

**CHEMISTRY**  
**ADVANCED LEVEL**

The syllabus builds on the foundation of the HKCE Chemistry syllabus, a knowledge of which is assumed.

The syllabus has been designed for a two-year chemistry course at advanced level. It will adequately prepare students for further studies in chemistry and related disciplines.

The syllabus is not a teaching syllabus and the order of the topics listed is not intended to suggest a teaching sequence. Explanatory notes have been included in the syllabus as appropriate to indicate the scope and depth of treatment. However, the length of the notes on any particular section should not be regarded as an indication of the time to be spent on that section.

Experiments and activities suggested in the syllabus are more than enough. Some of the experiments and/or activities are alternative ones which are similar in nature. Teachers are advised to make discretionary choices as appropriate.

**AIMS**

The aims of the syllabus are to enable candidates:

1. to develop an interest in the study of chemistry and scientific literacy for adult life in a changing world;
2. to develop an understanding of the facts and patterns in the empirical world;

3. to develop an understanding of the concepts and principles of chemistry;
4. to develop experimental skills and an awareness of safety problems;
5. to develop skills for scientific investigation, including the ability to observe, to analyse and to interpret data objectively;
6. to develop the ability to communicate using the language of chemistry;
7. to develop the ability to solve problems and to make rational decisions;
8. to develop an appreciation of chemistry and its application in daily life; and
9. to develop an awareness of the social, economic, environmental and technological implications of chemistry.

### **ASSESSMENT OBJECTIVES**

The objectives of the examination are to test the following abilities:

1. to recall and show understanding of chemical facts, patterns, principles, terminology and conventions;
2. to show an understanding of the use of apparatus and materials in performing experiments,
3. to handle materials, manipulative apparatus, carry out experiments safely and make accurate observations;
4. to demonstrate an understanding of the method used in chemical investigation;
5. to analyse and interpret data from various sources, and draw relevant conclusions;
6. to manipulate and translate chemical data and to perform calculations;
7. to apply chemical knowledge to explain observations and to solve problems which may involve unfamiliar situations;
8. to select and organise scientific information from appropriate sources and to communicate this information in an appropriate and logical manner;
9. to understand the social, economic, environmental and technological implications of the applications of chemistry; and
10. to make decisions based on the examination of evidence and arguments.

**MODE OF ASSESSMENT**

The table below outlines the various components of the assessment:

Paper	Description	Weighting	Duration
1	Section A: Short questions ( <i>compulsory</i> questions)	24%	3 hours
	Section B: Questions on practical chemistry ( <i>compulsory</i> questions)	8%	
	Section C: Essay questions (a choice of 1 out of 2 questions)	8%	
2	Section A: Structured questions set mainly on topics 1-10 of the syllabus ( <i>compulsory</i> questions)	24%	3 hours
	Section B: Structured questions set mainly on topics 11-13 of the syllabus ( <i>compulsory</i> questions)	16%	
3	Teacher Assessment Scheme (TAS) <sup>1</sup>	20%	
	OR		
4	Practical examination		3 hours

<sup>1</sup> Candidates may opt to sit the practical examination (Paper 4) or use their previous TAS results (obtained in 2011 or 2012 examination) to substitute for the practical examination.

### **The Written Papers (Papers 1 and 2)**

The examination papers may contain questions set on unfamiliar situations. In such questions, candidates may be required to study information presented in the form of text, diagrams and graphs, and to apply their skills and knowledge acquired to answer questions set on the information given.

Chemical information, including some useful constants, characteristic infra-red absorption wavenumber ranges, standard reduction potentials and a Periodic Table will be provided for both Papers 1 and 2.

### **The Practical Examination (Paper 4)**

The practical examination will include

- (a) an experiment on quantitative chemistry, and
- (b) an experiment involving an observational and deductive exercise.

In the examination, candidates will be provided with the appropriate apparatus, and instructions indicating what has to be done and which critical observation must be made.

Candidates will be expected to show their ability to work accurately within the limits of the apparatus and chemical reactions involved. Candidates will also be expected to perform chemical calculations and/or to draw conclusions from the observations.

(Note : Experiments may be set for which candidates are not expected to have had previous experience. In such cases, full instructions will be given.)

No textbooks, notes etc. may be used in the examination.

**NOTES**

1. In general, SI units will be used.
2. In naming compounds, the useful references are “Guidelines for Systematic Chemical Nomenclature (2002)” by the Hong Kong Examinations and Assessment Authority, and “Chemical Nomenclature, Symbols and Terminology for Use in School Science” (1985) by the Association for Science Education (U.K.). The overriding rule for the naming of compounds is clarity and lack of ambiguity rather than adherence to strict rules.
3. “An English-Chinese Glossary of Terms Commonly Used in the Teaching of Chemistry in Secondary Schools” (1999) prepared by the Curriculum Development Council, issued by the Education Department is a useful reference for the Chinese terms.
4. All candidates, both school and private candidates, may be required to submit their laboratory books for inspection.

**1. Atoms, Molecules and Stoichiometry**

All substances are made up of atoms. Understanding atoms can help us comprehend intriguing phenomena such as bonding and structure, and predict properties of matter. In this beginning section, students will revisit some of the concepts learnt in the S4-5 curriculum. The introduction of mass spectrometry, a modern instrumental technique commonly used in the determination of relative atomic/molecular masses of chemical species, can help students recognise the limitations of conventional techniques and hence appreciate the importance of physical methods in chemical analysis.

Another focus of the section is the mole concept and stoichiometry. Students should recognise that owing to the small size of atoms, molecules and ions, properties of these species are often compared on a mole basis and that the Avogadro constant is a number which chemists commonly use in the comparison of physical and chemical properties of substances. Stoichiometry is the study of quantitative composition of chemical substances and the quantitative changes that take place during chemical reactions. Doing calculations on chemical stoichiometry can help students reinforce their concepts learnt in quantitative chemistry.

Students are expected to know the ideal gas equation, which describes the pressure, volume and temperature relationship of gases. However, knowledge of the kinetic theory of gases and the non-ideal behaviour of real gases are *not* required.

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
1.1	The atomic structure	Protons, neutrons and electrons as constituents of the atom. The relative masses and charges of a proton, neutron and electron. The atomic nucleus. Relative size of the atom and atomic nucleus.	

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
1.2	Relative isotopic, atomic and molecular masses	A brief account of the mass spectrometer in determining relative isotopic, atomic and molecular masses. (Linked with Section 12.8)	Inspect mass spectra of some elements.
1.3	The mole concept	The mole and the Avogadro constant. Molar volume of gases. Ideal gas equation, $pV=nRT$ , and its application to molar mass determination. Partial pressure of gas and its relationship to mole fraction.	Determine the molar mass of a volatile liquid.
1.4	Empirical and molecular formulae	Derivation of empirical formula using combustion data or composition by mass. Molecular formula derived from empirical formula and relative molecular mass.	
1.5	Chemical equation and stoichiometry	The stoichiometric relationship between reactants and products in a reaction. Calculations involving (i) reacting masses, (ii) volumes of gases, and (iii) concentrations and volumes of solutions.	Perform titrations involving acidbase reactions, redox reactions or other changes to illustrate concepts related to stoichiometry.

## 2. The Electronic Structure of Atoms and the Periodic Table

Our understanding of the structure of atom is mainly based on indirect evidences, e.g. the Bohr's model of hydrogen atom is based on atomic emission spectrum. Reading stories of how different models of atom evolved is like following the steps of the scientists. This can help students realise the importance of creative thinking and logical deduction in the study of science. In addition, students should recognise that the contemporary models of atoms are by far the best representations of atomic structures. They should know that all scientific theories do have their limitations and are ever evolving. Many of the atomic models are based on quantum mechanics. Students are *not* required to know the mathematical treatment involved.

The atomic properties of an element are related to its electronic configuration and hence its position in the Periodic Table. Students should appreciate the variation of atomic properties of elements across a period and descending a group. They should also be able to predict properties of an unknown element with reference to its position in the Periodic Table. As topics 2.5 and 7.1 are linked, students may need to refer the two topics from time to time to build up a clear picture about atomic properties and the Periodic Table.

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
2.1	Atomic emission spectrum	Characteristics of the emission spectrum of atomic hydrogen. Interpretation of the spectrum using the relationship $E=h\nu$ leading to the idea of discrete energy levels. Convergence limits and ionisation. Uniqueness of atomic emission spectra.	Observe emission spectra through a spectroscope or study emission spectra of elements.  Read article or write essay on the development of the various models of atom to appreciate the evolutionary nature of science.  Detect the presence of elements in a sample by flame test.



	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
2.2	Electronic structure: electron shell and subshell	Evidences of existence of shells and subshells from plots of the following graphs: (i) successive ionisation enthalpies for a particular element, and (ii) first ionisation enthalpies against atomic numbers (up to $Z=20$ ).	
2.3	Atomic orbital	Wave nature of electrons. Atomic orbital as a representation of a region in space within which there is a high probability of finding an electron. Pictorial representations of s, p and d orbitals. The number and relative energies of the s, p and d orbitals for the principal quantum numbers 1, 2 and 3, and also of 4s and 4p orbitals.	
2.4	Electronic configuration	Building up of electronic configurations of atoms based on three principles : (i) electrons enter the orbitals in order of ascending energy (aufbau principle), (ii) orbitals of the same energy must be occupied singly before pairing occurs (Hund's rule), and (iii) electrons occupying the same orbital must have opposite spins (Pauli exclusion principle).	

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
		Electronic configurations of isolated atoms from H to Kr. Electronic configurations of atoms represented by (i) notations using 1s, 2s, 2p, ... etc., and (ii) 'electrons-in-boxes' diagrams.	
2.5	The Periodic Table and atomic properties of elements	The Periodic Table, showing the s-, p-, d- and f-blocks. Interpretation of the trends of ionisation enthalpies and atomic radii of the elements in the Periodic Table. (Linked with Section 7.1)	Search and present information about different versions of the Periodic Table or read article on the development of the Periodic Table.

### 3. Energetics

Chemical reactions are accompanied by energy changes. The energy absorbed or released by a chemical system may take different forms. This section begins by introducing the basic concepts of chemical energetics and enthalpy terms commonly encountered. Carrying out experiments using simple calorimetric methods can help students better understand the concepts of energetics. The use of equipment like the bomb calorimeter is *not* expected.

Although energetics can provide us important information about the stability of compounds and account for most of the reactions encountered in secondary school chemistry, students should also realise the effect of entropy on the spontaneity of a reaction. The driving force of a reaction is in fact a balance between enthalpy and entropy changes. Calculations involving entropy and free energy are *not* required.

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
3.1	Energy changes in chemical reactions	Conservation of energy. Endothermic and exothermic reactions and their relationship to breaking and forming of bonds.	Search and present information about the use of chemical energy in daily life.
3.2	Standard enthalpy changes	Enthalpy change, $\Delta H$ , as heat change at constant pressure. Standard enthalpy change of: (i) neutralisation, (ii) solution, (iii) formation, and (iv) combustion. Experimental determination of enthalpy changes of reactions using simple calorimetric method.	Determine the enthalpy changes of neutralisation, solution or combustion.
3.3	Hess's law	Use of Hess's law to determine enthalpy changes which cannot be easily obtained by experiment directly. Enthalpy level diagrams. Calculations involving enthalpy changes of reactions.	Determine the enthalpy change of formation of metal oxides, metal carbonates or the enthalpy change of hydration of metal salts.
3.4	Spontaneity of changes	Entropy change ( $\Delta S$ ) as the change in the degree of disorder of a system. Free energy change ( $\Delta G$ ) as the driving force of a change. Understanding of the relationship: $\Delta G = \Delta H - T \Delta S$ .	Show the spontaneity of endothermic changes.  Rationalise the spontaneity of changes with examples such as (a) the dissolution of $\text{NH}_4\text{Cl}(\text{s})$ (b) the dissolution of $\text{PbCl}_2(\text{s})$

#### 4. Bonding and Structure

This section builds on Section 2 of the S4-5 Chemistry curriculum. Students should appreciate that the existence of the vast variety of substances in the material world is related to bonding and structure. They will learn how to draw Lewis structures of simple chemical species and to account for the properties of simple compounds in terms of the interaction between particles involved.

In this section, students should learn that the octet rule has its limitations. The formation of chemical bonds should better be explained in terms of electrostatic interactions. The energetics for the formation of a compound can provide us some quantitative information about the relative stability of the compound. Students will also study chemical bonds with intermediate bond type. This helps to broaden their understanding of chemical bonding to bonds which are not purely ionic or purely covalent. Studying the pressure-temperature diagrams of water and carbon dioxide can help students understand the change of phases in relation to the intermolecular forces and kinetic energy of molecules. However, the phase rule is *not* required.

Students may have recognised the regular arrangement of particles in crystalline solids. Building models and learning with the use of appropriate chemical software can help students visualise how particles are arranged in solids.

This section is concluded by a study of the relationship between structures and properties of substances. As the properties of a substance are related to the nature of particles it contains as well as its structure, knowing the structure of a substance can help us decide its application. Sometimes materials are designed to have specific properties. Students are encouraged to make further reading on how the development of modern chemistry changes our world by synthesis of new materials.

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
4.1	The nature of forces holding atoms together	Electrostatic interactions between electrons and nuclei leading to different types of bonding.	
4.2	Metallic bonding	Metallic bonding illustrated by a model consisting of cationic lattice and mobile valence electrons.  Strength of metallic bond in relation to metallic radius and the number of valence electrons per atom.	
	Metallic crystals	Close-packed and open structures: hexagonal and cubic close-packed, and body-centred cubic structures. Octahedral and tetrahedral holes. Unit cells and coordination numbers.	Display/Build models of metallic crystals.
	Alloys	Properties of alloys as compared with their constituents.	Search and present information about the properties and uses of alloys
4.3	Ionic bonding	Formation of ions – the tendency for atoms of elements in Groups I, II, VI and VII to attain electronic configurations of noble gases.	
	Energetics of formation of ionic compounds	Born-Haber cycles for the formation of ionic compounds in terms of enthalpy changes of atomisation and ionisation, electron affinities and lattice enthalpies	Compare the standard enthalpy changes of formation of $\text{MgCl}(\text{s})$ , $\text{MgCl}_2(\text{s})$ and $\text{MgCl}_3(\text{s})$ to establish the formula of magnesium chloride.

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
	Ionic crystals	Extended three-dimensional structures of ionic compounds as exemplified by sodium chloride, caesium chloride and calcium fluoride. Unit cells and coordination numbers.	Build lattice models of NaCl(s), CsCl(s) and CaF <sub>2</sub> (s).  Display three-dimensional images of crystal structures using computer programs
	Ionic radius	Comparison of sizes of ions with their parent atoms. Comparison of sizes of isoelectronic particles.	
4.4	Covalent bonding	Formation of covalent bond by overlap of atomic orbitals. Dative covalent bond. Multiple bonds.	
	Bond enthalpy, bond length and covalent radius	Estimation of bond enthalpies using data from energetics. Bond enthalpies as a comparison of the strength of covalent bonds. Relationship between covalent bond enthalpies and bond lengths as illustrated by hydrogen halides. Determination of covalent radii from covalent bond lengths of simple molecules.	

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
	Shapes of molecules and of polyatomic ions	The directional nature of covalent bonds. Explanation and prediction of the shapes of simple molecules and polyatomic ions (as illustrated by $\text{BF}_3$ , $\text{CH}_4$ , $\text{NH}_3$ , $\text{H}_2\text{O}$ , $\text{PCl}_5$ , $\text{SF}_6$ , $\text{NH}_4^+$ and $\text{NH}_2^-$ ) using the Valence Shell Electron Pair Repulsion Theory. Bond angles.	Display/Build models of simple molecules.
	Covalent crystals	Exemplified by diamond, graphite and quartz.	Display/Build models of diamond, graphite and quartz.
4.5	Bonding intermediate between ionic and covalent		
	Incomplete electron transfer in ionic compounds	Comparison of the experimental lattice enthalpies of compounds e.g. silver halides and zinc sulphide, with the theoretical values calculated on a completely ionic model leading to the idea of polarisation of ions.	
	Polarity of covalent bond	Displacement of an electron cloud leading to the formation of a polar covalent bond. Dipole moment as evidence for bond polarisation in simple molecules.	Investigate the effect of a non-uniform electrostatic field on a jet of liquid.

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
		Unequal sharing of bonded electron pairs explained in terms of the electronegativity difference between bonded atoms. Electronegativity (Pauling's scale) introduced as an arbitrary measure of an atom's tendency in a molecule to attract electrons	
4.6	Intermolecular forces		
	van der Waals forces	Brief discussion of the origin of van der Waals forces in terms of permanent, instantaneous and induced dipoles. Comparison of the covalent and van der Waals radii of non-metals to indicate the relative strength of covalent bonds and van der Waals forces.	
	Molecular crystals	Exemplified by iodine, carbon dioxide and buckminsterfullerene (C <sub>60</sub> ).  The pressure-temperature diagram of carbon dioxide.	Display models of iodine, carbon dioxide and buckminsterfullerene.  Search and present information about the discovery and applications of fullerenes.



	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
	Hydrogen bonding	<p>A study of the boiling points and enthalpy changes of vaporisation of the hydrides of Groups IV, V, VI and VII and compounds like alcohols and carboxylic acids leading to the idea of hydrogen bonding.</p> <p>Nature of hydrogen bonding.</p> <p>Relative strength of van der Waals forces and hydrogen bonding.</p> <p>Hydrogen bonding in ice, proteins and DNA (deoxyribonucleic acid).</p> <p>The pressure-temperature diagram of water.</p>	<p>Determine the strength of the hydrogen bond formed between ethanol molecules.</p> <p>Investigate the effect of hydrogen bond on liquid flow.</p>
4.7	Structures and properties of substances	<p>Interpretation of the physical properties of substances based on their structures and bonding.</p>	<p>Investigate the properties of buckminsterfullerene.</p> <p>Read article or write essay on the impact of the development of modern materials, such as semiconductors, nanotubes and liquid crystals, on our daily life.</p>

## 5. Chemical Kinetics

We know from our experience that some reactions take a long time to occur, while others happen extremely rapidly. Chemical kinetics is the study of reaction rates, factors that affect reaction rates and reaction mechanisms.

In this section, students will learn different methods commonly used in following the progress of a reaction and how rate equations can be obtained from experimental results. With the use of more sophisticated instruments such as data-loggers, practical work can be performed more effectively and yield better results.

Students should know that rate equations are based on experimental results, while reaction mechanisms are suggested pathways of reactions. The simple collision theory provides an explanation for single-step gaseous reactions in terms of collision between molecules. The transition state theory describes how reacting species react to give the transition state and then the products. The use of computer simulation can help students better understand how a reaction proceeds. However, mathematical treatment involving the two theories is *not* required.

Catalysts play an important role both in research and in chemical industries. Students should know the two classes of catalysis, namely homogeneous catalysis and heterogeneous catalysis, and draw an appropriate energy profile for a catalytic reaction. They should also be aware that practically all reactions occurring in living systems are catalysed by enzymes and that each enzyme is specific for a particular process.

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
5.1	Rate of chemical reaction	The meaning of the rate of a chemical reaction. Following a reaction by chemical and physical methods, viz. following the change in amount of reactant/product by titration, determining the volume of gas formed, or colorimetric measurement of light intensity at different times.	

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
5.2	Factors influencing reaction rate	Effects of concentration, temperature, pressure, surface area and catalyst on reaction rate.	Design and perform experiments to investigate factors affecting reaction rate.
5.3	Rate equation and order of reaction	Simple rate equations determined from experimental results. Zeroth, first and second order reactions. Rate constants. Half-life of a first order reaction.	Determine the order of a reaction.
5.4	Arrhenius equation	Explanation of the effect of temperature change on reaction rate in terms of activation energy. Application of the Arrhenius equation $\ln k = \text{constant} - \frac{E_a}{RT}$ to determine the activation energy of a reaction.	Determine the activation energy of a reaction.
5.5	The interpretation of reaction rate at molecular level	Elementary and multi-step reactions. Rate determining step. Application of simple collision theory to gaseous systems and its limitation. Distribution of kinetic energy of molecules in a gas. Maxwell-Boltzmann distribution curve and its variation with temperature. Transition state and energy profile.	Simulate the Maxwell-Boltzmann curves at different temperatures using computer programs e.g. spreadsheets.

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
5.6	Catalysis	<p>Catalysts can change the rate of a reaction by providing an alternative pathway for the reaction. (Linked with Section 10.2c)</p> <p>Homogeneous and heterogeneous catalysis</p> <p>Applications of catalysis: iron in the Haber process, catalytic converters in car exhaust systems and enzymes in the production of alcoholic drinks.</p>	<p>Investigate the catalytic effect of</p> <ul style="list-style-type: none"><li>(a) acid on the iodination of propanone</li><li>(b) manganese(IV) oxide on the decomposition of hydrogen peroxide</li><li>(c) <math>\text{Mn}^{2+}(\text{aq})</math> on the reaction between <math>\text{MnO}_4^{-}(\text{aq})</math> and <math>\text{C}_2\text{O}_4^{2-}(\text{aq})</math> in acidic medium.</li></ul> <p>Search and present information about the importance of catalysis.</p>

## 6. Chemical Equilibrium

The concept of a state of equilibrium is fundamental in chemistry. Students should appreciate the dynamic nature of chemical equilibrium, in particular the constancy of intensive properties and the shifting of equilibrium position when a system at equilibrium is subjected to change. It is therefore important to control variables such as pressure, concentration and temperature in an industrial process so that the optimal reaction conditions can be established.

The equilibrium law provides a quantitative relationship of the concentrations of the reactants and products in system at equilibrium. Students should know the equilibrium constants,  $K_c$  and  $K_p$ . They should learn the application of the equilibrium law to some systems including the partition of a solute between two immiscible liquids, acids and bases as well as saturated solutions of sparingly soluble electrolytes.

As an acid-base reaction involves the transfer of protons from an acid to a base, a redox reaction involves the transfer of electrons from a reducing agent to an oxidising agent. Students should appreciate that the likely direction of a redox reaction can be predicted by comparing the reduction potentials of the half-cells involved.

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

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
6.1	Dynamic equilibrium	Characteristics of dynamic equilibrium.	Investigate some equilibrium systems: (a) Effect of pH on an aqueous solution of $\text{Br}_2$ (b) Effect of pH on the $\text{K}_2\text{Cr}_2\text{O}_7(\text{aq})/\text{K}_2\text{CrO}_4(\text{aq})$ system.

<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
The equilibrium law	Equilibrium constants expressed in terms of concentrations ( $K_c$ ) and partial pressures ( $K_p$ ).	Determine $K_c$ for a reaction: $\text{CH}_3\text{CO}_2\text{H}(\ell) + \text{C}_2\text{H}_5\text{OH}(\ell)$ $\rightleftharpoons \text{CH}_3\text{CO}_2\text{C}_2\text{H}_5(\ell) + \text{H}_2\text{O}(\ell)$ or $\text{Fe}^{3+}(\text{aq}) + \text{NCS}^-(\text{aq})$ $\rightleftharpoons \text{FeNCS}^{2+}(\text{aq})$
Partition coefficient	Partition coefficient of a non-volatile solute between two immiscible liquids. Applications: solvent extraction and chromatography.	Determine the partition coefficient of ethanoic acid between water and 2-methylpropan-1-ol.
Effect of concentration, pressure and temperature on equilibrium	Changes in concentration and pressure result in the adjustment of the system without changing the value of equilibrium constant, $K$ . Calculations on equilibrium composition involving changes in concentration/pressure.  A change in temperature results in the adjustment of the system to a new equilibrium constant. Relation of temperature and the value of $K$ illustrated by the equation: $\ln K = \text{constant} - \frac{\Delta H}{RT}$	Predict the shift in equilibrium position by calculating the reaction quotient.  Investigate the effect of temperature and pressure change on the following reaction: $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
		Equilibrium and kinetic considerations in industrial processes as exemplified by the Haber process. (Linked with Section 5)	
6.2	Ionic equilibrium		
	Concept of acid/base	Brønsted-Lowry theory. (Linked with Section 11.5)	
	Dissociation of water and pH	Ionic product of water, $K_w$ . pH and its measurement.	
	Strong and weak acids/bases	Dissociation constants for weak acids ( $K_a$ ) and weak bases ( $K_b$ ). Use of $K_a$ and $K_b$ ( $pK_a$ and $pK_b$ ) values to compare the strength of weak acids or weak bases. Calculations involving pH, $K_a$ and $K_b$ . (For dissociation involving more than one step, calculations are limited to one of these steps only.)	Determine $K_a$ of a weak acid/ $K_b$ of a weak base by pH measurement.
	Buffer	Principle of buffer action. Calculations involving the composition and pH of buffer solutions.	Compare the effects of acid/alkali on the pH of buffered and unbuffered solutions.

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
	Acid-base titration and the choice of indicator	pH titration curves. Simple theory of acid-base indicators. Choice of indicators in relation to their pH range of colour changes.	Determine the pH ranges of some acid-base indicators. Perform acid-base titrations using method of double indicator.
	Solubility product	Solubility product ( $K_{sp}$ ) of a sparingly soluble electrolyte. Calculation of $K_{sp}$ from solubility and vice versa. Common ion effect.	Determine the solubility product of a sparingly soluble electrolyte.
6.3	Redox Equilibrium		
	Electrochemical cell	Electromotive force (e.m.f.) measurement of electrochemical cells of metal-metal ion systems. e.m.f. values to compare the relative tendencies of half-cells to release or gain electrons. Other systems involving non-metal ions (e.g. $I_2(aq)$ , $2I^-(aq)   Pt$ ), ions in different oxidation states (e.g. $Fe^{3+}(aq)$ , $Fe^{2+}(aq)   Pt$ ) and metal-metal salt (e.g. $PbSO_4(s)$ , $[Pb(s) + SO_4^{2-}(aq)]   Pt$ ).	Investigate the e.m.f. of some electrochemical cells.



<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
Electrode potential	<p>The standard hydrogen electrode as a reference. The convention of standard reduction potentials is adopted.</p> <p>The electrochemical series.</p> <p>Use of the standard electrode potential (<math>E^\ominus</math>) values to compare the strength of oxidising/reducing agents, and to calculate the e.m.f. of cells.</p> <p>Prediction of the feasibility of redox reactions from electrode potential values and the limitation of this approach due to kinetic factor.</p> <p>The Nernst equation at 298 K</p> $E = E^\ominus + \frac{0.059}{n} \log \frac{[ox]}{[red]}$ <p>as an empirical relationship of the variation of electrode potential with concentration of ionic species involved.</p>	<p>Test predictions about the feasibility of redox reactions.</p> <p>Investigate the effect of changes in ionic concentration on the e.m.f. of a cell.</p>
Secondary cell	<p>Electrochemical processes of secondary cells as illustrated by lead-acid accumulator.</p> <p>Applications of secondary cells in daily life.</p>	<p>Search and present information about secondary cells used in daily life such as lead-acid accumulator as car battery and lithium battery in electronic products.</p>

<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
Fuel cell	Principles of fuel cells as exemplified by hydrogen-oxygen fuel cell.	Display working models of fuel cells. Search and present information about the applications of fuel cells.

### 7. Periodic Properties of the Elements in the Periodic Table

Through the study of this section, students can develop an understanding about the importance of the Periodic Table in chemistry. Knowledge and concepts about the periodic trends of physical properties of some elements and periodic relationship of properties of selected oxides are required.

<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
7.1 Periodic variation in physical properties of the elements H to Ar	Variations in first ionisation enthalpies, atomic radii, electronegativities and melting points. Interpretation of these variations in terms of structure and bonding. (Linked with Section 2.5)	
7.2 Periodic relationship among the oxides of the elements Li to Cl	Bonding and stoichiometric composition of the oxides of these elements, and their behaviour with water, dilute acids and dilute alkalis.	Investigate the properties of the oxides of the Period 3 elements.

**8. The s-Block Elements**

Students are expected to develop knowledge and concepts about the trends in properties of s-block elements and some of their compounds. The emphasis of this section is the similarity of properties among the s-block elements and their compounds.

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
8.1	Characteristic properties of the s-block elements	Metallic character and low electronegativity. Formation of basic oxides and hydroxides. Predominantly ionic bonding with fixed oxidation state in their compounds. Characteristic flame colours of salts. Weak tendency to form complexes.	Read articles on the use of s-block compounds in fireworks.
8.2	Variation in properties of the s-block elements and their compounds	Variations in atomic radii, ionisation enthalpies, hydration enthalpies and melting points. Interpretation of these variations in terms of structure and bonding. Reactions of the elements with oxygen and water. Reactions of the oxides with water, dilute acids and dilute alkalis. Relative thermal stability of the carbonates and hydroxides. Relative solubility of the sulphates(VI) and hydroxides.	Investigate the effect of heat on carbonates. Investigate the solubility of sulphates(VI) and hydroxides of Group II elements.

## 9. The p-Block Elements

Through the study of this section, students can develop knowledge and concepts about the variations in properties of the halogens and their compounds. Another focus of this section is on the group IV elements. While the study of halogens places emphasis on the similarities that exist between elements in a particular group of the Periodic Table, the study of the group IV elements brings out the differences. The section includes a study of silicon, which helps students develop some understanding about the second most abundant element on the earth, and the study on silicates which aims to help students develop an important concept - structural differences of substances at the submicroscopic level can affect their macroscopic properties.

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
9.1	The halogens		
	Characteristic properties of the halogens	High electronegativity and electron affinity. Ionic and covalent bonding in oxidation state $-1$ .	Extraction of iodine from seaweed.
	Variation in properties of the halogens and their compounds	Variations in melting and boiling points, electronegativities and electron affinities of halogens. Interpretation of these variations in terms of structure and bonding. Relative oxidising power of halogens: comparative study of reactions of ( $\text{Cl}_2$ , $\text{Br}_2$ and $\text{I}_2$ ) with sodium, iron(II) ions and thiosulphate. Disproportionation of the halogens in alkalis. Comparative study of the reactions of halide ions with halogens, silver(I) ions, sulphuric(VI) acid and phosphoric(V) acid. Acidic properties of hydrogen halides and the anomalous behaviour of hydrogen fluoride.	Investigate the reactions of (a) halogens with alkalis, (b) halide ions in solution with halogens and silver(I) ions, and (c) solid halides with sulphuric(VI) and phosphoric(V) acids.

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
9.2	Group IV elements	Interpretation of variation in melting point and boiling point of the elements in terms of structure and bonding.  Dissimilarity in properties of elements as illustrated by the composition of oxides and chlorides.	
	Silicon and silicates	Uses of silicon. Bonding and structures of silicates. Effect of structure on properties of silicates as exemplified by chain silicates, sheet silicates and network silicates.	Search and present information of the importance of silicon and its compounds such as feldspar, mica and quartz in daily life.

**10. The d-Block Elements**

Through the study of this section, students can develop knowledge and concepts about the properties of selected d-block elements and their compounds. The emphases of this section are the properties like variable oxidation states, ability to form complexes and coloured ions, and catalytic properties of d-block elements and their compounds. To broaden students' understanding about the process of complex formation, students are expected to learn some transition metal complexes which involve monodentate, bidentate and multidentate ligands. However, calculations involving stability constants are *not* required.

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
10.1	General features of the d-block elements from Sc to Zn	Electronic configurations. (Linked with Section 2.4) d-Block elements as metals. Comparison of ionisation enthalpies, melting points, hardness and reactions with water between d-block and s-block metals.	
10.2	Characteristic properties of the d-block elements and their compounds:	Interpretation of the characteristic properties, viz. variable oxidation states, complex formation and coloured ions in terms of electronic structures, successive ionisation enthalpies, atomic and ionic radii.	
(a)	Variable oxidation states	Exemplified by vanadium and manganese. Interconversion of oxidation states of each element.	Investigate the redox reactions of vanadium or manganese compounds.

<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
(b) Complex formation	<p>Formation of transition metal complexes as with monodentate ligands (<math>\text{H}_2\text{O}</math>, <math>\text{NH}_3</math>, <math>\text{Cl}^-</math> and <math>\text{CN}^-</math>), bidentate ligands (<math>\text{N}_2\text{NCH}_2\text{CH}_2\text{NH}_2</math> and <math>\text{C}_2\text{O}_4^{2-}</math>) and multidentate ligands (EDTA).</p> <p>Nomenclature of transition metal complexes with monodentate ligands.</p> <p>Displacement of ligands and relative stability of complexes.</p>	<p>Search information on the use of EDTA in food industry and chelation therapy, and rationalise its applications.</p> <p>Investigate the hardness of water using EDTA titration.</p> <p>Investigate the relative stability of some copper(II) complexes.</p>
(c) Catalytic properties	<p>Exemplified by the use of Fe in Haber process, <math>\text{Fe}^{2+}</math> or <math>\text{Fe}^{3+}</math> in the reaction between peroxodisulphate(VI) and iodide ions, and <math>\text{MnO}_2</math> in the decomposition of hydrogen peroxide.</p> <p>(Linked with Section 5.6)</p>	<p>Investigate the catalytic action of d-block ions on the reaction between peroxodisulphate(VI) and iodide ions.</p>

## 11. Fundamentals of Organic Chemistry

Organic chemistry is a very important branch of chemistry as judged from the uniqueness of carbon and ubiquitousness of organic compounds. After studying this section, students should have a basic understanding of organic chemistry. Together with the basic concepts and knowledge acquired in previous learning, students can build up concepts related to the bonding and structural characteristics of some common organic compounds. However, a study of conformations in molecules is *not* expected. Furthermore, students are expected to be able to use systematic names and common trivial names of organic compounds to communicate knowledge and understanding in study and in daily life. Lastly, students should develop some fundamental concepts required for comprehending organic reactions to be covered in Section 12.

<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
11.1 Bonding and structure	Orbital hybridisation of carbon: sp, sp <sup>2</sup> and sp <sup>3</sup> . Structures and shapes of hydrocarbons: (i) Saturated hydrocarbons exemplified by methane and ethane (formation of $\sigma$ bond) (ii) Unsaturated hydrocarbons exemplified by ethene and ethyne (formation of $\pi$ bond) (iii) Aromatic hydrocarbons exemplified by benzene (delocalisation of $\pi$ electrons)	Display/Build models of some hydrocarbon molecules like simple alkanes, simple alkenes and benzene.  Compare the enthalpy changes of hydrogenation and combustion of benzene and cyclohexene.
11.2 Functional groups and homologous series	Studies of the following functional groups: >C=C<, -C≡C-, -X, -OH, -O-, -CHO, >C=O, -CO <sub>2</sub> H, -NH <sub>2</sub> , -NHR, -NR <sub>2</sub> , -CN, -CO <sub>2</sub> R, -COX, -CONH <sub>2</sub> and (-CO) <sub>2</sub> O.	Display/Build models of compounds with different functional groups.



	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
		Effects of functional groups and the length of carbon chains on physical properties of organic compounds.	Compare physical properties of the following compounds: propane, butanes, pentanes, methoxymethane, methoxyethane, ethoxyethane, ethanol, propan-1-ol and butan-1-ol.
11.3	Systematic nomenclature	Systematic nomenclature of compounds containing carbon chains of <i>not</i> more than eight carbon atoms.	Search trivial names of common organic compounds.
11.4	Isomerism		
	Structural isomerism	Isomers containing the same functional group and isomers containing different functional groups.	
	Stereoisomerism	Geometrical isomerism. Rigidity of C=C bond leading to <i>cis/trans</i> isomers in acyclic organic compounds.  Enantiomerism as exemplified by compounds with one chiral carbon.	Display/Build models of but-2-enes. Compare the properties of <i>cis</i> - and <i>trans</i> - butenedioic acids.  Illustrate optical activity using crossed polaroids or a polarimeter. Study three-dimensional models of compounds with chiral carbons. Search and present information on 'chiral drugs'.

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
11.5	Organic acids and organic bases	Relation of structural characteristics of organic compounds and their acid-base properties as exemplified by carboxylic acids, amines and alcohols. (Linked with Section 6.2)	Compare the $pK_a$ / $pK_b$ values of the following compounds: ethanoic acid, chloroethanoic acid, ethanamine, phenylamine and ethanol.
11.6	Reaction mechanism	Formation of reactive species (free radicals, nucleophiles and electrophiles) by homolysis or heterolysis. Conventions for writing reaction mechanisms.	

**12. Chemistry of Organic Compounds**

In this section, students are expected to study several types of organic reactions by examining their general mechanisms in the light of appropriate examples. This helps students understand organic reactions in a systematic and logical manner. Students should appreciate that many organic reactions can be interpreted from the bonding and structural characteristics of molecules. This section also includes some common methods used in the elucidation of the structures of organic compounds through analysis of their physical and chemical properties, as well as spectroscopic data. However, details related to fragmentation pattern in mass spectra are *not* expected.

<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
12.1 Alkanes and radical substitution	Crude oil as a source of alkanes. Chemical principles and economic importance of fractional distillation of crude oil and cracking process. Combustion of alkanes.  General mechanism of free radical substitution as exemplified by mono-chlorination of alkanes with <i>not</i> more than four carbon atoms. Stability of primary, secondary and tertiary alkyl radicals. Chlorination and bromination of alkanes.	Discuss the relationship between global warming and the use of fossil fuels.  Investigate the reactions of saturated hydrocarbons with chlorine and bromine.

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
12.2	Alkenes and electrophilic addition	<p>Catalytic hydrogenation. (Linked with Section 12.7) Comparison of relative stability of alkenes in terms of enthalpy changes of hydrogenation. (Linked with Section 3.2)</p> <p>General mechanism of electrophilic addition as exemplified by reactions of alkenes and hydrogen halides. Regioselectivity of hydrogen halide addition: Markovnikov's rule. Stability of primary, secondary and tertiary carbocations. Addition of chlorine and bromine. Acid-catalysed hydration.</p>	<p>Rationalise the process of hardening oil in the manufacture of margarine.</p> <p>Test unsaturated hydrocarbons.</p>
12.3	Benzene and electrophilic substitution	<p>Aromaticity as illustrated by delocalisation of <math>\pi</math> electrons in benzene. Basic structures of polyaromatic hydrocarbons (PAH).</p> <p>General mechanism of electrophilic substitution as exemplified by mono-halogenation of benzene.</p> <p>Nitration, sulphonation, halogenation and alkylation of benzene.</p>	<p>Read articles on the health hazard associated with PAH.</p> <p>Investigate the chemical properties of cyclohexane, cyclohexene and methylbenzene.</p>

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
12.4	Halogeno-compounds and nucleophilic substitution	<p>Primary, secondary and tertiary haloalkanes; halobenzenes.</p> <p>General mechanism of nucleophilic substitution (<math>S_N1</math> and <math>S_N2</math>) as exemplified by reaction with hydroxide. (Linked with Section 5.3)</p> <p>Stereochemistry related to <math>S_N1</math> and <math>S_N2</math> reactions.</p> <p>Substitution reactions of haloalkanes with hydroxide, alkoxides, cyanide and ammonia.</p> <p>Comparison of rates of hydrolysis of haloalkanes and halobenzenes.</p> <p>Dehydrohalogenation of haloalkanes. (Linked with Section 12.2)</p>	<p>Discuss the beneficial and detrimental consequences of using halogeno-compounds.</p> <p>Investigate the kinetics of the hydrolysis of 2-chloro-2-methylpropane.</p> <p>Study stereochemistry of <math>S_N1</math> and <math>S_N2</math> reactions using computer animations.</p> <p>Compare the rates of hydrolysis of</p> <ol style="list-style-type: none"><li>chloro-, bromo- and iodo-alkanes.</li><li>primary, secondary and tertiary haloalkanes.</li><li>haloalkanes and halobenzene.</li></ol>
12.5	Carbonyl compounds and nucleophilic addition	<p>Structures of aldehydes and ketones.</p>	<p>Search information on the uses of aldehydes and ketones.</p> <p>Isolate essential oils from common spices.</p>

	<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
		General mechanism of nucleophilic addition as exemplified by reaction with hydrogen cyanide.	
		Addition-elimination (condensation) reactions with hydrazines.	Identify carbonyl compounds by preparing their derivatives.
12.6	Derivatives of carboxylic acid and nucleophilic acyl substitution	Structures of carboxylic acids, anhydrides, acyl chlorides, esters and amides. General mechanism of nucleophilic acyl substitution as exemplified by hydrolysis of acyl chloride.	
		Reactions of carboxylic acids with thionyl chloride, alcohols, ammonia and amines.	Investigate the reactions of carboxylic acids.
		Reactions of acyl chlorides with water, alcohols, ammonia and amines.	

<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
	Hydrolysis of anhydrides.	
	Hydrolysis of esters. Reactions of esters with ammonia and amines.	Analyse commercial aspirin tablets. Search and present information on oils and fats: (a) structures and bonding in oils and fats (b) saturated and unsaturated oils and fats (c) health issues related to oils and fats
	Hydrolysis of amides.	
	Dehydration of amides and hydrolysis of nitriles.	
12.7 Redox reactions	Oxidation of alkyl benzenes using acidified $\text{KMnO}_4$ .  Redox reactions of alkenes with reagents such as alkaline $\text{KMnO}_4$ , $\text{O}_3$ and $\text{H}_2/\text{Pd}$ . (Linked with Section 12.2)  Autooxidation of oils and fats Principle of BHA /BHT as antioxidants.	

<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
12.8 Structure determination of organic compound	<p>Redox reactions involving alcohols, carbonyl compounds and carboxylic acids with reagents: acidified <math>K_2Cr_2O_7</math>, acidified <math>KMnO_4</math>, <math>NaBH_4</math> and <math>LiAlH_4</math>.</p> <p>Calculation of empirical formula and molecular formula from analytical data. (Linked with Section 1.4)</p> <p>Structural information of organic compounds from their physical properties and chemical properties.</p> <p>Structural information of organic compounds from modern chemical instrumental methods.</p> <p>(i) Use of infra-red (IR) spectrum in the identification of the following groups: C–H, O–H, N–H, C=C, C=O, C≡C and C≡N.</p> <p>(ii) Use of mass spectra to obtain structural information from masses of molecular ions and common fragments such as <math>R^+</math>, <math>RCO^+</math> and <math>C_6H_5CH_2^+</math>.</p> <p>(Linked with Section 1.2)</p>	<p>Read articles on the development of environmentally benign oxidising agents like <math>H_2O_2</math> and oxygen.</p> <p>Detect the presence of functional groups by chemical tests.</p> <p>Inspect of IR and mass spectra of organic compounds.</p> <p>Identify an unknown organic compound from given information, e.g. IR and MS spectra, physical and chemical properties of the compound.</p>



**13. Chemistry in Action**

One of the contributions of chemists to our society is to synthesise a range of very useful materials like plastics. Chemists also play an indispensable role in the development of new drugs for the well being of humans. Students are expected to view structures of some common drugs, but recitation of the structures of common drugs is *not* required. A study of the science of polymers and the active ingredients of some commonly used drugs facilitates students to develop a better understanding of the relation of science, technology, society and environment. Finally, students are expected to have an appreciation of the role of chemistry on the sustainable development through the study of concepts and applications related to green chemistry.

<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
13.1 Polymers		
Naturally occurring polymers	Exemplified by proteins, polysaccharides and DNA. Proteins as macromolecules made up of amino acids via peptide linkages.	
Synthetic polymers	Addition polymerisation. Formation and uses of addition polymers as exemplified by polyethene (PE), polypropene (PP), polystyrene (PS), polyvinyl chloride (PVC), polytetrafluoroethene (PTFE) and polymethyl methacrylate (PMMA).	Watch video on fabrication of plastics.
	Condensation polymerisation. Formation and uses of polyamides and polyesters as exemplified by nylon, Kevlar, Dacron and urea-methanal.	Discuss the impacts of the development of polymers on our society.

<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
	<p>Effect of structure on properties such as density, hardness, rigidity, elasticity and biodegradability as exemplified by</p> <ol style="list-style-type: none"><li>high density polyethene and low density polyethene,</li><li>nylon and Kevlar,</li><li>vulcanisation of polymers, and</li><li>biodegradable plastics.</li></ol>	<p>Search and present information related to structures and properties of polymeric materials used as adhesives, semiconductors and drug-carriers.</p>
13.2 Drugs	<p>Key stages of drug development as exemplified by the development of aspirin and <i>cis</i>-platin:</p> <ol style="list-style-type: none"><li>lead compound discovery,</li><li>molecular modification,</li><li>formulation development,</li><li>safety tests and human trials, and</li><li>approval for marketing.</li></ol>	<p>Study the structures and uses of common drugs:</p> <ol style="list-style-type: none"><li>over-the-counter drugs like aspirin, acetaminophen and vitamin C, and</li><li>prescription drugs like albuterol, amlodipine, loratadine, amoxicillin and omeprazole.</li></ol> <p>Search and present information on the historical development of aspirin or <i>cis</i>-platin. Extract acetylsalicylic acid from commercial aspirin tablets.</p>

<i>Topics</i>	<i>Explanatory Notes</i>	<i>Relevant Activities</i>
	Narcotic drugs such as morphine and heroin, and their adverse effects. Stimulants such as ketamine and phenylethylamine, and their adverse effects.	Discuss physiological action and psychological effect of common narcotic and stimulant drugs like morphine, codeine, heroin, cannabis, lysergic acid diethylamide (LSD), Ecstasy and ketamine.  Discuss the pros and cons on using drugs.
13.3 Green Chemistry	Principles of green chemistry for promoting sustainable development.  Green chemistry practices as exemplified by (i) decaffeination using supercritical carbon dioxide, and (ii) the use of H <sub>2</sub> O <sub>2</sub> in the presence of manganese based catalyst as bleaching agent.	Discuss the feasibility of using the principles of green chemistry for daily life applications of chemistry  Search and present information on the application of green chemistry in practices.