrate with chromate indicator (Mohr's method) • design and perform experiments to investigate the salt contents in snacks and compare the results with the figures given on the food labels # • perform an experiment to determine the percentage (w/v) of	• prepare standard solution of ammonium iron(II) sulphate and to use the solution prepared to standardise potassium permanganate solution

Sub-topics	**Learning and teaching activities** **[Inquiry-based experiments are marked with #]**	**Key practical tasks**
	hypochlorite in a sample of bleach # • perform an experiment to investigate the iron content in some commercial 'iron tablets' # • perform an experiment for the iodometric titration of ascorbic acid in a sample of vitamin C tablets or fruit juices #	
d. Instrumental analytical methods	• study the relationship between solution colour, concentration of solution, colour of light source, and absorbance with the aid of a computer simulation • perform experiments to determine the amount of food dye present in soft drinks by using a colorimeter / a custom-made LED colorimeter / a suitable mobile application # • perform an experiment to determine the amount of copper in a brass sample by using a colorimeter / a custom-made LED colorimeter #	• determine the concentration of an unknown solution using a colorimeter
e. Contribution of analytical chemistry to our society	• discuss the importance of integrity in recording and reporting data • search for and present information on the principle and application of instrumental analysis such as gas chromatography for blood alcohol content and gas chromatography-mass spectrometry for tracking organic pollutants • identify fingerprints by iodine sublimation • search for and present information related to the use of chemical methods in forensic science	

Values and Attitudes

Students are expected to develop, in particular, the following *values and attitudes*:

- to be committed to the impartial and objective gathering, analysing and reporting of information.
- to respect the views of others and evidence-based conclusions.
- to be aware of the impact of chemistry in social, economic, industrial, environmental and technological contexts.
- to show a continuing interest in and curiosity about the advancement of science.
- to appreciate the importance of following standard methods and chemical analysis, and of validating measurements.

STSE Connections

Students are encouraged to appreciate and comprehend issues which reflect the interconnections of science, technology, society and the environment. Related examples are:

- Separation and purification techniques are used both in the laboratory and in daily life. The supply of clean water to people in metropolitan districts involves a number of techniques such as filtration, precipitation and distillation. For travellers to rural districts, 'safe' drinking water can be made from water obtained from natural sources by adding iodine tincture followed by ascorbic acid.
- Consumers often read reports of food containing carcinogens, heavy metals, pesticides, herbicides, or insecticides. Analytical chemists, with the aid of suitable tools and instruments, can provide information to assist in the understanding of the incidents.
- Chemicals of different natures can cause different threats or hazards to our environment. Analytical chemistry can provide qualitative and quantitative evidence in such cases.
- Forensic science is important in terms of its role in some legal proceedings. More specifically, chemistry plays a significant role in the process of gathering evidence and providing logical and valid conclusions.

Topic XIV Scientific Inquiry in Chemistry (20 hours)

Overview

This topic aims to provide students with learning experiences of practising the scientific method and facilitate them to acquire the essential skills of scientific inquiry. A portion of curriculum time is set aside for this purpose. Students are expected to conduct experiments/investigations with an inquiry-based approach throughout the Chemistry curriculum. Through the learning process in different inquiry-based practical activities, students should be able to enhance their understanding of the scientific method as well as develop different skills for conducting scientific investigations in chemistry.

Learning Objectives

By conducting a number of inquiry-based experiments/investigations during their study of the Chemistry curriculum, students are expected to develop the following knowledge, skills, and values and attitudes:

<u>Knowledge and Skills</u>

Students are expected to:

- recognise that scientific knowledge and theories are developed through observation, formulation of hypotheses, collection of evidence, investigation and generation of explanations;
- identify, define and delimit questions to investigate when presented with chemistry-related problems;
- design and write experimental procedures for inquiry-based experiments/investigations in chemistry;
- identify and distinguish between dependent, independent and control variables in an experiment;
- conduct fair tests and generate valid data;
- carry out risk assessments for inquiry-based experiments/investigations in chemistry;
- suggest ways to improve the validity and reliability of inquiry-based experiments/investigations in chemistry;
- carry out designed procedures for inquiry-based experiments/investigations in chemistry and adapt experimental steps if necessary;
- use appropriate reporting styles to communicate the data and findings from inquiry-based experiments/investigations in chemistry;
- decide on and apply relevant knowledge and concepts of chemistry and mathematics for

analysing experimental data and drawing meaningful conclusions;
- evaluate the validity of conclusions with reference to the investigation process and the data and information gathered; and
- use appropriate digital tools (e.g. data-loggers and sensors, spreadsheets, graphing software and AI), to collect, process and interpret data, search for and organise chemical information, and evaluate the reliability and scientific accuracy of digital and AI-generated outputs.

Values and Attitudes

Students are expected to:
- value the importance of fair tests and experiments;
- value the need for accuracy and precision in data collection during scientific investigations;
- appreciate the importance of careful laboratory techniques and precise calculations in obtaining accurate results;
- tolerate the uncertainty involved in experimentation;
- respect the views of others and evidence-based conclusions;
- appreciate the creativity and perseverance required to develop workable solutions to problems;
- value the importance of using digital tools and AI critically and responsibly, recognising both their benefits and limitations in scientific inquiry;
- appreciate the need to integrate digital technologies and AI with sound scientific reasoning when solving chemistry-related problems; and
- be aware of the need to integrate science knowledge with other disciplines, such as mathematics and technology, to provide solutions to real-life problems.

Implementation

A number of inquiry-based practical activities are suggested for different topics in the curriculum. Teachers can select and arrange those practical activities to engage students with the key learning components related to scientific inquiry. These key learning components include:

- Identifying questions to study and make predictions
- Carrying out risk assessments for experiments
- Planning and writing experimental procedures
- Conducting investigations to collect valid and reliable data
- Performing data analyses and communicating the experimental findings
- Discussing the validity of findings and conclusions of experiments

- Suggesting ways to improve the feasibility, validity and/or reliability of experiments

Teachers are encouraged to utilise the 20 hours of the curriculum time flexibly and arrange throughout the curriculum a number of practical activities that engage students in the selected learning components of scientific inquiry listed above. For instance, in an inquiry-based experiment on a particular topic, students could be required to carry out the risk assessment and design the experimental procedures on their own, while detailed instructions for other parts of the experiment, such as data analyses and guiding questions for discussing the validity and reliability of experimental results, are provided. In another inquiry-based experiment, students could be provided with experimental procedures in advance while being required to carry out data analyses and design the best way to communicate the experimental findings. For academically advanced students, teachers may consider arranging a more comprehensive investigation that involves all of the key learning components mentioned above. The inquiry-based experiments/investigations can focus on a single topic in the curriculum (i.e. topic-based) or related to multiple topics (i.e. cross-topic in nature). Some suggested practical activities across the curriculum are listed below:

- Extracting useful substances from plant materials and testing their use as indicators for acid-base titrations
- Using a titration experiment to determine the concentration of ethanoic acid in vinegar or the concentration of sodium hydroxide in drain cleaner
- Designing and performing experiments to investigate the salt contents in snacks and comparing the results with the figures on the food labels
- Performing experiments to determine the amount of food dye present in soft drinks using a colorimeter, a custom-made LED colorimeter, or a suitable mobile application
- Investigating the iron content in some commercial ‘iron tablets’
- Analysing the vitamin C content in citrus fruits
- Designing and performing electroplating experiments

Considering the allocation of lesson time and students’ experience and skills in practical activities, teachers should decide and plan the extent of support and guidance necessary for students to complete the assigned inquiry-based experiments/investigations. For example, teachers may consider adopting a guided-inquiry approach and providing feasible experimental methods for an investigation as a reference for students while guiding them in designing, planning and writing the experimental steps. Alternatively, teachers may guide students to conduct an investigation using provided procedures but require them to decide on appropriate presentations (e.g. in terms of tables and graphs) to display the data and perform data analyses. Even for an inquiry-based experiment/investigation with all instructions provided for procedures and data analyses, students can still engage in discussions regarding the validity of results and suggest improvements for the investigation. For academically advanced students with sufficient lesson time, teachers may consider adopting an open inquiry approach, allowing students to carry out their own investigations.

Communicating an investigation with clarity and accuracy is an essential skill in scientific inquiry. Therefore, students should be provided with ample opportunities to practice writing experimental reports throughout the curriculum, including but not limited to occasions when they conduct the inquiry-based experiments/investigations in chemistry.

Assessment

Based on the key learning components of scientific inquiry that students engage in during a particular inquiry-based experiment/investigation, teachers can make reference to one or more of the following assessment criteria when providing feedback on students' work:

- Feasibility of the investigation plan and/or the self-designed experimental procedures
- Understanding of relevant chemistry concepts and concerns about safety
- Manipulative skills and general bench performance
- Proper risk assessment for experiments
- Proper data collection procedures and handling of possible sources of error
- Ability to analyse and interpret data obtained from first-hand investigations
- Ability to evaluate the validity and reliability of the investigation process and findings
- Ability to communicate the experimental procedures, data and/or findings effectively
- Appropriateness of references to support the methods and findings
- Attitudes towards the investigation

A variety of assessment methods, such as observation, questioning, oral presentations and scrutiny of written products, including proposals and reports, can be used where appropriate.

Chapter 3 Assessment Framework

3.1 Assessment Objectives

The assessment objectives of Chemistry are to evaluate the abilities of candidates to:

1. demonstrate an understanding of knowledge, facts, patterns, principles, terminology and conventions of chemistry;
2. apply knowledge, principles and concepts of chemistry in both familiar and unfamiliar contexts;
3. show an understanding of the purposes of using different apparatus and materials in performing experiments;
4. handle materials, manipulate apparatus, carry out experiments safely and make accurate observations;
5. demonstrate an understanding of the methods used in scientific inquiry;
6. analyse and interpret data presented in different forms, including tables, graphs and diagrams;
7. manipulate and translate chemical data and perform calculations;
8. select and organise scientific information from appropriate sources including experiments, describe, analyse and evaluate the information, and draw appropriate conclusions;
9. demonstrate an understanding of the applications of chemistry to daily life and its contributions to the modern world;
10. recognise the ethical, moral, social, economic, environmental and technological implications of chemistry; and
11. make suggestions, decisions and judgments based on scientific evidence and arguments.

3.2 Assessment Design

3.2.1 Mode of assessment

The public assessment of Chemistry consists of a public examination component and a school-based assessment component as outlined in the following table:

Component		Weighting	Duration
Public Examination	Paper 1 Conventional Questions	56%	2 hours 15 minutes
	Paper 2 Multiple-choice Questions	24%	1 hour
School-based Assessment (SBA)		20%	——

3.2.2 Public examination

Paper 1 consists of conventional questions, including short questions, structured questions and essay questions, set on both the core and extension components of the curriculum. It carries 56% of the subject mark. Candidates are required to answer all questions in Paper 1.

Paper 2 consists of multiple-choice questions set on both the core and extension components of the curriculum. It carries 24% of the subject mark. Candidates are required to answer all questions in Paper 2.

Questions set on the extension component would **not** exceed 30% of the written paper marks.

3.2.3 School-based assessment (SBA)

School-based assessment (SBA) is compulsory for all school candidates. Candidates will be assessed by their teachers on their performance of a wide range of skills involved in practical work throughout S5 and S6. Candidates are required to perform a stipulated amount of practical work, which may include conducting experiments, reporting and interpreting experimental results, etc. The work should be integrated closely with the curriculum and form a part of the normal learning and teaching process. Apart from these, candidates may also make use of their knowledge and understanding of chemistry to design and conduct experiments with an inquiry-based approach, through which their generic skills, practical skills, process skills and reporting skills, etc. would be developed and assessed.

The table below summarises the minimum number of assessments required in S5 and S6 for the SBA and the respective weighting in the subject:

	Minimum number of assessments*	Weighting in the subject
S5	2	20%
S6	2	

* Over the two years of S5 and S6, there should be at least one assessment for Volumetric Analysis (VA), one assessment for Qualitative Analysis (QA) and two assessments for Other Experiments (EXPT).

* Inquiry-based experiments can be done in lieu of Other Experiments (EXPT). In this case, assessments on ‘proposal’ and/or ‘report’ should be performed. These assessments can satisfy the minimum requirement for Other Experiments (EXPT).

For monitoring and authentication purposes, candidates are required to keep good custody of all their work in SBA until the publication of the HKDSE examination results.

Private candidates need not complete the SBA component. Their subject result will be based entirely on their public examination results.

The detailed requirements, regulations, assessment criteria, guidelines and methods of assessment will be provided in the SBA Teachers' Handbook for HKDSE Chemistry published by the Hong Kong Examinations and Assessment Authority in due course.

The Use of Digital Educational Tools and Artificial Intelligence for Learning, Teaching and Assessment of Chemistry

Digital educational tools and artificial intelligence (AI) provide strong support for learning and teaching and promote pedagogical innovation in Chemistry. Through the appropriate use of digital tools and AI-assisted strategies, teachers can design interactive learning activities more effectively, better understand students' learning progress and needs, and enhance teaching effectiveness through diversified pedagogical strategies.

In Chemistry learning and teaching, teachers can make good use of AI technologies, such as generative AI (GenAI), personalised learning platforms and learning analytics tools, to support the design of learning activities and assessment tasks that are more closely aligned with students' learning needs. In particular, AI tools can assist teachers in analysing students' learning performance, identifying common misconceptions and learning difficulties, and providing feedback or suggestions for refining learning and teaching materials, thereby supporting students' learning in Chemistry.

With appropriate teacher guidance and the development of fundamental digital skills, AI-assisted learning tasks can also support effective self-directed learning. These learning experiences help enhance students' learning motivation and self-reflection, while strengthening their knowledge acquisition and conceptual understanding.

Teachers may make appropriate use of AI and digital educational tools, including simulations, animations, three-dimensional molecular visualisation and data analysis tools, to help students develop a deeper understanding of abstract chemical concepts, particularly those involving sub-microscopic particle models, symbolic representations and quantitative relationships. Online learning platforms and AI-assisted tools may also be used to provide students with diversified learning experiences and timely feedback, thereby promoting self-directed learning and enhancing overall learning effectiveness.

The following are examples of applications of digital educational tools for teachers' reference:

Digital Educational Tools	Pedagogical Use
Data-loggers and Sensors	• Facilitate real-time data collection and instant graphical representation in practical work. • Support scientific inquiry by enabling students to design experiments, observe trends promptly, and focus on data interpretation, evaluation and discussion rather than manual data plotting.
Mobile Devices	• Enable students to conduct experiments using mobile applications (e.g. determining the amount of food dye present in soft drinks).

Digital Educational Tools	Pedagogical Use
	• Allow students to capture videos of chemical reactions and analyse them qualitatively or quantitatively.
Computer Simulations	• Enable students to directly observe and manipulate abstract or sub-microscopic entities and processes (e.g. molecular shapes, intermolecular forces, chemical equilibrium and reaction rates) in a virtual environment. • Interactive simulation experiments allow students to manipulate variables by themselves and establish the connection of chemical concepts with experimental observations. • Help address misconceptions and promote conceptual understanding through inquiry-based exploration.
Multimedia Resources (Animations and videos)	• Animations and videos help students visualise abstract concepts and industrial or laboratory processes that are otherwise inaccessible. • Stimulate interest, support conceptual understanding, and allow repeated observation of experimental techniques and phenomena.
Online Learning and Assessment Platforms	• Provide online chemistry-related lectures, reading activities, interactive learning resources on experiments and data analysis, and online assessments with instant feedback. • Support formative assessment, help teachers identify students' learning difficulties, and promote self-directed and collaborative learning beyond the classroom.
Artificial Intelligence (AI)	• Support diagnostic and formative assessment by analysing students' responses to questions to identify misconceptions, learning difficulties and topic-specific weaknesses. • Provide adaptive learning and practice tasks (e.g. chemical symbols and formulae, balancing equations, mole calculations and naming of organic compounds) to support progressive skill and concept development. • Enhance learning effectiveness by assisting students in understanding abstract and sub-microscopic concepts (e.g. molecular structures, chemical equilibrium and structure–property relationships) through visualisation and modelling. • Assist teachers in designing curriculum-aligned learning and assessment materials tailored to students' needs, thereby creating teaching space for laboratory work, class discussion and deeper conceptual understanding.

The table below illustrates how different digital educational tools can be used flexibly and complementarily to support lesson design, learning activities and assessment, hence helping teachers identify and select appropriate tools according to specific purposes of learning activities in Chemistry.

Purposes of Learning Activities	Data-loggers and Sensors	Mobile Devices	Computer Simulations	Multimedia Resources (Animations and videos)	Online Learning and Assessment Platforms	Artificial Intelligence (AI)
Visualisation and modelling of abstract concepts			✓	✓		✓
Inquiry-based exploration and conceptual understanding		✓	✓	✓		✓
Practical work and data handling	✓	✓		✓	✓	✓
Online reading, practice and quizzes, and self-directed learning				✓	✓	✓
Assessment for learning and feedback					✓	✓

Pedagogical Considerations of Using AI in Chemistry

When applying AI (including GenAI) to support learning and teaching, teachers should strike an appropriate balance between AI-assisted learning, hands-on scientific investigations and other teacher-guided learning activities. Teachers are required to exercise professional judgement in determining the appropriate use of AI and to ensure that they continue to play the role of learning facilitators. Students should be provided with sufficient opportunities to engage in authentic learning experiences, including practical laboratory work, scientific investigations, reflective discussions on socio-scientific issues and scientific reasoning, to deepen conceptual understanding and develop scientific inquiry skills.

For learning and teaching materials designed with the assistance of GenAI, teachers should clearly indicate the AI-generated components and avoid practices that may compromise academic integrity. Teachers should verify the authenticity, accuracy and consistency of AI-generated content before use. When AI tools are used to support assessment or feedback, teachers should conduct manual review and moderation to ensure assessment quality and uphold academic integrity.

Teachers should also foster students' awareness of the ethical and responsible use of AI, including an understanding of its limitations and potential inaccuracies. Students should be guided to evaluate AI-generated outputs critically, verify information using authoritative sources, and use AI as an assistive tool rather than a substitute for scientific reasoning.

The Use of AI in Chemistry Lesson Setting

When planning Chemistry lessons, teachers should clearly define the learning objectives and consider how AI can be used to support students' engagement in the related scientific practices, such as applying chemical concepts to novel contexts, analysing and interpreting experimental data, and constructing and evaluating explanations.

When planning Chemistry lessons involving the use of AI, teachers should consider the following:
- the intended learning objectives and expected learning outcomes;
- how AI can support, rather than replace, students' conceptual understanding and scientific inquiry;
- the provision of appropriate scaffolding and guidance for students' use of AI tools;
- learning strategies to facilitate knowledge consolidation and knowledge transfer; and
- the balance between digital learning experiences and other teacher-guided learning activities, including practical laboratory work, scientific investigations, reflective discussion on socio-scientific issues and scientific reasoning.

Example of Using Digital Educational Tools and AI in Classroom Design

AI tools can assist in visualising the abstract microscopic world of Chemistry. With well-designed learning and teaching activities, teachers can create opportunities for students to link macroscopic properties with the interactions between atoms, ions and molecules at the sub-microscopic level through active, constructive and interactive learning. When designing AI-assisted activities, teachers should focus on guiding students to apply relevant prior knowledge and transfer their acquired understanding to novel contexts, while critically evaluating AI-generated information.

Topic: Topic IV Microscopic World II

Learning outcomes:

- Predict and draw three-dimensional diagrams to represent shapes of (i) molecules with central atoms obeying octet rule; and (ii) molecules with central atoms not obeying octet rule and with no lone pair of electrons (such as BF_3, PCl_5 and SF_6)

Learning activities	The Use of Digital Educational Tools / AI
1. Teachers first guide students to predict and hand-draw structural formulae (including lone pairs) and three-dimensional shapes for selected molecules (e.g. HCHO, SO_2 and PH_3), with explanations based on electron pair repulsion.	No AI
2. Through teacher questioning and peer discussion, students extend their reasoning to determine molecular polarity and relate structure to properties.	No AI
3. Students then upload their hand-drawn work and explanations to a generative AI (GenAI) tool. With clear constraints set by the teacher, the AI is only allowed to identify possible error types and suggest checking steps, but not provide final answers.	Using GenAI to provide tailored feedback on students' answers
4. Students verify the AI feedback using authorised simulation tools (e.g. PhET), revise their work after discussing with peers, and submit to teachers both original and revised versions as learning evidence.	Using other digital learning tools to assist learning

- As an extension, students apply the same AI-assisted approach to explain boiling-point trends of molecules such as BF_3, SF_6 and H_2O by relating molecular shape, polarity and intermolecular forces. Through peer discussion and reflection, students refine their understanding of sub-microscopic models and strengthen scientific reasoning.

Connections across Learning of Senior Secondary Science Subjects

In the course of the learning and teaching of Biology (S4-6), Chemistry (S4-6) and Physics (S4-6) curricula, students will encounter scientific inquiry skills and subject contents that are interconnected across science subjects. These shared learning elements are key to nurturing students' scientific literacy. Although the three science disciplines are offered as distinct elective subjects at the senior secondary level, they are underpinned by shared scientific principles and inquiry methods. Students taking two or three science electives can reinforce their learning effectiveness through the transfer of knowledge and skills across the subjects.

To enhance the coherence and depth of learning across Biology, Chemistry and Physics, this section explicitly highlights the common scientific inquiry skills and contents. Teachers can adopt an integrated teaching approach accordingly, which not only reinforces common scientific skills in students but also enhances their understanding of the nature of science in the process and practice of science. In particular, Chemistry teachers should not focus solely on teaching subject-specific knowledge within the chemical discipline but should also proactively strengthen the shared scientific competences common to science subjects. This will facilitate students in articulating their scientific skills from junior secondary science to advance learning in senior secondary level, and equip them with the competencies to conduct evidence-based inquiry, critically evaluate data, and make informed decision in scientific and real-life contexts.

Common scientific inquiry skills across Biology (S4-6), Chemistry (S4-6) and Physics (S4-6) curricula

Experimental inquiry, data processing and scientific reasoning skills are fundamental to Biology, Chemistry and Physics at the senior secondary level, and they also permeate the entire Science Education Key Learning Area. These skills are progressively developed through Science (S1-3) curriculum and enable students to generate reliable empirical evidence, analyse data quantitatively and qualitatively, evaluate experimental limitations, and draw valid and evidence-based conclusions.

Through the practical tasks recommended in the respective Curriculum and Assessment Guides for the senior secondary science subjects, students experience the systematic and evidence-driven nature of scientific investigation. The shared emphasis on scientific inquiry not only consolidates the essential science competences but also reinforces transferable skills such as critical thinking, problem-solving, and collaboration, while cultivating positive values and attitudes including integrity in data handling, commitment to safety and awareness of ethical considerations in scientific practice.

1. Experimental inquiry skills

By conducting the recommended practical tasks set out in the respective Curriculum and Assessment Guides, ranging from structured practical work and inquiry to more open-ended investigative studies, students actively engage in the essential processes of scientific inquiry in a systematic and reflective manner, including observation, hypothesis formulation, experimental design, data collection, data interpretation, and conclusion drawing. Engaging in practical activities across Biology, Chemistry, and Physics enables students to both deepen subject understanding and appreciate the common science principles underlying practical activities across disciplines, such as the tentative yet evidence-based nature of scientific knowledge, the importance of validity and reliability, and the role of creativity and perseverance in advancing understanding.

The following **experimental inquiry skills** are commonly articulated across the three subjects, with clear progression from the junior secondary level:

E1 Planning and designing investigations
E2 Risk assessment and safe laboratory practices
E3 Selecting and handling apparatus and materials
E4 Controlling variables and ensuring experimental reliability
E5 Accurate and precise measurement and observation
E6 Data collection and recording
E7 Evaluation and improvement of experiments

E1 Planning and designing investigations

Students studying Biology, Chemistry or Physics should be able to	Articulation with Science (S1-3) curriculum
• Formulate testable hypotheses or research questions based on observations or relevant prior scientific knowledge • Identify questions to study and make predictions • Select appropriate methods and justify experimental approaches • Identify independent, dependent, and control variables • Design logical and feasible procedures to address the research question • Plan and write experimental procedures	✓ Formulating a hypothesis based on observed phenomena ✓ Identifying independent variables, dependent variables and control variables ✓ Choosing from alternative experimental methods or improving the method for a scientific investigation

E2 Risk assessment and safe laboratory practices

Students studying Biology, Chemistry or Physics should be able to	Articulation with Science (S1-3) curriculum
• Carry out risk assessments for experiments / scientific investigations • Implement appropriate safety measures (e.g. use of personal protective equipment, proper handling of chemicals, high-voltage electrical equipment, or biological specimens) • Demonstrate responsible laboratory practice, including proper waste disposal, adherence to safety rules (e.g. always attend to the heat source), and appropriate emergency procedures • Conduct investigations safely to collect valid and reliable data	✓ Using apparatus appropriately and safely

E3 Selecting and handling apparatus and materials

Students studying Biology, Chemistry or Physics should be able to	Articulation with Science (S1-3) curriculum
• Select apparatus and materials appropriate to the required precision, scale, and nature of the investigation • Use instruments and materials properly and competently • Handle materials efficiently to minimise waste and ensure experimental feasibility	✓ Using apparatus appropriately and safely

E4 Controlling variables and ensuring experimental reliability

Students studying Biology, Chemistry or Physics should be able to	Articulation with Science (S1-3) curriculum
• Design controlled experiments to investigate relationships (correlational or causal) between variables • Identify potential confounding factors and minimise their effect • Use repeated trials and averaging measurements to reduce the effect of random errors • Assess reliability and suggest improvements to enhance experimental design	✓ Setting up a controlled experiment to minimise confounding factors to identify causation ✓ Identifying independent variables, dependent variables and control variables

E5 Accurate and precise measurement and observation

Students studying Biology, Chemistry or Physics should be able to	Articulation with Science (S1-3) curriculum
• Use measuring instruments correctly and read scales to appropriate precision • Distinguish between accuracy and precision • Make careful qualitative observations (e.g. colour change, precipitate formation, behavioural response, unexpected phenomena) • Comment on accuracy and precision in scientific measurements	✓ Making qualitative observations and quantitative measurements ✓ Commenting accuracy and precision in a scientific measurement

E6 Data collection and recording

Students studying Biology, Chemistry or Physics should be able to	Articulation with Science (S1-3) curriculum
• Collect sufficient and relevant data to address the research question • Record measurements with appropriate units and significant figures • Record raw data systematically in tables or structured formats • Perform initial data processing where appropriate (e.g. averaging or unit conversions) • Present data clearly to facilitate further analysis	✓ Making qualitative observations and quantitative measurements ✓ Using tables and graphs for organising and presenting data

E7 Evaluation and improvement of experiments

Students studying Biology, Chemistry or Physics should be able to	Articulation with Science (S1-3) curriculum
• Evaluate the feasibility, validity and reliability of experiments • Suggest ways to improve the feasibility, validity, and/or reliability of experiments • Identify limitations and sources of error in experiments • Propose refinements or alternative approaches for future studies	✓ Choosing from alternative experimental methods or improving the method for a scientific investigation

2. Data processing skills

After collecting data from experiments, students are required to process and analyse the data in order to draw valid conclusions to support or refute the set hypothesis. The fundamental knowledge and skills are developed in the Science (S1-3) curriculum. At the senior secondary level, these skills will be further strengthened and applied with greater mathematical rigour and conceptual depth across Biology, Chemistry and Physics.

The following **data processing skills** are commonly articulated across the three subjects, with clear progression from the junior secondary level:

D1 Use of SI unit and unit prefixes, and derivation of units
D2 Significant figures and treatment of measurement errors
D3 Graphical presentation of relationships and functions
D4 Data analysis and interpretation

D1 Use of SI unit and unit prefixes, and derivation of units

Students studying Biology, Chemistry or Physics should be able to	Articulation with Science (S1-3) curriculum
• Use SI units appropriately when expressing physical, chemical and biological quantities • Perform unit conversions accurately, including the use of prefixes and scientific notation • Derive and interpret compound units from base SI units where appropriate • Represent quantities with appropriate order of magnitude	✓ Using scientific notation, significant figures and ratio for expressing and comparing scientific data

D2 Significant figures and treatment of measurement errors

Students studying Biology, Chemistry or Physics should be able to	Articulation with Science (S1-3) curriculum
• Record measurements with appropriate precision according to the measuring instrument used • Express calculated results using an appropriate number of significant figures • Distinguish between accuracy and precision • Reduce the effect of random errors through repeated measurements and averaging • Identify anomalous results and evaluate their impact on reliability	✓ Using scientific notation, significant figures and ratio for expressing and comparing scientific data

D3 Graphical presentation of relationships and functions

Students studying Biology, Chemistry or Physics should be able to	Articulation with Science (S1-3) curriculum
• Select appropriate variables for the x- and y-axes based on the nature of the independent and dependent variables • Choose suitable scales and units, axis labels, and graph titles for clear and accurate graphical representation • Plot data accurately (by hand and/or using digital tools) to construct appropriate line graphs or scatter graphs, or other suitable graph types • Recognise and represent common mathematical relationships graphically	✓ Using tables and graphs for data analysis

D4 Data analysis and interpretation

Students studying Biology, Chemistry or Physics should be able to	Articulation with Science (S1-3) curriculum
• Perform data analyses to identify patterns, trends or relationships in the collected data • Draw appropriate best-fit lines or curves from graphical data, and use them to interpret trends, interpolate/extrapolate values or determine slopes/intercepts • Interpret graphical representations to identify patterns, relationships, anomalies, or limitations in the data • Relate graphical and numerical results to underlying scientific principles • Evaluate limitations of data and suggest improvements	✓ Using tables and graphs for data analysis ✓ Identifying outliers and handling data from repeated measurements to assess the uncertainty incurred

3. Scientific reasoning skills

Scientific reasoning skills involve deductive, inductive and abductive reasoning as foundational processes, these are applied in the construction, evaluation, and revision of scientific models and argumentations. Through such reasoning, students interpret empirical evidence, construct coherent scientific explanations, and critically evaluate claims and models. Progressively developed from the Science (S1-3) curriculum, these higher-order cognitive skills are central to scientific literacy as emphasised in the Science Education Key Learning Area. In senior secondary Biology, Chemistry, and Physics, students apply scientific reasoning when analysing experimental data, evaluating the validity of conclusions, applying concepts to novel situations, and examining Science, Technology, Society and the Environment-related issues using evidence-based judgement.

The following **scientific reasoning skills** are commonly articulated across the three subjects, with clear progression from the junior secondary level:

R1 Scientific reasoning: deduction, induction and abduction
R2 Application of reasoning: scientific modelling and argumentation

R1 Scientific reasoning: deduction, induction and abduction

Students studying Biology, Chemistry or Physics should be able to	Articulation with Science (S1-3) curriculum
• Draw logical inferences from observations, experimental data or scientific information • Examine evidence and apply logical reasoning to draw valid conclusions • Make informed judgements when outcomes involve uncertainty or probability • Use inductive reasoning to generalise from specific observations or data to broader trends, patterns, conclusions or models • Apply deductive reasoning to predict specific outcomes from a set of general observations or data and established laws, principles, theories, models, or established trends	✓ Using specific data to induce a general trend, conclusion or model ✓ Using a set of general observations, trend or model to deduce a specific result ✓ Making inference to the best possible explanation to the observed phenomenon ✓ Making informed decision based on the probability of phenomenon to be occurred

Students studying Biology, Chemistry or Physics should be able to	Articulation with Science (S1-3) curriculum
• Apply abductive reasoning to infer the most plausible explanation consistent with available evidence when multiple interpretations are possible • Recognise the appropriate contexts, strengths, and limitations of inductive, deductive and abductive reasoning in scientific inquiry	

R2 Application of reasoning: scientific modelling and argumentation

Students studying Biology, Chemistry or Physics should be able to	Articulation with Science (S1-3) curriculum
• Apply appropriate scientific models to explain phenomena, interpret data, and predict outcomes in familiar and novel contexts • Evaluate the strengths, limitations, assumptions, and tentative nature of scientific models • Construct and present reasoned scientific arguments supported by empirical evidence, logical reasoning, and relevant scientific principles • Engage in scientific argumentation as a systematic process to analyse, explain, critique, or defend scientific explanations of natural phenomena • Integrate new concepts or evidence into existing knowledge frameworks and apply them critically to new situations • Appreciate the evolutionary nature of scientific knowledge, where models and explanations are subject to continuous revision based on accumulating evidence	✓ Using specific data to induce a general trend, conclusion or model ✓ Using a set of general observations, trend or model to deduce a specific result ✓ Making inference to the best possible explanation to the observed phenomenon ✓ Making informed decision based on the probability of phenomenon to be occurred

<u>Related subject contents across Biology (S4-6), Chemistry (S4-6) and Physics (S4-6) curricula</u>

Biology, Chemistry, and Physics are offered as distinct elective subjects at the senior secondary level. Nevertheless, they share many fundamental concepts and principles. Students who concurrently study two or three science subjects gain significant advantages in developing a more comprehensive and interconnected understanding of the unified nature of science. By exploring common concepts through different disciplinary perspectives, such as matter, energy and interactions from subatomic to universe scales, students can deepen their understanding across subjects, enabling them to apply knowledge flexibly in novel or real-life contexts. For example, understanding the conservation of energy in Physics strengthens the interpretation of enthalpy changes in Chemistry and energy flow in biological ecosystems, fostering deep, transferable conceptual understanding.

Furthermore, studying multiple science subjects promotes fluency in shared language and conventions. Students will become more proficient in using precise scientific terminology (e.g. mole, potential difference, activation energy), symbolic representations (e.g. equations, graphs, structural formulae), and quantitative tools (e.g. significant figures, unit conversions, error estimation). These shared representational practices can reduce barriers between subjects, foster communication of science ideas, and strengthen overall scientific literacy.

Making the cross-disciplinary connections explicit enables students to develop a more integrated and coherent understanding of science. More specifically, students taking two or three science subjects will constantly recognise that concepts learned in one science subject often provide explanatory frameworks for phenomena in another, thereby deepening understanding and promoting knowledge transfer.

The following table provides examples of related contents of Biology, Chemistry and Physics curricula, illustrating how core ideas, such as energy transformations, the structure of matter, particle interactions, radiation, and the relationship between structure and function, are developed and applied in different disciplinary contexts.

Examples of related subject contents of Biology, Chemistry and Physics:

Chemistry	**Physics**	**Biology**
Enthalpy changes in chemical reaction	Temperature, heat and internal energy; Heat transfer process; Change of state; Law of conservation of energy in a closed system	Energy flow in ecosystems; energy transformations in cellular respiration and photosynthesis; Regulation of body temperature
Mole concept; Avogadro's Law; Molar volume	Gas laws	Gas exchange in humans and plants
Rate of reaction	Kinetic theory	Factors affecting rate of enzymatic reactions; Diffusion and osmosis across cell membranes
IR spectroscopy and colorimetry	EM wave spectrum; Intensity	Effects of light intensity on photosynthesis; Light absorption in photosynthetic pigments
Chemical cells; Electrolysis	Electric circuit	Nerve impulse transmission
Bond polarity; Intermolecular forces	Electrostatics; Scalars and vectors	Enzyme-substrate binding; water properties
Atomic structure; Subatomic particles; Isotopes	Atomic model; Radioactive decay; Isotopes	Structure and chemical bonding in biomolecules (e.g. DNA nucleotides, proteins)
Fossil fuels and carbon compounds	Energy sources	Use of resources in ecosystems

Mathematical skills across Biology (S4-6), Chemistry (S4-6) and Physics (S4-6) curricula

A strong foundation in mathematics is essential for the study of Biology, Chemistry, and Physics at senior secondary level, as many mathematical skills are shared or closely related across the three disciplines. These include algebraic manipulation and formula application, data handling and graphical analysis, as well as application of geometry and trigonometry. Examples of related mathematical skills of Biology, Chemistry and Physics are tabulated below for reference:

Mathematical skills	Contexts in Science Subjects (Examples)
Manipulation of equations and functions	**Biology** • Apply equations related to microscopy (e.g. magnification = image size / actual size). **Chemistry** • Solve algebraic equations (e.g. rate = k[reactant1]^x[reactant2]^y) • Perform calculations involving logarithms (e.g. pH = -log[H^+], Arrhenius equation) **Physics** • Derive and apply equations to solve problems for topics such as mechanics, electricity and magnetism, and quantum physics
Handling data and use of units	**Biology** • Convert between metric units (e.g. millimeters to micrometers) when calculating the sizes of sub-cellular structures • Apply appropriate measurement units when quantifying environmental conditions **Chemistry** • Express physical quantities (e.g. molecular mass, concentration) using appropriate units and how they can be inter-converted • Calculate a mean titre **Physics** • Perform dimensional analysis by unit conversion and matching of SI units • Apply the concept of order of magnitude and significant figures in experimental measurements

Use and interconversions of ratios, fractions and percentages	**Biology** • Calculate percentages to determine the efficiency of energy transfer between trophic levels **Chemistry** • Determine empirical formulae and molecular formulae from compositions by mass and molar masses **Physics** • Find the efficiency of transformer, electrical appliance, and machines
Constructing and interpreting graphs	**Biology** • Plot graphs to determine physical properties of biological tissues • Interpret curves to deduce physiological changes over time or distance **Chemistry** • Determine the activation energy of a chemical reaction • Calculate enthalpy changes from experimental results **Physics** • Plot and analyse graphs for physical laws • Interpret the physical meaning of slope and intercepts
Application of geometry and trigonometry	**Biology** • Understand three-dimensional structures of biomolecules **Chemistry** • Predict and draw three-dimensional diagrams to represent molecular shapes **Physics** • Apply addition of vector to find resultant vector and resolve a vector into components (e.g. acceleration, force) • Apply dot product and cross product in mechanics (e.g. work done), and electricity and magnetism (e.g. magnetic force)

Students who study two or three science subjects benefit significantly, as they can reinforce these common mathematical skills, leading to deeper conceptual understanding and greater fluency in applying mathematics to solve scientific problems. This advantage is further amplified when students also take Mathematics Extended Part (Module 1 or 2) alongside the science subjects, as the study of extended mathematics enables them to understand advanced science topics at a deeper level. For example, knowledge of calculus from Module 1 or 2 equips students with a stronger grasp of concepts such as the meaning of rate of change and the relationship between the area under a curve and physical quantities in the kinematics topic in Physics. Such synergy not only supports but also extends learning across all three subjects.

Summary of proposed updates in contents of the Chemistry curriculum

Direction of the updates	Proposed changes in the curriculum contents	Rationales
Improving vertical articulation with the junior secondary Science	The topic "Planet Earth" is removed as its learning contents have been subsumed into Unit 13 Our Planet Earth of the updated Science (S1-3) Curriculum.	• To enrich the chemistry-related learning elements in the Science (S1-3) curriculum for better interfacing between junior and senior levels
Integrating the compulsory and elective parts	• Rate equation, activation energy and catalysis from "Industrial Chemistry" are subsumed into "Rate of Reaction" (See Page 59 – 60) • The processes in the chloroalkali industry from "Industrial Chemistry" are subsumed into "Redox Reactions, Chemical Cells and Electrolysis" (See page 43) • The production of ammonia in the Haber process and the principles and practices of green chemistry from "Industrial Chemistry" are subsumed into "Chemical Equilibrium" (See Page 66) • Condensation polymerisation from "Materials Chemistry" is subsumed into "Important Organic Synthetic Products" (See Page 79 – 80)	• To facilitate teachers to integrate the teaching of related topics in a more coherent manner to reduce overlapping in teaching and thus releasing some lesson time
Trimming and fine-tuning selected contents, and	The following sub-topics / learning outcomes are trimmed:	• To create space for integrating the compulsory and elective parts

Direction of the updates	Proposed changes in the curriculum contents	Rationales
rearranging the sequence of topics and sub-topics	• Fossil Fuels and Carbon Compounds - Describe the steps involved in the monosubstitution of methane with chlorine using suitable diagrams or equations • Chemistry of Carbon Compounds - Hydrolysis of N-substituted amides • Industrial Chemistry - Conversion of methane to methanol • Materials Chemistry - Structures and properties of cellulose and chitin - Formation and uses of PTFE, PMMA, cyanoacrylate, HDPE/LDPE and Kevlar - Vulcanization of polymers - Plastics fabrication processes - Metallic crystal structures - Chemical structures and structural features of organic liquid crystals - Uses of nanomaterials • Analytical Chemistry - Test for presence of carbonyl compounds using 2,4-dinitrophenylhydrazine	
	Rearrangement of the sequence of topics and sub-topics	• To enhance teaching coherence by moving "Fossil fuels and carbon

Direction of the updates	Proposed changes in the curriculum contents	Rationales
	• "Fossil fuels and carbon compounds" is moved after "Microscopic world II" and "Redox reactions, chemical cells and electrolysis" in the topic sequence • Calculation involving percentage by mass of an element in a compound is moved from "Metals" to "Fossil fuels and carbon compounds" • Calculation involving molar volume of gases is moved from "Rate of reaction" to "Acids and bases"	compounds" closer to "Chemistry of carbon compounds" in the topic sequence • To equip students with understanding of intermolecular forces from "Microscopic world II" so that they can understand gradation in physical properties of a homologous series in "Fossil fuels and carbon compounds" • To enhance the progressive development of mole concept and calculations across topics

Direction of the updates	Proposed changes in the curriculum contents	Rationales

	Some learning outcomes in the following topics are refined:
	• Acids and bases
	  - Molar volume of gases (See Page 29)
	• Chemical equilibrium
	  - Equilibrium constant (See Page 65)
	  - The effect of concentration, temperature and catalyst on chemical equilibria in homogenous reactions (See Page 66)
	• Chemistry of carbon compounds
	  - Isomerism (See Page 72)
	  - Typical reactions of various functional groups (See Page 73 -74)
	• Important Organic Synthetic Products
	  - Common over-the-counter drugs (See Page 78)
	• Patterns in the Chemical World
	  - General properties of transition metals (See Page 84)
		• To enhance the clarity of existing learning objectives and outcomes
		• To add learning outcomes that build on prior knowledge, reinforcing students' understanding and consolidating students' learning

Direction of the updates	Proposed changes in the curriculum contents	Rationales
Strengthening learning elements on Science, Technology, Society and the Environment (STSE) connections and sustainability	The following learning outcomes in relation to STSE connections are added: • Recognise the need of recycling rechargeable batteries • Recognise the benefits and the challenges of using hydrogen fuel cells for transportation • Recognise the need for alternative sources of energy • State the advantages and disadvantages of biodegradable plastics as exemplified by PLA • Discuss the environmental impact of the use of plastics	• To enable students to develop a sense of environmental responsibility and appreciate how chemistry is interconnected with sustainable development
Reinforcing scientific inquiry skills throughout the curriculum	A new topic "Scientific Inquiry in Chemistry" is included to replace "Investigative Study in Chemistry". It outlines key learning components of scientific inquiry, from which teachers can select and incorporate into practical activities across different topics. Meanwhile, in the suggested learning and teaching activities of the curriculum topics, inquiry-based experiments are marked with # for teachers' reference and key practical tasks are included.	• To provide students with ample scientific inquiry learning experiences to enhance their scientific inquiry abilities

Membership of the Working Group on the Review of the Chemistry Curriculum and Assessment

(From April 2023 to August 2024)

Chairperson:	Dr HUI Chi-kuen
Members:	Ms CHAN Ching-yan, Liza
	Ms CHAN Kam-lam, Annie
	Dr HO Koon-sing, Gray
	Mr KWOK Chi-fung
	Mr LEE Ka-ming, Raymond
	Dr MAK Kin-wah, Kendrew
	Mr NG Ka-wo
	Mr NG King-hong, Ringo
	Ms SIU Wai-yan, Vian
	Dr SZE Tung-po, Eric
	Ms TSE Suk-man, Anita
	Dr WONG Tsz-wing
Ex-officio Members:	Dr CHENG Siu-lin, Sophia (EDB)
	Ms CHU Suk-ching, Fanny (HKEAA)
Secretary:	Ms CHAN Wai-long, Phoenix (EDB)

Membership of the CDC-HKEAA Committee on Chemistry

(From September 2023 to August 2025)

Chairperson:	Dr WONG Tsz-wing
Members:	Ms CHAN Ching-yan, Liza
	Prof CHAN Ho-wai, Dennis
	Ms CHAN Kam-lam, Annie
	Dr FUNG Hong-sang
	Dr HO Koon-sing, Gray
	Mr KWOK Chi-fung
	Mr LEE Wai-shing, Ray
	Ms SIU Wai-yan, Vian
	Mr WONG Ka-kui
Ex-officio Members:	Dr CHENG Siu-lin, Sophia (EDB)
	Ms CHU Suk-ching, Fanny (HKEAA)
Secretary:	Ms CHAN Wai-long, Phoenix (EDB)

Membership of the CDC-HKEAA Committee on Chemistry

(From September 2025 to August 2027)

Chairperson:	Dr WONG Tsz-wing
Members:	Dr CHAN Ka-long, Donald Dr FUNG Hong-sang Prof HO Wing-kei, Keith Mr LEE Wai-shing Dr MAN Wai-lun Mr NG King-hong, Ringo Ms SIU Wai-yan, Vian Mr WONG Ka-kui Mr YEUNG Wai-leung
Ex-officio Members:	Dr CHENG Siu-lin, Sophia (EDB) Mr LEUNG Kin-ping (HKEAA)
Secretary:	Mr CHAN Ka-wai, Michael (EDB)