UNIT 1. INTRODUCTION TO CHEMISTRY

1.1 Introduction to the particulate nature of matter and chemical change & 1.2 The mole concept

Essential Idea:

- Physical and chemical properties depend on the ways in which atoms combine
- The mole makes it possible to correlate the number of particles with the mass that can be measured
- Nature of science:
- Making quantitative measurements with replicates to ensure reliability-definite and multiple proportions.
- The concept of the mole developed from the related concept of "equivalent mass" in the early 19th century.
- Making quantitative measurements with replicates to ensure reliability-definite and multiple proportions.

	Assessment statement	Teacher's notes
1.1a	Describe the different forms of matter in terms of composition and properties.	 Atoms of different elements combine in fixed ratios to form compounds, which have different properties from their component elements. Mixtures contain more than one element and/or compound that are not chemically bonded together and so retain their individual properties. Mixtures are either homogeneous or heterogeneous. Names and symbols of elements
1.1b	Describe how matter undergoes physical and chemical changes.	 Explanation of observable changes in physical properties and temperature during changes of state. Names of the changes of state—melting, freezing, vaporization (evaporation and boiling), condensation, sublimation and deposition Refrigeration and how it is related to the changes of state. Freeze-drying of foods.
1.2a	 Apply the mole concept to describe amounts of a substance Identify the seven SI units of measures 	 The mole concept applies to all kinds of particles: atoms, molecules, ions, electrons, formula units, and so on. The mole is a fixed number of particles and refers to the amount, <i>n</i>, of substance. The approximate value of Avogadro's constant (<i>L</i>), 6.022 × 10²³ mol⁻¹, should be known.
1.2b	Define the terms <i>relative atomic mass</i> (A_r) and <i>relative molecular mass</i> (M_r) .	
1.2c	Calculate the molar masses of atoms, ions, molecules and formula units.	Masses of atoms are compared on a scale relative to ¹² C and are expressed as relative atomic mass (A_r) and relative formula/molecular mass (M_r). Molar mass (M) has the units g mol ⁻¹ (g/mol) and is a derived SI unit.
1.2d	Solve problems involving the relationships between the number of particles, the amount of substance in moles and the mass in grams.	Solve for percent composition
1.2e	Distinguish between the terms <i>empirical formula</i> and <i>molecular formula</i> .	The empirical formula and molecular formula of a compound give the simplest ratio and the actual number of atoms present in a molecule respectively.
1.2f	Determine the empirical formula from the percentage composition or from other experimental data.	 Interconversion of the percentage composition by mass and the empirical formula. Obtaining and using experimental data for deriving empirical formulas from reactions involving mass changes. Aim 6: Experiments could include percent mass of hydrates, burning of magnesium or calculating Avogadro's number. Aim 7: Data loggers can be used to measure mass changes during reactions.
1.2g	Determine the molecular formula of a compound from its empirical formula and molar mass.	Aim 8 : The negative environmental impacts of refrigeration and air conditioning systems are significant. The use of CFCs as refrigerants has been a major contributor to ozone depletion.

Theory of knowledge: Chemistry deals with enormous differences in scale. The magnitude of Avogadro's constant is beyond the scale of our everyday experience. How does our everyday experience limit our intuition?

Utilization: The molar volume for crystalline solids is determined by the technique of X-ray crystallography.

International-mindedness:

• The SI system (Système International d'Unités) refers to the metric system of measurement, based on seven base units.

- The International Bureau of Weights and Measures (BIPM according to its French initials) is an international standards organization, which aims to ensure uniformity in the application of SI units around the world.
- Chemical symbols and equations are international, enabling effective communication amongst scientists without need for translation.

11.1 Uncertainty and error in measurements and results

Essential Idea: All measurement has a limit of precision and accuracy, and this must be taken into account when evaluating experimental results. **Nature of science:** Making quantitative measurements with replicates to ensure reliability—precision, accuracy, systematic, and random errors must be interpreted through replication

	Assessment statement	Teacher's notes
11.1a	 Compare qualitative observations, quantitative observations and interpretations Describe and give examples of random errors (uncertainties) and systematic errors. 	 Qualitative data includes all non-numerical information obtained from observations not from measurement. Quantitative data are obtained from measurements, and are always associated with random errors/uncertainties, determined by the apparatus, and by human limitations such as reaction times.
11.1b	Distinguish between <i>precision</i> and <i>accuracy</i> .	It is possible for a measurement to have great precision yet be inaccurate (for example, if the top of a meniscus is read in a pipette or a measuring cylinder).
11.1c	Describe ways that uncertainties can be reduced in an experiment.	 Propagation of random errors in data processing shows the impact of the uncertainties on the final result. Experimental design and procedure usually lead to systematic errors in measurement, which cause a deviation in a particular direction. Repeat trials and measurements will reduce random errors but not systematic errors.
11.1d	 State random uncertainty as an uncertainty range (±). State uncertainties as absolute and percentage uncertainties. 	Record uncertainties in all measurements as a range (\pm) to an appropriate precision.
11.1e	State the results of calculations to the appropriate number of significant figures.	 The number of significant figures in a result is based on the figures given in the data. When adding or subtracting, the final answer should be given to the least number of decimal places. When multiplying or dividing the final answer is given to the least number of significant figures. Note that the data value must be recorded to the same precision as the random error. SI units should be used throughout the program. Dimensional analysis is a procedure used to effectively calculate results.
11.1f	Determine the uncertainties in results	 Propagation of uncertainties in processed data, including the use of percentage uncertainties. Discussion of systematic errors in all experimental work, their impact on the results and how they can be reduced. Estimation of whether a particular source of error is likely to have a major or minor effect on the final result. Calculation of percentage error when the experimental result can be compared with a theoretical or accepted result. Only a simple treatment is required. For functions such as addition and subtraction, absolute uncertainties can be added. If one uncertainty is much larger than others, the approximate uncertainty in the calculated result can be taken as due to that quantity alone.

International-mindedness: As a result of collaboration between seven international organizations, including IUPAC, the International Standards Organization (ISO) published the *Guide to the Expression of Uncertainty in Measurement* in 1995. This has been widely adopted in most countries and has been translated into several languages.

Theory of knowledge: Science has been described as a self-correcting and communal public endeavour. To what extent do these characteristics also apply to the other areas of knowledge?

- Utilization:
 - Crash of the Mars Climate Orbiter spacecraft.

• Original results from CERN regarding the speed of neutrinos were flawed.

11.2 Graphical techniques

Essential Idea: Graphs are a visual representation of trends in data **Nature of science:** The idea of correlation—can be tested in experiments whose results can be displayed graphically.

	Assessment statement	Teacher's notes		
11.2a	Sketch graphs to represent dependences and interpret graph behavior.	 Students should be able to give a qualitative physical interpretation of a particular graph, for example, the variables are proportional or inversely proportional. Interpretation of graphs in terms of the relationships of dependent and independent variables. Graphical techniques are an effective means of communicating the effect of an independent variable on a dependent variable, and can lead to determination of physical quantities. Sketched graphs have labelled but unscaled axes, and are used to show qualitative trends, such as variables that are proportional or inversely proportional. 		
11.2b	Construct graphs from experimental data.	Drawn graphs have labeled and scaled axes, and are used in quantitative measurements. Aim 7: Graph-plotting software may be used, including the use of spreadsheets and the derivation of best-fit lines and gradients		
11.2c	Draw best-fit lines through data points on a graph.	 These can be curves or straight lines. Production and interpretation of best-fit lines or curves through data points, including an assessment of when it can and cannot be considered as a linear function. 		
11.2d	Determine the values of physical quantities from graphs.	Calculation of quantities from graphs by measuring slope (gradient) and intercept, including appropriate units.		

International-mindedness: Charts and graphs, which largely transcend language barriers, can facilitate communication between scientists worldwide.

Theory of knowledge: Graphs are a visual representation of data, and so use sense perception as a way of knowing. To what extent does their interpretation also rely on the other ways of knowing, such as language and reason?

Utilization: Graphical representations of data are widely used in diverse areas such as population, finance and climate modelling.

Interpretation of these statistical trends can often lead to predictions, and so underpins the setting of government policies in many areas such as health and education.

Aim 6: The distinction and different roles of Class A and Class B glassware could be explored.

Aim 8: Consider the moral obligations of scientists to communicate the full extent of their data, including experimental uncertainties. The "cold fusion" case of Fleischmann and Pons in the 1990s is an example of when this was not fulfilled.

UNIT 2 ATOMIC STRUCTURE

2.1 The nuclear atom

Essential Idea: The mass of an atom is concentrated in its minute, positively charged nucleus **Nature of science:**

- Evidence and improvements in instrumentation—alpha particles were used in the development of the nuclear model of the atom that was first proposed by Rutherford.
- Paradigm shifts-the subatomic particle theory of matter represents a paradigm shift in science that occurred in the late 1800s.

	Assessment statement	Teacher's notes
2.1a	Discuss the progression of the atomic model as a series of experiments which produced more details about the structure of matter.	Democritus-Dalton-Thomson-Rutherford-Bohr-Quantum. Aim 7: Simulations of Rutherford's gold foil experiment can be undertaken.
2.1b	State the position of protons, neutrons and electrons in the atom.	 Atoms contain a positively charged dense nucleus composed of protons and neutrons (nucleons). Negatively charged electrons occupy the space outside the nucleus.
2.1c	State the relative masses and relative charges of protons, neutrons and electrons.	Relative masses and charges of the subatomic particles should be known, actual values are given in section 4 of the data booklet. The mass of the electron can be considered negligible. The accepted values are:

			relative mass	relative charge
		proton	1	+1
		neutron	1	0
		electron	5×10-4	_1
2.1d	Define the terms mass number (A), atomic number (Z) and isotopes of an element.			
2.1e	Deduce the symbol for an isotope given its mass number	Use of the nuclear symbol notation	$A_{Z}X$ to ded	uce the number of protons, neutrons
	and atomic number.	and electrons in atoms and ions, or	example,	² C
2.1f	Calculate the number of protons, neutrons and electrons in atoms and ions from the mass number, atomic number and charge.			
2.1g	Discuss the uses of radioisotopes	Radioisotopes are used in nuclear n research, as tracers in biochemical a "chemical clocks" in geological and Aim 8: Radionuclides carry danger cells.	nedicine fo and pharma d archaeolo s to health	r diagnostics, treatment and iceutical research, and as gical dating. due to their ionizing effects on
2.1h	Describe how the mass spectrometer may be used to determine relative atomic mass using the ¹² C scale.	The mass spectrometer is used to de element from its isotopic compositi	etermine th on.	e relative atomic mass of an
2.1i	Calculate non-integer relative atomic masses and abundance of isotopes from given data, including mass spectra.			

International-mindedness: Isotope enrichment uses physical properties to separate isotopes of uranium, and is employed in many countries as part of nuclear energy and weaponry programs.

Theory of knowledge:

- Richard Feynman: "If all of scientific knowledge were to be destroyed and only one sentence passed on to the next generation, I believe it is that all things are made of atoms." Are the models and theories which scientists create accurate descriptions of the natural world, or are they primarily useful interpretations for prediction, explanation and control of the natural world?
- No subatomic particles can be (or will be) directly observed. Which ways of knowing do we use to interpret indirect evidence, gained through the use of technology?

Utilization: PET (positron emission tomography) scanners give three-dimensional images of tracer concentration in the body, and can be used to detect cancers.

2.2 Electron configuration

Essential Idea: The electron configuration of an atom can be deduced from its atomic number

Nature of science:

- Developments in scientific research follow improvements in apparatus—the use of electricity and magnetism in Thomson's cathode rays.
- Theories being superseded—quantum mechanics is among the most current models of the atom.
- Use theories to explain natural phenomena-line spectra explained by the Bohr model of the atom.

	Assessment statement	Teacher's notes
2.2a	Describe the electromagnetic spectrum.	 Description of the relationship between color, wavelength, frequency and energy across the electromagnetic spectrum. The value of Planck's constant (<i>h</i>) and <i>E=hv</i> are given in the data booklet in sections 1 and 2. TOK: Infrared and ultraviolet spectroscopy are dependent on technology for their existence. What are the knowledge implications of this?
2.2b	Distinguish between a <i>continuous spectrum</i> and a <i>line spectrum</i> .	Aim 6 : Emission spectra could be observed using discharge tubes of different gases and a spectroscope. Flame tests could be used to study spectra.
2.2c	Explain how the lines in the emission spectrum of hydrogen are related to electron energy levels.	 Emission spectra are produced when photons are emitted from atoms as excited electrons return to a lower energy level. The line emission spectrum of hydrogen provides evidence for the existence of electrons in discrete energy levels, which converge at higher energies. Description of the emission spectrum of the hydrogen atom, including the relationships between the lines and energy transitions to the first, second

		 and third energy levels. Details of the electromagnetic spectrum are given in the data booklet in section 3. The names of the different series in the hydrogen line emission spectrum are not required. Aim 7: Interactive simulations modeling the behavior of electrons in the hydrogen atom can be used.
2.2d	 Describe electron distribution within atoms using the Quantum Model. 1. State the relative energies of s, p, d and f orbitals in a single energy level. 2. State the maximum number of orbitals in a given energy level. 3. Draw the shape of an s orbital and the shapes of the p_x, p_y and p_z orbitals. 	 The main energy level or shell is given an integer number, <i>n</i>, and can hold a maximum number of electrons, 2n². A more detailed model of the atom describes the division of the main energy level into s, p, d and f sub-levels of successively higher energies. Sub-levels contain a fixed number of orbitals, regions of space where there is a high probability of finding an electron. Each orbital has a defined energy state for a given electronic configuration and chemical environment and can hold two electrons of opposite spin. Recognition of the shape of an s atomic orbital and the p_x, p_y and p_z atomic orbitals.
2.2e	Deduce the electron configurations for atoms and ions up to $Z = 36$. -Writing electron configurations & orbital diagrams	 Application of the Aufbau Principle, Hund's Rule and the Pauli Exclusion Principle to write electron configurations for atoms and ions up to Z = 36. Full electron configurations (eg 1s²2s²2p⁶3s²3p⁴) and condensed electron configurations (eg [Ne] 3s²3p⁴) should be covered. Orbital diagrams should be used to represent the character and relative energy of orbitals. Orbital diagrams refer to arrow-in-box diagrams, such as the one given below. N: 11 11 12 11 1 N: 12 2s 2p The electron configurations of Cr and Cu as exceptions should be covered.

International-mindedness: The European Organization for Nuclear Research (CERN) is run by its European member states (20 states in 2013), with involvements from scientists from many other countries. It operates the world's largest particle physics research center, including particle accelerators and detectors used to study the fundamental constituents of matter.

Theory of knowledge:

- Heisenberg's Uncertainty Principle states that there is a theoretical limit to the precision with which we can know the momentum and the position of a particle. What are the implications of this for the limits of human knowledge?
- "One aim of the physical sciences has been to give an exact picture of the material world. One achievement ... has been to prove that this aim is unattainable." —*Jacob Bronowski*. What are the implications of this claim for the aspirations of natural sciences in particular and for knowledge in general?

Utilization:

- Absorption and emission spectra are widely used in astronomy to analyze light from stars.
- Atomic absorption spectroscopy is a very sensitive means of determining the presence and concentration of metallic elements.
- Fireworks—emission spectra.

12.1 Electrons in Atoms

Essential Idea: The quantized nature of energy transitions is related to the energy states of electrons in atoms and molecules **Nature of science:** Experimental evidence to support theories—emission spectra provide evidence for the existence of energy levels.

	Assessment statement	Teacher's notes
12.1a	Explain how evidence from first ionization energies across periods accounts for the existence of main energy levels and sub-levels in atoms.	 In an emission spectrum, the limit of convergence at higher frequency corresponds to the first ionization energy. Trends in first ionization energy across periods account for the existence of main energy levels and sub-levels in atoms
12.1b	Explain how successive ionization energy data is related to the electron configuration of an atom.	 Successive ionization energy data for an element give information that shows relations to electron configurations. Deduction of the group of an element from its successive ionization energy data. Explanation of the trends and discontinuities in first ionization energy across a period. Aim 7: Databases could be used for compiling graphs of trends in ionization energies and simulations are available for the Davisson-Germer electron

		diffraction experiment.
12.1c	Calculate the energy of an emission photon using frequency.	 Solving problems using <i>E=hv</i> Calculation of the value of the first ionization energy from spectral data which gives the wavelength or frequency of the convergence limit.

International-mindedness: In 2012 two separate international teams working at the Large Hadron Collider at CERN independently announced that they had discovered a particle with behavior consistent with the previously predicted "Higgs boson". **Theory of knowledge:**

- "What we observe is not nature itself, but nature exposed to our method of questioning."—Werner Heisenberg. An electron can behave as a wave or a particle depending on the experimental conditions. Can sense perception give us objective knowledge about the world?
- The de Broglie equation shows that macroscopic particles have too short a wavelength for their wave properties to be observed. Is it meaningful to talk of properties which can never be observed from sense perception?

Utilization: Electron microscopy has led to many advances in biology, such as the ultrastructure of cells and viruses. The scanning tunneling microscope (STM) uses a stylus of a single atom to scan a surface and provide a 3-D image at the atomic level.

UNIT 3 PERIODIC TABLE & PERIODICITY

3.1 The periodic table

Essential Idea: The arrangement of elements in the periodic table helps to predict their electron configurations. **Nature of science:** Obtain evidence for scientific theories by making and testing predictions based on them—scientists organize subjects based on structure and function; the periodic table is a key example of this. Early models of the periodic table from Mendeleev, and later Moseley, allowed for the prediction of properties of elements that had not yet been discovered.

	Assessment statement	Teacher's notes	
3.1a	Describe the arrangement of elements in the periodic table in order of increasing atomic number. -Mendeleev's and Moseley's periodic table models	The periodic table is arranged into four blocks associated with the four sub- levels—s, p, d, and f. Aim 6: Be able to recognize physical samples or images of common elements.	
3.1b	Distinguish between the terms <i>group</i> and <i>period</i> on the periodic table.	 The periodic table consists of groups (vertical columns) and periods (horizontal rows). The group numbering scheme from group 1 to group 18, as recommended by IUPAC, should be used. -CAS & IUPAC system of numbering families 	
3.1c	Apply the relationship between the electron configuration of elements and their position in the periodic table.	 The period number (n) is the outer energy level that is occupied by electrons. The periodic table shows the positions of metals, non-metals and metalloids. The terms alkali metals, halogens, noble gases, transition metals, lanthanoids and actinoids should be known Deduction of the electron configuration of an atom from the element's position on the periodic table, and vice versa. 	
3.1d	Apply the relationship between the number of electrons in the highest occupied energy level for an element and its position in the periodic table.	The number of the principal energy level and the number of the valence electrons in an atom can be deduced from its position on the periodic table.	
Inter	International-mindedness: The development of the periodic table took many years and involved scientists from different countries building		

International-mindedness: The development of the periodic table took many years and involved scientists from different countries building upon the foundations of each other's work and ideas.

Theory of knowledge: What role did inductive and deductive reasoning play in the development of the periodic table? What role does inductive and deductive reasoning have in science in general?

Utilization: Other scientific subjects also use the periodic table to understand the structure and reactivity of elements as it applies to their own disciplines.

3.2 Periodic trends

Essential Idea: Elements show trends in their physical and chemical properties across periods and down groups **Nature of science:** Looking for patterns—the position of an element in the periodic table allows scientists to make accurate predictions of its physical and chemical properties. This gives scientists the ability to synthesize new substances based on the expected reactivity of elements.

	Assessment statement	Teacher's notes
3.2a	Define the terms <i>first ionization energy, successive ionization energies</i> and <i>electronegativity</i> .	
3.2b	Describe and explain the trends in atomic radii, ionic radii, first ionization energies, electronegativities and	• Vertical and horizontal trends in the periodic table exist for atomic radius, ionic radius, ionization energy, electron affinity and electronegativity.

	melting points for elements in various families and periods, specifically with reference to alkali metals (group 1) and halogens (group 17).	 Prediction and explanation of the metallic and non-metallic behavior of an element based on its position in the periodic table. Discussion of the similarities and differences in the properties of elements in the same group. For ionization energy, the discontinuities in the increase across a period should be covered. Aim 3: Apply the organization of the periodic table to understand general trends in properties. Aim 4: Be able to analyze data to explain the organization of the elements
3.2c	Discuss the trends in chemical properties for elements within a period or a group/family.	 Oxides change from basic through amphoteric to acidic across a period. Construction of equations to explain the pH changes for reactions of Na₂O, MgO, P₄O₁₀, and the oxides of nitrogen and sulfur with water. Group trends should include the treatment of the reactions of alkali metals with water, alkali metals with halogens and halogens with halide ions. Aim 6: Experiment with chemical trends directly in the laboratory or through the use of teacher demonstrations. Aim 6: The use of transition metal ions as catalysts could be investigated. Aim 7: Periodic trends can be studied with the use of computer databases. Aim 8: Non-metal oxides are produced by many large-scale industrial processes and the combustion engine. These acidic gases cause large-scale pollution to lakes and forests, and localized pollution in cities. What is the global impact of acid deposition?

International-mindedness: Industrialization has led to the production of many products that cause global problems when released into the environment.

Theory of knowledge:

- The predictive power of Mendeleev's periodic table illustrates the "risk-taking" nature of science. What is the demarcation between scientific and pseudoscientific claims?
- The Periodic Table is an excellent example of classification in science. How does classification and categorization help and hinder the pursuit of knowledge?

13.1 First-row d-block elements

Essential Idea: The transition elements have characteristic properties, these properties are related to their all having incomplete d sublevels **Nature of science:** Looking for trends and discrepancies—transition elements follow certain patterns of behavior. The elements Zn, Cr and Cu do not follow these patterns and are therefore considered anomalous in the first-row d-block

	Assessment statement	Teacher's notes
13.1a	Discuss the characteristic properties of transition elements.	Transition elements have variable oxidation states, form complex ions with ligands, have colored compounds, and display catalytic and magnetic properties.
13.1b	Explain why Sc and Zn are not considered to be transition elements.	Zn is not considered to be a transition element as it does not form ions with incomplete d-orbitals.
13.1c	Explain the existence of variable oxidation number in ions of transition elements.	 Transition elements show an oxidation state of +2 when the s-electrons are removed. Explanation of the ability of transition metals to form variable oxidation states from successive ionization energies. In addition, they should be familiar with the oxidation numbers of the following: Cr (+3, +6), Mn (+4, +7), Fe (+3) and Cu (+1).
13.1d	Define the term <i>ligand</i> .	
13.1e	Describe and explain the formation of complexes of d- block elements.	 Explanation of the nature of the coordinate bond within a complex ion. Include [Fe(H₂O)₆]³⁺, [Fe(CN)₆]³⁻, [CuCl₄]²⁻ and [Ag(NH₃)₂]⁺. Only monodentate ligands are required. Deduction of the total charge given the formula of the ion and ligands present.
13.1f	Explain why some complexes of d-block elements are colored.	Students need only know that, in complexes, the d sub-level splits into two sets of orbitals of different energy and the electronic transitions that take place between them are responsible for their colors.
13.1g	State examples of the catalytic action of transition elements and their compounds.	Examples should include: - MnO ₂ in the decomposition of hydrogen peroxide - V ₂ O ₅ in the Contact process

		 Fe in the Haber process and in heme Ni in the conversion of alkenes to alkanes Co in vitamin B₁₂ Pd and Pt in catalytic converters. The mechanisms of action will not be assessed.
13.1h	Discuss the magnetic properties in transition metals in terms of unpaired electrons.	

Guidance: Common oxidation numbers of the transition metal ions are listed in the data booklet in sections 9 and 14.

International-mindedness: The properties and uses of the transition metals make them important international commodities. Mining for precious metals is a major factor in the economies of some countries.

Theory of knowledge: The medical symbols for female and male originate from the alchemical symbols for copper and iron. What role has the pseudoscience of alchemy played in the development of modern science?

Aim 6: The oxidation states of vanadium and manganese, for example, could be investigated experimentally. Transition metals could be analyzed using redox titrations.

Aim 8: Economic impact of the corrosion of iron.

13.2 Colored complexes

Essential Idea: d-orbitals have the same energy in an isolated atom, but split into two sub-levels in a complex ion. The electric field of ligands may cause the d-orbitals in complex ions to split so that the energy of an electron transition between them corresponds to a photon of visible light.

Nature of science:

- Models and theories—the color of transition metal complexes can be explained through the use of models and theories based on how electrons are distributed in d-orbitals.
- Transdisciplinary-color linked to symmetry can be explored in the sciences, architecture, and the arts.

	Assessment statement	Teacher's notes
13.2a	Explain how transition metals in complex ions are able to produce color.	 The d sub-level splits into two sets of orbitals of different energy in a complex ion. Complexes of d-block elements are colored, as light is absorbed when an electron is excited between the d-orbitals. The color absorbed is complementary to the color observed.
13.2b	Discuss how the identity of the transition metal and/or ligand affect the color of the complex ion.	 Explanation of the effect of the identity of the metal ion, the oxidation number of the metal and the identity of the ligand on the color of transition metal ion complexes. Explanation of the effect of different ligands on the splitting of the d-orbitals in transition metal complexes and color observed using the spectrochemical series.

Guidance:

- The spectrochemical series is given in the data booklet in section 15. A list of polydentate ligands is given in the data booklet in section 16.
- Students are not expected to recall the color of specific complex ions.
- The relation between the color observed and absorbed is illustrated by the color wheel in the data booklet in section 17.
- Students are not expected to know the different splitting patterns and their relation to the coordination number. Only the splitting of the 3d orbitals in an octahedral crystal field is required.

Aim 6: The colors of a range of complex ions, of elements such as Cr, Fe, Co, Ni and Cu could be investigated.

Aim 7: Complex ions could be investigated using a spectrometer data logger.

Aim 8: The concentration of toxic transition metal ions needs to be carefully monitored in environmental systems.

UNIT 4 BONDING

4.1 Ionic bonding and structure

Essential Idea: Ionic compounds consist of ions held together in lattice structures by ionic bonds **Nature of science:** Use theories to explain natural phenomena—molten ionic compounds conduct electricity but solid ionic compounds do not. The solubility and melting points of ionic compounds can be used to explain observations.

	Assessment statement	Teacher's notes
4.1a	Describe the ionic bond as the electrostatic attraction between oppositely charged ions.	The ionic bond is due to electrostatic attraction between oppositely charged ions.
4.1b	Describe how ions can be formed as a result of electron transfer.	 Positive ions (cations) form by metals losing valence electrons. Negative ions (anions) form by non-metals gaining electrons.

4.1c	Deduce the charge of the stable ion that is formed when elements either lose or gain electrons.	The number of electrons lost or gained is determined by the electron configuration of the atom.
4.1d	Discuss why transition elements can form more than one ion.	Include examples such as Fe ²⁺ and Fe ³⁺ . Nomenclature; -ic/-ous vs. Roman Numerals (Stock)
4.1e	Predict whether a compound of two elements would be ionic from the position of the elements in the periodic table or from their electronegativity values.	Δ e.n./ chemical bond table
4.1f	State the formula of common polyatomic ions formed as oxyanions of nonmetals.	Students should know the names of these polyatomic ions: NH_4^+ , OH^- , NO_3^- , HCO_3^- , CO_3^{-2-} , SO_4^{-2-} and PO_4^{-3-} . Calculate oxidation states of nonmetals in polyatomic ions
4.1g	 Describe the lattice structure formed in ionic compounds Discuss the physical properties of ionic compounds 	 Under normal conditions, ionic compounds are usually solids with lattice structures. Explanation of the physical properties of ionic compounds (volatility, electrical conductivity and solubility) in terms of their structure.
4.1h	Provide the correct formula and name of an ionic compound given the elements or polyatomic ions composition.	Deduction of the formula and name of an ionic compound from its component ions, including polyatomic ions.

Theory of knowledge:

General rules in chemistry (like the octet rule) often have exceptions. How many exceptions have to exist for a rule to cease to be useful? What evidence do you have for the existence of ions? What is the difference between direct and indirect evidence?

Utilization: Ionic liquids are efficient solvents and electrolytes used in electric power sources and green industrial processes.

Aim 3: Use naming conventions to name ionic compounds.

Aim 6: Students could investigate compounds based on their bond type and properties or obtain sodium chloride by solar evaporation. **Aim 7**: Computer simulation could be used to observe crystal lattice structures.

4.2 Covalent bonding

Essential Idea: Covalent compounds form by the sharing of electrons.

Nature of science:

- Looking for trends and discrepancies—compounds containing non-metals have different properties than compounds that contain non-metals and metals.
- Use theories to explain natural phenomena—Lewis introduced a class of compounds which share electrons. Pauling used the idea of electronegativity to explain unequal sharing of electrons.

	Assessment statement	Teacher's notes
4.2a	Describe how the covalent bond is formed as a result of electron sharing.	 A covalent bond is the electrostatic attraction between a pair(s) of electrons and positively charged nuclei. Coordinate covalent bonds are required. Examples include CO, NH4⁺and H₃O⁺.
4.2b	 Explain how the number of shared electron pairs relate to the number of covalent bonds. State and explain the relationship between the number of bonds, bond length and bond strength. 	 Single, double and triple covalent bonds involve one, two and three shared pairs of electrons respectively. Examples should include O₂, N₂, CO₂, HCN, C₂H₄ (ethene) and C₂H₂ (ethyne). Bond length decreases and bond strength increases as the number of shared electrons increases.
4.2c	Predict the relative polarity of chemical bonds from electronegativity values	 Bond polarity results from the difference in electronegativities of the bonded atoms. Deduction of the polar nature of a covalent bond from electronegativity values. Bond polarity can be shown either with partial charges, dipoles or vectors. Aim 7: Simulations may be used here.
4.2d	Use naming conventions to name covalently bonded compounds	

4.3 Covalent Structures -- 14.1 Shapes of molecules and ions -- 14.2 Hybridization

Essential Ideas:

• Lewis (electron dot) structures show the electron domains in the valence shell and are used to predict molecular shapes

• Larger structures and more in-depth explanations of bonding systems often require more sophisticated concepts and theories of bonding.

• Hybridization results from the mixing of atomic orbitals to form the same number of new equivalent hybrid orbitals that can have the same mean energy as the contributing atomic orbitals

Nature of Science:

- Scientists use models as representations of the real world—the development of the model of molecular shape (VSEPR) to explain observable properties.
- Principle of Occam's razor—bonding theories have been modified over time. Newer theories need to remain as simple as possible while maximizing explanatory power, for example the idea of formal charge.
- The need to regard theories as uncertain—hybridization in valence bond theory can help explain molecular geometries, but is limited. Quantum mechanics involves several theories explaining the same phenomena, depending on specific requirements.

	Assessment statement	Teacher's notes
4.3a 14.1a	 Deduce the Lewis (electron dot) structures of molecules and ions for up to four electron pairs on each atom. Evaluate Lewis structures by calculating formal charges on atoms. 	 A pair of electrons can be represented by dots, crosses, a combination of dots and crosses or by a line. For example, chlorine can be shown as: CI × CI × Or × CI × CI × Or × CI × CI × Or Lewis (electron dot) structures show all the valence electrons in a covalently bonded species. The "octet rule" refers to the tendency of atoms to gain a valence shell with a total of 8 electrons. Formal charge (FC) can be used to decide which Lewis (electron dot) structure is preferred from several. The FC is the charge an atom would have if all atoms in the molecule had the same electronegativity. FC = (Number of valence electrons)-1/2(Number of bonding electrons)-(Number of non-bonding electrons). The Lewis (electron dot) structure with the atoms having FC values closest to zero is preferred.
4.3b 14.1b	Predict the electron domain geometry and the molecular geometry (shape and bond angles) for species with two, three and four electron domains on the central atom using the valence shell electron pair repulsion theory (VSEPR).	 Shapes of species are determined by the repulsion of electron pairs according to VSEPR theory. Predicting of bond angles from molecular geometry which includes both bonding and non-bonding pairs of electrons. The term "electron domain" should be used in place of "negative charge center". Examples should include CH₄, NH₃, H₂O, NH₄⁺, H₃O⁺, BF₃, C₂H₄, SO₂, C₂H₂ and CO₂: Aim 7: Computer simulations could be used to model VSEPR structures.
14.1c	 Describe exceptions to the octet rule by constructing Lewis structures that possess either more or less than 4 electron domains on the central atom. Deduce the Lewis (electron dot) structures of molecules and ions showing all valence electrons for up to six electron pairs on each atom. Deduce geometric structures using VSEPR theory for molecules and ions containing five and six electron domains and associated bond angles. 	 Some atoms, like Be and B, might form stable compounds with incomplete octets of electrons Exceptions to the octet rule include some species having incomplete octets and expanded octets.
14.1d	Predict the shape and bond angles for species with five and six negative charge centers using the VSEPR theory.	Examples should include PCl ₅ , SF ₆ , XeF ₄ and PF ₆ ⁻ . Aim 7: Interactive simulations are available to illustrate this.
14.1e	 Describe σ and π bonds. Predict whether sigma (σ) or pi (π) bonds are formed from the specific linear combination of atomic orbitals. 	 Covalent bonds result from the overlap of atomic orbitals. A sigma bond (σ) is formed by the direct head-on/end-to-end overlap of atomic orbitals, resulting in electron density concentrated between the nuclei of the bonding atoms. A pi bond (π) is formed by the sideways overlap of atomic orbitals, resulting in electron density above and below the plane of the nuclei of the bonding atoms.
14.2a	 Explain hybridization in terms of the mixing of atomic orbitals to form new orbitals for bonding. Explanation of the relationships between Lewis (electron dot) structures, electron domains, molecular geometries and types of hybridization.(sp, sp² and sp³). 	Students should consider sp, sp ² and sp ³ hybridization, and the shapes and orientation of these orbitals. Examples of hybridization should include methane, ethene and ethyne Aim 7 : Computer simulations could be used to model hybrid orbitals.
14.2b	Describe the delocalization of π electrons and explain how this can account for the structures of some species. -Draw resonance structures using Lewis structures	 Resonance structures occur when there is more than one possible position for a double bond in a molecule. Delocalization involves electrons that are shared by/between all atoms in a

		 molecule or ion as opposed to being localized between a pair of atoms. Resonance involves using two or more Lewis (electron dot) structures to represent a particular molecule or ion. A resonance structure is one of two or more alternative Lewis (electron dot) structures for a molecule or ion that cannot be described fully with one Lewis (electron dot) structure alone. Examples should include NO₃⁻, NO₂⁻, CO₃²⁻, O₃, RCOO⁻ and benzene. 	
4.3c	Predict whether or not a molecule is polar from its molecular shape and bond polarities.	 Dipole moments exist in polar molecules where a separation of partial charges are produced from differing atomic electronegativities. Molecular polarities of geometries corresponding to five and six electron domains should also be covered. 	
14.1f	 Explain differences in wavelengths of light required to dissociate oxygen and ozone. Describe of the mechanism of the catalysis of ozone depletion when catalyzed by CFCs and NO_x. 	The chemical properties of diatomic oxygen and ozone are dependent upon the bonding structure of each molecule.	
4.3d	Explain the properties of giant covalent compounds in terms of their structures.	Carbon and silicon form giant covalent/network covalent structures.	
4.3e	Describe and compare the structure and bonding in the three allotropes of carbon (diamond, graphite and C_{60} fullerene).	Allotropes of carbon (diamond, graphite, graphene, C ₆₀ buckminsterfullerene) and SiO ₂ should be covered.	
Theor	Theory of knowledge:		

- Does the need for resonance structures decrease the value or validity of Lewis (electron dot) theory? What criteria do we use in assessing the validity of a scientific theory?
- Covalent bonding can be described using valence bond or molecular orbital theory. To what extent is having alternative ways of describing the same phenomena a strength or a weakness?
- Hybridization is a mathematical device which allows us to relate the bonding in a molecule to its symmetry. What is the relationship between the natural sciences, mathematics and the natural world? Which role does symmetry play in the different areas of knowledge?

• IUPAC (International Union of Pure and Applied Chemistry) is the world authority in developing standardized nomenclature for both organic and inorganic compounds

• How has ozone depletion changed over time? What have we done as a global community to reduce ozone depletion?

• To what extent is ozone depletion an example of both a success and a failure for solving an international environmental concern?

Utilization:

- Drug action and links to a molecule's structure.
- Vision science and links to a molecule's structure.

Aim 1: Global impact of ozone depletion.

Aim 8: Moral, ethical, social, economic and environmental implications of ozone depletion and its solution.

4.4 Intermolecular forces

Essential Idea: The physical properties of molecular substances results from different types of forces between their molecules **Nature of science:** Obtain evidence for scientific theories by making and testing predictions based on them—London (dispersion) forces and hydrogen bonding can be used to explain special interactions. For example, molecular covalent compounds can exist in the liquid and solid states. To explain this, there must be attractive forces between their particles which are significantly greater than those that could be attributed to gravity.

	Assessment statement	Teacher's notes
4.4a	Deduce of the types of intermolecular force present in substances, based on their structure and chemical formula	 Intermolecular forces (attractions), also known as "van der Waals forces", is an inclusive term, which includes dipole–dipole, dipole-induced dipole and London (dispersion) forces. The term "London (dispersion) forces" refers to instantaneous induced dipole-induced dipole forces that exist between any atoms or groups of atoms and should be used for non-polar entities. These are attractions between molecules that have temporary dipoles,

		 permanent dipoles or hydrogen bonding. The relative strengths of these interactions are London (dispersion) forces < dipole-dipole forces < hydrogen bonds. Aim 7: Computer simulations could be used to show intermolecular forces interactions.
4.4b Deduce the physical p (volatility, electrical c of their structure and	roperties of covalent compounds onductivity and solubility) in terms ntermolecular forces.	The presence of hydrogen bonding can be illustrated by comparing: HF and HCl H ₂ O and H ₂ S NH ₃ and PH ₃ CH ₃ OCH ₃ and CH ₃ CH ₂ OH CH ₃ CH ₂ CH ₃ , CH ₃ CHO and CH ₃ CH ₂ OH.

Theory of knowledge: The nature of the hydrogen bond is the topic of much discussion and the current definition from the IUPAC gives six criteria which should be used as evidence for the occurrence of hydrogen bonding. How does a specialized vocabulary help and hinder the growth of knowledge?

4.5 Metallic bonding

Essential Idea: Metallic bonds involve a lattice of cations with delocalized electrons **Nature of science:** Use theories to explain natural phenomena—the properties of metals are different from covalent and ionic substances and this is due to the formation of non-directional bonds with a "sea" of delocalized electrons.

	Assessment statement	Teacher's notes
4.5a	Describe the metallic bond as the electrostatic attraction between a lattice of positive ions and delocalized electrons.	 A metallic bond is the electrostatic attraction between a lattice of positive ions and delocalized electrons. The strength of a metallic bond depends on the charge of the ions and the radius of the metal ion. Aim 1: Global impact of value of precious metals and their extraction processes and locations. Aim 7: Computer simulations could be used to view examples of metallic bonding.
4.5b	 Explain the physical properties of metals, such as, electrical conductivity and malleability. Explanation of trends in melting points of metals. 	Trends should be limited to s- and p-block elements. Aim 8: Students should appreciate the economic importance of these properties and the impact that the large-scale production of iron and other metals has made on the world.
4.5c	Describe the composition and properties of alloys in terms of non-directional bonding.	 Alloys usually contain more than one metal and have enhanced properties. Examples of various alloys should be covered.
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International-mindedness: The availability of metal resources, and the means to extract them, varies greatly in different countries, and is a factor in determining national wealth. As technologies develop, the demands for different metals change and careful strategies are needed to manage the supply of these finite resources.

UNIT 5: CHEMICAL REACTIONS & EQUATIONS

1.3 Chemical equations: Reacting masses and volumes

Essential Idea: Mole ratios in chemical equations can be used to calculate reacting ratios by mass and gas volume. **Nature of science:** Making careful observations and obtaining evidence for scientific theories—Avogadro's initial hypothesis

	Assessment statement	Teacher's notes
1.3a	Write balanced chemical equations when reactants and products are specified.	Students should be aware of the difference between coefficients and subscripts.
1.3b	Identify the mole ratio of any two species in a chemical equation.	
1.3c	Apply the state symbols (s), (l), (g) and (aq) in a chemical equation	TOK: When are these symbols necessary in aiding understanding and when are they redundant?
1.3d	Define the type of chemical reaction based on reactivity patterns: synthesis, decomposition, single replacement,	Balancing of equations should include a variety of types of reactions.

	double replacement (metathesis), combustion and acid base.	
1.3e	Describe the driving forces behind chemical reactions: redox & metathesis (decrease in ion concentrations).	
1.3f	Solve stoichiometric problems relating to reacting quantities, limiting and excess reactants, theoretical, experimental and percentage yields.	Reactants can be either limiting or excess. The experimental yield can be different from the theoretical yield.
1.3g	Apply Avogadro's law to calculate reacting volumes of gases.	Avogadro's law enables the mole ratio of reacting gases to be determined from volumes of the gases. The molar volume of an ideal gas is a constant at specified temperature and pressure. Values for the molar volume of an ideal gas are given in the data booklet in section 2. The molar volume of an ideal gas under standard conditions is $2.24 \times 10^{-2} \text{ m}^3 \text{ mol}^{-1} (22.4 \text{ dm}^3 \text{ mol}^{-1}).$
1.3h	 Solve stoichiometric problems involving the relationship between temperature, pressure and volume for a fixed mass of an ideal gas. Analyze graphs showing relationships between temperature, pressure and volume for a fixed mass of an ideal gas. 	
1.3i	Solve problems using the ideal gas equation, $PV = nRT$	The ideal gas equation, $PV = nRT$, and the value of the gas constant (<i>R</i>) are given in the data booklet in sections 1 and 2.
1.3j	Describe how real gases deviate from ideal behavior at low temperature and high pressure.	
1.3k	Calculate the molar mass of a gas from the ideal gas equation by obtaining and using experimental data	
1.31	Distinguish between the terms <i>solute</i> , <i>solvent</i> , <i>solution</i> and <i>concentration</i> .	 The molar concentration of a solution is determined by the amount of solute and the volume of solution. A standard solution is one of known concentration. Units of concentration to include: g dm⁻³, mol dm⁻³ and parts per million (ppm). The use of square brackets to denote molar concentration is required for example, [HC1].
1.3m	Solve stoichiometric problems involving molar concentration, amount of solute and volume of solution.	
13.n	Calculate the concentration of a solution by using the experimental method of titration and a standard solution.	

• The SI unit of pressure is the Pascal (Pa), N m⁻², but many other units remain in common usage in different countries. These include atmosphere (atm), millimeters of mercury (mm Hg), Torr, bar and pounds per square inch (psi). The bar (10⁵ Pa) is now widely used as a convenient unit, as it is very close to 1 atm. The SI unit for volume is m³, although liter is a commonly used unit.

Theory of knowledge:

- Chemical equations are the "language" of chemistry. How does the use of universal languages help and hinder the pursuit of knowledge?
- Lavoisier's discovery of oxygen, which overturned the phlogiston theory of combustion, is an example of a paradigm shift. How does scientific knowledge progress?
- The ideal gas equation can be deduced from a small number of assumptions of ideal behavior. What is the role of reason, perception, intuition and imagination in the development of scientific models?

Utilization:

- Stoichiometric calculations are fundamental to chemical processes in research and industry, for example in the food, medical, pharmaceutical and manufacturing industries.
- Gas volume changes during chemical reactions are responsible for the inflation of air bags in vehicles and are the basis of many other explosive reactions, such as the decomposition of TNT (trinitrotoluene).
- The concept of percentage yield is vital in monitoring the efficiency of industrial processes.

Aim 6: Experimental design could include excess and limiting reactants. Experiments could include gravimetric determination by

precipitation of an insoluble salt.

Aim 7: Data loggers can be used to measure temperature, pressure and volume changes in reactions or to determine the value of the gas constant, *R*.

Aim 8: The unit parts per million, ppm, is commonly used in measuring small levels of pollutants in fluids. This unit is convenient for communicating very low concentrations, but is not a formal SI unit.

UNIT 6: OXIDATION & REDUCTION

9.1 Introduction to oxidation and reduction & 9.2 Redox equations

Essential idea: Redox (reduction-oxidation) reactions play a key role in many chemical and biochemical processes. **Nature of science:** How evidence is used—changes in the definition of oxidation and reduction from one involving specific elements (oxygen and hydrogen), to one involving electron transfer, to one invoking oxidation numbers is a good example of the way that scientists broaden similarities to general principles.

	Assessment statement	Teacher's notes
9.1a	Define <i>oxidation</i> and <i>reduction</i> in terms of electron loss and gain.	Oxidation and reduction can be considered in terms of oxygen gain/hydrogen loss, electron transfer or change in oxidation number.
9.1b	Identify the oxidation state of an atom in an ion or a compound.	 Variable oxidation numbers exist for transition metals and for most main- group non-metals. Oxidation number and oxidation state are often used interchangeably, though IUPAC does formally distinguish between the two terms. Oxidation numbers for transition metals are represented by Roman numerals according to IUPAC. Oxidation states should be represented with the sign given before the number, eg +2 not 2+. The oxidation state of hydrogen in metal hydrides (-1) and oxygen in peroxides (-1) should be covered. Oxidation numbers should be shown by a sign (+ or –) and a number, for example, +7 for Mn in KMnO4. TOK: Are oxidation numbers "real"?
9.1c	State the name of a transition metal compound from a given formula, applying oxidation numbers represented by Roman numerals.	Oxidation numbers in names of compounds are represented by Roman numerals, for example, iron(II) oxide, iron(III) oxide.
9.1d	 Deduce whether an element undergoes oxidation or reduction in reactions using oxidation numbers. Name the oxidizing and reducing agents, in redox reactions. 	An oxidizing agent is reduced and a reducing agent is oxidized.
9.1e	Predict the possibility of a redox reaction from the activity series or reaction data.	 The activity series ranks metals according to the ease with which they undergo oxidation. Lab experiments involving single replacement reactions in aqueous solutions should be included.
9.1f	Write a balanced redox reaction equation using half- equations in acidic or neutral solutions.	 H⁺ and H₂O should be used where necessary to balance half-equations in acid solution. The balancing of equations for reactions in alkaline solution will not be assessed. Solution of a range of redox titration problems.
9.1g	Apply the Winkler Method to calculate BOD.	The Winkler Method can be used to measure biochemical oxygen demand (BOD), used as a measure of the degree of pollution in a water sample.

International-mindedness: Access to a supply of clean drinking water has been recognized by the United Nations as a fundamental human right, yet it is estimated that over one billion people lack this provision. Disinfection of water supplies commonly uses oxidizing agents such as chlorine or ozone to kill microbial pathogens.

Theory of knowledge:

- Chemistry has developed a systematic language that has resulted in older names becoming obsolete. What has been lost and gained in this process?
- Oxidation states are useful when explaining redox reactions. Are artificial conversions a useful or valid way of clarifying knowledge? Utilization:
- Aerobic respiration, batteries, solar cells, fuel cells, bleaching by hydrogen peroxide of melanin in hair, household bleach, the browning of food exposed to air, etc.

- Driving under the influence of alcohol is a global problem which results in serious road accidents. A redox reaction is the basis of the breathalyzer test.
- Natural and synthetic antioxidants in food chemistry.
- Photochromic lenses.
- Corrosion and galvanization.

Aim 6: Experiments could include demonstrating the activity series, redox titrations and using the Winkler Method to measure BOD. **Aim 8**: Oxidizing agents such as chlorine can be used as disinfectants. Use of chlorine as a disinfectant is of concern due to its ability to oxidize other species forming harmful by-products (e.g. trichloromethane).

9.2 & 19.1: Electrochemical Cells

Essential idea: Voltaic cells convert chemical energy to electrical energy and electrolytic cells convert electrical energy to chemical energy **Essential idea:** Energy conversation between electrical and chemical energy lies at the core of electrochemical cells. **Nature of science:**

- Ethical implications of research—the desire to produce energy can be driven by social needs or profit.
- Employing quantitative reasoning-electrode potentials and the standard hydrogen electrode.
- Collaboration and ethical implications—scientists have collaborated to work on electrochemical cell technologies and have to consider the environmental and ethical implications of using fuel cells and microbial fuel cells.

	Assessment statement	Teacher's notes
9.2a	Construction and annotation of both types of electrochemical cells.	 Voltaic (<i>Galvanic</i>) cells: Voltaic cells convert energy from spontaneous, exothermic chemical processes to electrical energy. Oxidation occurs at the anode (negative electrode) and reduction occurs at the cathode (positive electrode) in a voltaic cell. Electrolytic cells: Electrolytic cells convert electrical energy to chemical energy, by bringing about non-spontaneous processes. Oxidation occurs at the anode (positive electrode) and reduction occurs at the cathode (negative electrode) in an electrolytic cell. For voltaic cells, a cell diagram convention should be covered. The term "cells in series" should be understood.
9.2b	Explain how a redox reaction is used to produce electricity in a voltaic cell and how current is conducted in an electrolytic cell.	 A voltaic cell generates an electromotive force (EMF) resulting in the movement of electrons from the anode (negative electrode) to the cathode (positive electrode) via the external circuit. The EMF is termed the cell potential (E°). Electrolytic processes to be covered in theory should include the electrolysis of aqueous solutions (e.g. sodium chloride, copper(II) sulfate, etc.) and water using both inert platinum or graphite electrodes and copper electrodes. Explanations should refer to E° values, nature of the electrode and concentration of the electrolyte.
9.2c	Distinguish between electron and ion flow in both electrochemical cells.	
9.2d	Conduct laboratory experiments involving a typical voltaic cell using two metal/metal-ion half-cells.	
9.2e	Predict of the products of the electrolysis of a molten salt.	
19.1a	Calculate cell potentials using standard electrode potentials.	The standard hydrogen electrode (SHE) consists of an inert platinum electrode in contact with 1 mol dm ⁻³ hydrogen ion and hydrogen gas at 100 kPa and 298 K. The standard electrode potential (E^o) is the potential (voltage) of the reduction half-equation under standard conditions measured relative to the SHE. Solute concentration is 1 mol dm ⁻³ or 100 kPa for gases. E^o of the SHE is 0 V.
19.1b	Predict whether a reaction is spontaneous or not using E° values.	
19.1c	Determine standard free-energy changes (ΔG°) using standard electrode potentials.	 ΔG^o = -nFE^o. When E^o is positive, ΔG^o is negative indicative of a spontaneous process. When E^o is negative, ΔG^o is positive indicative of a non-spontaneous process. When E^o is 0, then ΔG^o is 0. ΔG^o = -nFE^o is given in the data booklet in section 1. Faraday's constant = 96500 C mol⁻¹ is given in the data booklet in section 2.

19.1d	Describe the process of product formation from the electrolysis of aqueous solutions.	When aqueous solutions are electrolyzed, water can be oxidized to oxygen at the anode and reduced to hydrogen at the cathode.
19.1e	Determine the relative amounts of products formed during electrolytic processes.	Current, duration of electrolysis and charge on the ion affect the amount of product formed at the electrodes during electrolysis.
19.1f	Explain the process of electroplating.	Electroplating involves the electrolytic coating of an object with a metallic thin layer.

- Research in space exploration often centers on energy factors. The basic hydrogen–oxygen fuel cell can be used as an energy source in spacecraft, such as those first engineered by NASA in the USA. The International Space Station is a good example of a multinational project involving the international scientific community.
- Many electrochemical cells can act as energy sources alleviating the world's energy problems but some cells such as super-efficient microbial fuel cells (MFCs) (also termed biological fuel cells) can contribute to clean-up of the environment. How do national governments and the international community decide on research priorities for funding purposes?

Theory of knowledge:

• Is energy just an abstract concept used to justify why certain types of changes are always associated with each other? Are concepts such as energy **real**?

• The SHE is an example of an arbitrary reference. Would our scientific knowledge be the same if we chose different references? Utilization:

• Fuel cells.

- Heart pacemakers.
- Electroplating.
- Electrochemical processes in dentistry.
- Rusting of metals.

Aim 6: Construction of a typical voltaic cell using two metal/metal-ion half-cells.

Aim 6: Electrolysis experiments could include that of a molten salt. A video could also be used to show some of these electrolytic processes. Aim 8: Although the hydrogen fuel cell is considered an environmentally friendly, efficient alternative to the internal combustion engine, storage of hydrogen fuel is a major problem. The use of liquid methanol, which can be produced from plants as a carbon neutral fuel (one which does not contribute to the greenhouse effect), in fuel cells has enormous potential. What are the current barriers to the development of fuel cells? Aim 8: Biological fuel cells can produce electrical energy to power electrical devices, houses, factories etc. They can assist in environmental clean-up. Microbial fuel cells (MFCs) powered by microbes in sewage can clean up sewage which may result in cost-free waste water treatment.

UNIT 7 ENERGETICS/THERMODYNAMICS

Topic 5.1: Measuring energy changes

Essential Idea: The enthalpy changes from chemical reactions (and state changes) can be calculated from their effect on the temperature of their surroundings

Nature of science:

- Fundamental principle—conservation of energy is a fundamental principle of science.
- Making careful observations-measurable energy transfers between systems and surroundings.

	Assessment statement	Teacher's notes
5.1a	Describe the terms <i>exothermic reaction</i> , <i>endothermic reaction</i> relative to specific changes in energy.	 Heat is a form of energy. Temperature is a measure of the average kinetic energy of the particles. Total energy is conserved in chemical reactions. Chemical reactions that involve transfer of heat between the system and the surroundings are described as endothermic or exothermic.
5.1b	Explain how <i>standard enthalpy change of reaction</i> (ΔH°) describes relative changes in energy based on the nature of reactants and products.	 The enthalpy change (ΔH) for chemical reactions is indicated in kJ mol⁻¹. ΔH values are usually expressed under standard conditions, given by ΔH°, including standard states. Enthalpy changes of combustion (ΔH_c°) and formation (ΔH_f°) should be covered. Consider reactions in aqueous solution and combustion reactions. Standard state refers to the normal, most pure stable state of a substance measured at 100 kPa. Temperature is not a part of the definition of standard state, but 298 K is commonly given as the temperature of interest.
5.1c	Calculate the heat change when the temperature of a pure substance is changed using $q=mc\Delta T$.	The specific heat capacity of water is provided in the data booklet in section 2.
5.1d	Perform a calorimetry experiment for an enthalpy of	• Students can assume the density and specific heat capacities of aqueous

reaction and evaluate the results.	 solutions are equal to those of water, but should be aware of this limitation. Heat losses to the environment and the heat capacity of the calorimeter in experiments should be considered, but the use of a bomb calorimeter is not required.

International-mindedness: The SI unit of temperature is the Kelvin (K), but the Celsius scale (°C), which has the same incremental scaling, is commonly used in most countries. The exception is the USA which continues to use the Fahrenheit scale (°F) for all non-scientific communication.

Theory of knowledge: What criteria do we use in judging discrepancies between experimental and theoretical values? Which ways of knowing do we use when assessing experimental limitations and theoretical assumptions?

Utilization: Determining energy content of important substances in food and fuels.

Aim 6: Experiments could include calculating enthalpy changes from given experimental data (energy content of food, enthalpy of melting of ice or the enthalpy change of simple reactions in aqueous solution).

Aim 7: Use of databases to analyze the energy content of food.

Aim 7: Use of data loggers to record temperature changes.

5.2 Hess's law

Essential idea: In chemical transformations energy can neither be created nor destroyed (1st law of thermodynamics) **Nature of science:** Based on the conservation of energy and atomic theory, scientists can test the hypothesis that if the same products are formed from the same initial reactants then the energy change should be the same regardless of the number of steps.

	Assessment statement	Teacher's notes
5.2a	Explain how Hess's Law is used to calculate enthalpy changes for chemical reactions	The enthalpy change for a reaction that is carried out in a series of steps is equal to the sum of the enthalpy changes for the individual steps.
5.2b	Calculation of ΔH reactions using ΔH_{f}^{o} data.	Enthalpy of formation data can be found in the data booklet in section 12. An application of Hess's Law is ΔH reaction= $\Sigma(\Delta H_f^o \text{ products})-\Sigma(\Delta H_f^o \text{ reactants})$.
5.2c	Determine the enthalpy change of a reaction by calculating the sum of multiple reactions with known enthalpy changes.	
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International-mindedness: Recycling of materials is often an effective means of reducing the environmental impact of production, but varies in its efficiency in energy terms in different countries.

Theory of knowledge: Hess's Law is an example of the application of the conservation of energy. What are the challenges and limitations of applying general principles to specific instances?

Utilization: Hess's Law has significance in the study of nutrition, drugs, and Gibbs free energy where direct synthesis from constituent elements is not possible.

Aim 4: Discuss the source of accepted values and use this idea to critique experiments.

Aim 6: Experiments could include Hess's Law labs.

Aim 7: Use of data loggers to record temperature changes

5.3 Bond enthalpies

Essential Idea: Energy is absorbed when bonds are broken and released when bonds are formed

Nature of science: Measured energy changes can be explained based on the model of bonds broken and bonds formed. Since these explanations are based on a model, agreement with empirical data depends on the sophistication of the model and data obtained can be used to modify theories where appropriate.

	Assessment statement	Teacher's notes
5.3a	Define the term <i>average bond enthalpy</i> .	 Bond-forming releases energy and bond-breaking requires energy. Average bond enthalpy is the energy needed to break one mol of a bond in a gaseous molecule averaged over similar compounds. Discussion of the bond strength in ozone relative to oxygen in its importance to the atmosphere.
5.3b	Calculate the enthalpy changes from known bond enthalpy values and compare these to experimentally measured values.	 Bond enthalpy values are given in the data booklet in section 11. Average bond enthalpies are only valid for gases and calculations involving bond enthalpies may be inaccurate because they do not take into account intermolecular forces.
5.3c	Use potential energy profiles to determine whether reactants or products are more stable and if the reaction is exothermic or endothermic.	

International-mindedness: Stratospheric ozone depletion is a particular concern in the polar regions of the planet, although the pollution that causes it comes from a variety of regions and sources. International action and cooperation have helped to ameliorate the ozone depletion problem.

Utilization: Energy sources, such as combustion of fossil fuels, require high ΔH values.

Aim 6: Experiments could be enthalpy of combustion of propane or butane.

Aim 7: Data loggers can be used to record temperature changes.

Aim 8: Moral, ethical, social, economic and environmental consequences of ozone depletion and its causes

15.1 Energy cycles-- 15.2 Entropy & spontaneity

Essential Ideas:

- The concept of the energy change in a single step reaction being equivalent to the summation of smaller steps can be applied to changes involving ionic compounds
- A reaction is spontaneous if the overall transformation leads to an increase in total entropy (system plus surroundings). The direction of spontaneous changes always increases the total entropy of the universe at the expense of energy available to do useful work. This is known as the 2nd Law of Thermodynamics

Nature of science:

- Making quantitative measurements with replicates to ensure reliability—energy cycles allow for the calculation of values that cannot be determined directly.
- The idea of entropy has evolved through the years as a result of developments in statistics and probability.

	Assessment statement	Teacher's notes
15.1a	Construct Born-Haber cycles for group 1 and 2 oxides and chlorides.	 The following enthalpy/energy terms should be covered: ionization, atomization, electron affinity, lattice, covalent bond, hydration and solution. Representative equations (eg M⁺(g) → M⁺(aq)) can be used for enthalpy/energy of hydration, ionization, atomization, electron affinity, lattice, covalent bond and solution. Value for lattice enthalpies (section 18), enthalpies of aqueous solutions (section 19) and enthalpies of hydration (section 20) are given in the data booklet.
15.1b	Construct energy cycles from hydration, lattice and solution enthalpy.	 Enthalpy of solution, hydration enthalpy and lattice enthalpy are related in an energy cycle. Examples can include the dissolution of solid NaOH or NH4Cl in water.
15.1c	Calculate enthalpy changes from Born-Haber or dissolution energy cycles.	Lab experiments can include single replacement reactions in aqueous solutions.
15.1d	Relate size and charge of ions to lattice and hydration enthalpies.	
15.2a	Prediction of whether a change will result in an increase or decrease in entropy by considering the states of the reactants and products.	 Entropy (<i>S</i>) refers to the distribution of available energy among the particles. The more ways the energy can be distributed the higher the entropy. Entropy of gas>liquid>solid under same conditions.
15.2b	Calculation of entropy changes (Δ S) from given standard entropy values (S°).	Thermodynamic data is given in section 12 of the data booklet.
15.2c	Application of $\Delta G^{\circ} = \Delta H^{\circ} - T\Delta S^{\circ}$ in predicting spontaneity and calculation of various conditions of enthalpy and temperature that will affect this.	 Gibbs free energy (G) relates the energy that can be obtained from a chemical reaction to the change in enthalpy (ΔH), change in entropy (ΔS), and absolute temperature (T). Examine various reaction conditions that affect ΔG. ΔG is a convenient way to take into account both the direct entropy change resulting from the transformation of the chemicals, and the indirect entropy change of the surroundings as a result of the gain/loss of heat energy.
15.2d	Relation of ΔG to position of equilibrium.	

International-mindedness:

• The importance of being able to obtain measurements of something which cannot be measured directly is significant everywhere. Borehole temperatures, snow cover depth, glacier recession, rates of evaporation and precipitation cycles are among some indirect indicators of global warming. Why is it important for countries to collaborate to combat global problems like global warming?

• Sustainable energy is a UN initiative with a goal of doubling of global sustainable energy resources by 2030.

Theory of knowledge: Entropy is a technical term which has a precise meaning. How important are such technical terms in different areas of knowledge?

Utilization:

Other energy cycles—carbon cycle, the Krebs cycle and electron transfer in biology.

Aim 4: Discuss the source of accepted values and use this idea to critique experiments.

Aim 6: A possible experiment is to calculate either the enthalpy of crystallization of water or the heat capacity of water when a cube of ice is added to hot water.

Aim 7: Use of data loggers to record temperature changes. Use of databases to source accepted values.

Aims 1, 4 and 7: Use of databases to research hypothetical reactions capable of generating free energy.

Aim 6: Experiments investigating endothermic and exothermic processes could be run numerous times to compare reliability of repetitive data and compare to theoretical values.

UNIT 8 CHEMICAL KINETICS

6.1 Collision theory and rates of reactions

Essential Idea: The greater the probability that molecules will collide with sufficient energy and proper orientation, the higher the rate of reaction

Nature of science: The principle of Occam's razor is used as a guide to developing a theory—although we cannot directly see reactions taking place at the molecular level, we can theorize based on the current atomic models. Collision theory is a good example of this principle.

	Assessment statement	Teacher's notes
6.1a	Describe the Kinetic Molecular Theory in terms of the movement of particles whose average kinetic energy is proportional to temperature in Kelvin.	Species react as a result of collisions of sufficient energy and proper orientation.
6.1b	Distinguish between the terms <i>reaction rate, rate</i> <i>constant, overall order of reaction</i> and <i>order of reaction</i> with respect to a particular reactant.	The rate of reaction is expressed as the change in concentration of a particular reactant/product per unit time.
6.1c	Analyze graphical and numerical data from rate experiments to calculate the reaction rate	 Concentration changes in a reaction can be followed indirectly by monitoring changes in mass, volume and color. Calculation of reaction rates from tangents of graphs of concentration, volume or mass vs time should be covered. Students should be familiar with the interpretation of graphs of changes in concentration, volume or mass against time.
6.1d	Explain the effects of temperature, pressure/concentration and particle size on rate of reaction.	
6.1e	Using Maxwell–Boltzmann energy distribution curves, account for the probability of successful collisions and factors affecting these, including the effect of a catalyst.	Activation energy (E_a) is the minimum energy that colliding molecules need in order to have successful collisions leading to a reaction. By decreasing E_a , a catalyst increases the rate of a chemical reaction, without itself being permanently chemically changed.
6.1f	Investigate rates of reaction experimentally and evaluation of the results.	
6.1g	Use energy profiles models to correlate rates of reactions with and without catalysts.	

International-mindedness: Depletion of stratospheric ozone has been caused largely by the catalytic action of CFCs and is a particular concern in the polar regions. These chemicals are released from a variety of regions and sources, so international action and cooperation have been needed to ameliorate the ozone depletion problem.

Theory of knowledge: The Kelvin scale of temperature gives a natural measure of the kinetic energy of gas whereas the artificial Celsius scale is based on the properties of water. Are physical properties such as temperature invented or discovered?

Aims 1 and 8: What are some of the controversies over rate of climate change? Why do these exist?

Aim 6: Investigate the rate of a reaction with and without a catalyst.

Aim 6: Experiments could include investigating rates by changing concentration of a reactant or temperature.

Aim 7: Use simulations to show how molecular collisions are affected by change of macroscopic properties such as temperature, pressure and concentration.

Aim 8: The role that catalysts play in the field of green chemistry.

16.1 Rate expression and reaction mechanism

Essential Idea: Rate expressions can only be determined empirically and these limit possible reaction mechanisms. In particular cases, such as a linear chain of elementary reactions, no equilibria and only one significant activation barrier, the rate equation is equivalent to the slowest step of the reaction.

Nature of science: Principle of Occam's razor—newer theories need to remain as simple as possible while maximizing explanatory power. The low probability of three molecule collisions means stepwise reaction mechanisms are more likely.

	Assessment statement	Teacher's notes
16.1a	 Write a rate expression (rate law equation) for a chemical equation using experimental data, and Solve problems involving rate expressions. 	 Reactions may occur by more than one step and the slowest step determines the rate of reaction (rate determining step/RDS). The molecularity of an elementary step is the number of reactant particles taking part in that step. The value of the rate constant (<i>k</i>) is affected by temperature and its units are determined from the overall order of the reaction.
16.1b	 Explain how reactions can be represented as zero, first and second order reactions, and Use graphical representations of rates to identify zero, first and second order reactions. 	 The order of a reaction can be either integer or fractional in nature. The order of a reaction can describe, with respect to a reactant, the number of particles taking part in the rate-determining step. Calculations will be limited to orders with whole number values. Consider concentration-time and rate-concentration graphs. Use potential energy level profiles to illustrate multi-step reactions; showing the higher <i>E_a</i> in the rate-determining step in the profile.
16.1c	Propose reaction mechanisms for chemical reactions that are consistent with kinetic and stoichiometric data.	 Rate equations can only be determined experimentally. Catalysts alter a reaction mechanism, introducing a step with lower activation energy. Catalysts are involved in the rate-determining step. Any experiment which allows students to vary concentrations to see the effect upon the rate and hence determine a rate equation is appropriate.

International-mindedness:

The first catalyst used in industry was for the production of sulfuric acid. Sulfuric acid production closely mirrored a country's economic health for a long time. What are some current indicators of a country's economic health?

Theory of knowledge:

Reaction mechanism can be supported by indirect evidence. What is the role of empirical evidence in scientific theories? Can we ever be certain in science?

Utilization:

Cancer research is all about identifying mechanisms; for carcinogens as well as cancer-killing agents and inhibitors.

Aim 7: Databases, data loggers and other ICT applications can be used to research proposed mechanisms for lab work performed and to carry out virtual experiments to investigate factors which influence rate equations.

16.2 Activation Energy

Essential Idea: The activation energy of a reaction can be determined from the effect of temperature on a reaction rate. **Nature of science**: Theories can be supported or falsified and replaced by new theories—changing the temperature of a reaction has a much greater effect on the rate of reaction than can be explained by its effect on collision rates. This resulted in the development of the Arrhenius equation which proposes a quantitative model to explain the effect of temperature change on reaction rate.

	Assessment statement	Teacher's notes
16.2a	Describe the graphical representation of the Arrhenius equation in its linear form: $\ln k = -Ea/RT + \ln A.$	 The Arrhenius equation uses the temperature dependence of the rate constant to determine the activation energy. A graph of <i>1/T</i> against ln <i>k</i> is a linear plot with gradient - <i>E_a</i> / <i>R</i> and intercept, ln<i>A</i>. Consider various data sources in using the linear expression ln<i>k</i> = -<i>Ea/RT</i> + ln<i>A</i>. The expression ln<i>k</i>₁/<i>k</i>₂=<i>Ea/R</i>(1/<i>T</i>₂-1/<i>T</i>₁) is given in the data booklet.
16.2b	Explain the relationship between activation energy and rate constant using the Arrhenius equation $k=Ae^{-Ea/RT}$.	The frequency factor (or pre-exponential factor) (<i>A</i>) takes into account the frequency of collisions with proper orientations.
16.2c	Describe the relationships between temperature and rate constant; frequency factor and complexity of molecules colliding.	Use energy level diagrams to illustrate multi-step reactions showing the RDS (rate determining step) in the diagram.
16.2d	Calculate activation energies and frequency factors from reaction rate data.	

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• The flashing light of fireflies is produced by a chemical process involving enzymes.

• The relationship between the "lock and key" hypothesis of enzymes and the Arrhenius equation.

Aims 4 and 7: Use of simulations and virtual experiments to study effect of temperature and steric factors on rates of reaction.

Aim 6: Experiments could include those involving the collection of temperature readings to obtain sufficient data for a graph.

Aim 7: Graphing calculators can be employed to easily input and analyze data for E a and frequency factor values.

UNIT 9 EQUILIBRIUM

7.1 Equilibrium

Essential Idea: Many reactions are reversible. These reactions will reach a state of equilibrium when the rates of the forward and reverse reactions are equal. The position of equilibrium can be controlled by changing the conditions. **Nature of science:**

- Obtaining evidence for scientific theories—isotopic labelling and its use in defining equilibrium.
- Common language across different disciplines—the term dynamic equilibrium is used in other contexts, but not necessarily with the chemistry definition in mind.

	Assessment statement	Teacher's notes
7.1a	Describe the characteristics of chemical and physical systems in a state of equilibrium.	A state of equilibrium is reached in a closed system when the rates of the forward and reverse reactions are equal. Physical and chemical systems should be covered.
7.1b	Deduce of the equilibrium constant expression (K_c) from an equation for a homogeneous reaction.	 The equilibrium law describes how the equilibrium constant (<i>K_c</i>) can be determined for a particular chemical reaction. Relationship between <i>K_c</i> values for reactions that are multiples or inverses of one another should be covered. When <i>K_c</i> >> 1, the reaction goes almost to completion. When <i>K_c</i> << 1, the reaction hardly proceeds.
7.1c	Determine the relationship between different equilibrium constants (K_c) for the same reaction at the same temperature.	The magnitude of the equilibrium constant indicates the extent of a reaction at equilibrium and is temperature dependent.
7.1d	Application of Le Châtelier's principle to predict the qualitative effects of changes of temperature, pressure and concentration on the position of equilibrium and on the value of the equilibrium constant.	 The reaction quotient (Q) measures the relative amount of products and reactants present during a reaction at a particular point in time. Q is the equilibrium expression with non-equilibrium concentrations. The position of the equilibrium changes with changes in concentration, pressure, and temperature. A catalyst has no effect on the position of equilibrium or the equilibrium constant.

International-mindedness:

The Haber process has been described as the most important chemical reaction on Earth as it has revolutionized global food production. However, it also had a large impact on weaponry in both world wars.

Theory of knowledge:

Scientists investigate the world at different scales; the macroscopic and microscopic. Which ways of knowing allow us to move from the macroscopic to the microscopic?

Chemistry uses a specialized vocabulary: a closed system is one in which no matter is exchanged with the surroundings. Does our vocabulary simply communicate our knowledge; or does it shape what we can know?

The career of Fritz Haber coincided with the political upheavals of two world wars. He supervised the release of chlorine on the battlefield in World War I and worked on the production of explosives. How does the social context of scientific work affect the methods and findings of science? Should scientists be held morally responsible for the applications of their discoveries?

Utilization:

Square brackets are used in chemistry in a range of contexts: eg concentrations (topic 1.3), Lewis (electron dot) structures (topic 4.3) and complexes (topic 14.1).

Aim 6: Le Châtelier's principle can be investigated qualitatively by looking at pressure, concentration and temperature changes on different equilibrium systems.

Aim 7: Animations and simulations can be used to illustrate the concept of dynamic equilibrium.

Aim 8: Raise awareness of the moral, ethical, and economic implications of using science and technology. A case study of Fritz Haber can be used to debate the role of scientists in society.

17.1 The equilibrium law

Essential Idea: The position of equilibrium can be quantified by the equilibrium law. The equilibrium constant for a particular reaction only depends upon the temperature.

Nature of science: Employing quantitative reasoning—experimentally determined rate expressions for forward and backward reactions can be deduced directly from the stoichiometric equations and allow Le Châtelier's principle to be applied.

	Assessment statement	Teacher's notes
17.1a	Solve problems of homogeneous equilibrium using the expression for $K_{\rm c}$.	Le Châtelier's principle for changes in concentration can be explained by the equilibrium law.
17.1b	Describe the relationship between ΔG and the equilibrium constant.	The position of equilibrium corresponds to a maximum value of entropy and a minimum in the value of the Gibbs free energy.
17.1c	Solve problems relating Gibbs free energy and the equilibrium constant using the equation $\Delta G = -RT \ln K$.	The Gibbs free energy change of a reaction and the equilibrium constant can both be used to measure the position of an equilibrium reaction and are related by the equation, $\Delta G = -RT \ln K$.

Theory of knowledge:

• The equilibrium law can be deduced by assuming that the order of the forward and backward reaction matches the coefficients in the chemical equation. What is the role of deductive reasoning in science?

• We can use mathematics successfully to model equilibrium systems. Is this because we create mathematics to mirror reality or because the reality is intrinsically mathematical?

• Many problems in science can only be solved when assumptions are made which simplify the mathematics. What is the role of intuition in problem solving?

Utilization:

The concept of a closed system in dynamic equilibrium can be applied to a range of systems in the biological, environmental and human sciences.

Aim 6: The equilibrium constant for an esterification reaction and other reactions could be experimentally investigated.

Aim 7: The concept of a dynamic equilibrium can be illustrated with computer animation

UNIT 10 ACIDS & BASES

8.1Theories of acids and bases & 18.1 Lewis acids and bases

Essential Idea: Many reactions involve the transfer of a proton from an acid to a base

Essential Idea: The acid-base concept can be extended to reactions that do not involve proton transfer

Nature of science:

- Falsification of theories—HCN altering the theory that oxygen was the element which gave a compound its acidic properties allowed for other acid-base theories to develop.
- Theories being superseded—one early theory of acidity derived from the sensation of a sour taste, but this had been proven false.
- Public understanding of science—outside of the arena of chemistry, decisions are sometimes referred to as "acid test" or "litmus test".
- Theories can be supported, falsified or replaced by new theories—acid-base theories can be extended to a wider field of applications by considering lone pairs of electrons. Lewis theory doesn't falsify Brønsted–Lowry but extends it.

Assessment statement		Teacher's notes
8.1a	Deduction of the Brønsted–Lowry acid and base in a chemical reaction.	 A Brønsted–Lowry acid is a proton/H⁺ donor and a Brønsted–Lowry base is a proton/H⁺ acceptor. Amphiprotic species can act as both Brønsted–Lowry acids and bases. The difference between the terms amphoteric and amphiprotic should be covered. Students should know the representation of a proton in aqueous solution as both H⁺ (aq) and H₃O⁺ (aq).
8.1b	Deduction of the conjugate acid or conjugate base in a chemical reaction.	 A pair of species differing by a single proton is called a conjugate acid-base pair. The location of the proton transferred should be clearly indicated. For example, CH₃COOH/CH₃COO⁻ rather than C₂H₄O₂/C₂H₃O₂⁻.
18.1a	Describe Lewis' acid-base theory involving both inorganic and organic substances	 A Lewis acid is a lone pair acceptor and a Lewis base is a lone pair donor. When a Lewis base reacts with a Lewis acid a coordinate bond is formed. A nucleophile is a Lewis base and an electrophile is a Lewis acid. Both organic and inorganic examples should be studied. Relations between Brønsted–Lowry and Lewis acids and bases should be discussed.

- Acidus means sour in Latin, while *alkali* is derived from the Arabic word for calcined ashes. *Oxygene* means acid-forming in Greek, and reflects the mistaken belief that the element oxygen was responsible for a compound's acidic properties. Acid-base theory has been developed by scientists from around the world, and its vocabulary has been influenced by their languages.
- Acid-base theory has developed from the ideas of people from different parts of the world through both collaboration and competition.

Theory of knowledge:

- Acid and base behavior can be explained using different theories. How are the explanations in chemistry different from explanations in other subjects such as history?
- The same phenomenon can sometimes be explored from different perspectives, and explained by different theories. For example, do we judge competing theories by their universality, simplicity or elegance?

Utilization:

Syllabus and cross-curricular links:

Topic 3.2—the acid/base character of oxides

Topic 8.5—non-metal oxides are responsible for acid precipitation

Option B.2-amino acids acting as amphiprotic species

Option D.4-antacids are bases which neutralize excess hydrochloric acid in the stomach

Topics 4.2 and 4.3-covalent molecules and Lewis dot diagrams

Topic 13.2—transition metal complexes

Topic 20.1—nucleophiles

Aim 6: Transition metal complexes could be experimentally explored.

Aim 7: Animations can be used to distinguish between the different acid-base theories.

Aim 9: Each theory has its strengths and limitations. Lavoisier has been called the father of modern chemistry but he was mistaken about oxygen in this context.

8.2 Properties of acids and bases

Essential Idea: The characterization of an acid depends on empirical evidence such as the production of gases in reactions with metals, the color changes of indicators or the release of heat in reactions with metal oxides and hydroxides.

Nature of science:

Obtaining evidence for theories—observable properties of acids and bases have led to the modification of acid-base theories.

Assessment statement		Teacher's notes
8.2a	Write balanced chemical equations for reactions involving acids, including neutralization reactions with bases.	 Most acids have observable characteristic chemical reactions with reactive metals, metal oxides, metal hydroxides, hydrogen carbonates and carbonates. Salt and water are produced in exothermic neutralization reactions.
8.2b	Predict specific acids and bases needed to make different salts as the result of neutralization reactions.	Bases which are not hydroxides, such as ammonia, soluble carbonates and hydrogen carbonates should be covered.
8.2c	Experimentally find the concentration of an unknown acid/base through titration procedures using various indicators.	The color changes of different indicators are given in the data booklet in section 22

Utilization:

A number of acids and bases are used in our everyday life from rust removers to oven cleaners, from foods to toothpastes, from treatments for bee stings to treatment of wasp stings.

Aim 6: The evidence for these properties could be based on a student's experimental experiences.

8.3 The pH Scale -- 8.4 Strong and weak acids and bases -- 18.2 Calculations involving acids and bases

Essential Ideas:

- The pH scale is an artificial scale used to distinguish between acid, neutral and basic/alkaline solutions.
- The pH depends on the concentration of the solution. The strength of acids or bases depends on the extent to which they ionize/dissociate in aqueous solutions.
- The equilibrium law can be applied to acid-base reactions. Numerical problems can be simplified by making assumptions about the relative concentrations of the species involved. The use of logarithms is also significant here.

Nature of science:

- Occam's razor—the pH scale is an attempt to scale the relative acidity over a wide range of H⁺ concentrations into a very simple number.
- Improved instrumentation—the use of advanced analytical techniques has allowed the relative strength of different acids and bases to be quantified.
- Looking for trends and discrepancies—patterns and anomalies in relative strengths of acids and bases can be explained at the molecular level.

- The outcomes of experiments or models may be used as further evidence for a claim—data for a particular type of reaction supports the idea that weak acids exist in equilibrium.
- Obtaining evidence for scientific theories—application of the equilibrium law allows strengths of acids and bases to be determined and related to their molecular structure.

Asses	sment statement	Teacher's notes		
8.3a	Solve problems involving pH, [H ⁺] and [OH ⁻].	 pH=-log[H⁺(aq)] and [H⁺]=10^{-pH}. pOH = -log[OH⁻] and [OH⁻] = 10^{-pOH} A change of one pH unit represents a 10-fold change in the hydrogen ion concentration [<i>H</i>⁺]. pH values distinguish between acidic, neutral and alkaline solutions. The ionic product constant, <i>Kw</i>=[H⁺][OH⁻]=10⁻¹⁴ at 298 K Equations involving H₃O⁺ instead of H⁺ may be applied. 		
8.3b	Students should be familiar with the use of a pH meter and universal indicator.			
8.4a	Distinguish between strong and weak acids and bases in terms of the rates of their reactions with metals, metal oxides, metal hydroxides, metal hydrogen carbonates and metal carbonates and their electrical conductivities for solutions of equal concentrations.	 Strong and weak acids and bases differ in the extent of ionization. Strong acids and bases of equal concentrations have higher conductivities than weak acids and bases. A strong acid is a good proton donor and has a weak conjugate base. A strong base is a good proton acceptor and has a weak conjugate acid. The terms ionization and dissociation can be used interchangeably. See section 21 in the data booklet for a list of weak acids and bases. 		
18.2a	Solve problems for $[H^+ (aq)]$, $[OH^-(aq)]$, pH, and pOH, using the values associated with K_{a} , p K_{a} , K_{b} and p K_{b} .	The expression for the dissociation constant of a weak acid (K_a) and a weak base (K_b). For a conjugate acid base pair, $K_a \times K_b = K_w$. The value K_w depends on the temperature. Calculations of pH at temperatures other than 298 K can be assessed.		
18.2b	Discuss the relative strengths of acids and bases using values of K_{a} , pK_{a} , K_{b} and pK_{b} .	The relationship between K_a and pK_a is ($pK_a = -\log K_a$), and between K_b and pK_b is ($pK_b = -\log K_b$).		

Theory of knowledge:

• Chemistry makes use of the universal language of mathematics as a means of communication. Why is it important to have just one "scientific" language?

• The strength of an acid can be determined by the use of pH and conductivity probes. In what ways do technologies, which extend our senses, change or reinforce our view of the world?

International-mindedness: Mathematics is a universal language. The mathematical nature of this topic helps chemists speaking different native languages to communicate more objectively.

Aim 3: Students should be able to use and apply the pH concept in a range of experimental and theoretical contexts.

Aim 6: An acid–base titration could be monitored with an indicator or a pH probe.

Aim 6: Students should have experimental experience of working qualitatively with both strong and weak acids and bases. Examples to include: H₂SO₄ (aq), HCl (aq), HNO₃ (aq), NaOH (aq), NH₃ (aq).

Aim 7: Students could use data loggers to investigate the strength of acid and bases.

18.3 pH curves

Essential Idea: pH curves can be investigated experimentally but are mathematically determined by the dissociation constants of the acid and base. An indicator with an appropriate end point can be used to determine the equivalence point of the reaction. **Nature of science:**

Increased power of instrumentation and advances in available techniques—development in pH meter technology has allowed for more reliable and ready measurement of pH.

Assessment statement		Teacher's notes
18.3a	Describe the general shapes and essential components of graphs of pH against volume for titrations involving strong and weak acids and bases	 The characteristics of the pH curves produced by the different combinations of strong and weak acids and bases. The relationship between the pH range of an acid-base indicator, which is a weak acid, and its pK a value. Important features are: intercept with pH axis equivalence point buffer region

		• points where $pK_a = pH$ or $pK_b = pOH$.
18.3b	Select an appropriate indicator for a titration, given the equivalence point of the titration and the end point of the indicator.	 An acid-base indicator is a weak acid or a weak base where the components of the conjugate acid-base pair have different colors. The color change can be considered to take place over a range of pK a ± 1. For an indicator which is a weak acid: HIn_{(aq} ≓ H⁺_(aq) + In⁻_(aq) <i>Color A Color B</i> For an indicator which is a weak base: BOH_(aq) ≓ B⁺_(aq) + OH⁻_(aq) <i>Color A Color B</i>
18.3c	Describe how buffer solutions can be prepared by either mixing a weak acid/base with a solution of a salt containing its conjugate, or by partial neutralization of a weak acid/base with a strong acid/base.	 The buffer region on the pH curve represents the region where small additions of acid or base result in little or no change in pH. The composition and action of a buffer solution is dependent upon the identity of the weak acid/base and its concentration. The nature of the acid-base buffer always remains the same
18.3d	Predict the relative pH of aqueous salt solutions formed by the different combinations of strong and weak acids and bases.	 Salts formed from the four possible combinations of strong and weak acids and bases should be considered. The acidity of hydrated transition metal ions is covered also in topic 13.

Theory of knowledge: Is a pH curve an accurate description of reality or an artificial representation? Does science offer a representation of reality?

Syllabus and cross-curricular links:

Topic 5.1-thermometric/conductiometric titrations

Topic 16.2—What are the unusual mathematical features of a pH curve? Students should also be familiar with the use of natural logs when using the Arrhenius expression in topic 16.2

Aim 6: Experiments could include investigation of pH curves, determination of the p K_a of a weak acid, preparation and investigation of a buffer solution and the determination of the p K_a of an indicator.

Aim 7: Data logging, databases, spreadsheets and simulations can all be used. For example, the equivalence point could be determined by using a conductivity probe or a temperature probe.

8.5 Acid Deposition

Essential idea: Increased industrialization has led to greater production of nitrogen and sulfur oxides leading to acid rain, which damaging our environment. These problems can be reduced through collaboration with national and intergovernmental organizations. **Nature of science:** Risks and problems—oxides of metals and non-metals can be characterized by their acid—base properties. Acid deposition is a topic that can be discussed from different perspectives. Chemistry allows us to understand and to reduce the environmental impact of human activities.

	Assessment statement	Teacher's notes
8.5a	Write balanced chemical equations that describe the combustion of sulfur and nitrogen to their oxides and the subsequent formation of H ₂ SO ₃ , H ₂ SO ₄ , HNO ₂ and HNO ₃ .	Acid deposition is formed when nitrogen or sulfur oxides dissolve in water to form HNO ₃ , HNO ₂ , H ₂ SO ₄ and H ₂ SO ₃ . Sources of the oxides of sulfur and nitrogen and the effects of acid deposition should be covered. Rain is naturally acidic because of dissolved CO ₂ and has a pH of 5.6. Acid deposition has a pH below 5.6.
8.5b	Distinguish between the pre-combustion and post- combustion methods of reducing sulfur oxides emissions.	
8.5c	Write acid deposition equations for acid deposition with reactive metals and carbonates.	

International-mindedness: The polluter country and polluted country are often not the same. Acid deposition is a secondary pollutant that affects regions far from the primary source. Solving this problem requires international cooperation.

Theory of knowledge: All rain is acidic but not all rain is "acid rain". Scientific terms have a precise definition. Does scientific vocabulary simply communicate our knowledge in a neutral way or can it have value-laden terminology?

Aim 6: The effects of acid rain on different construction materials could be quantitatively investigated.

Aim 8: A discussion of the impact of acid rain in different countries will help raise awareness of the environmental impact of this secondary pollutant and the political implications.

Aim 8: Other means of reducing oxide production—bus use, car pooling, etc. could be discussed.

UNIT 10 ORGANIC CHEMISTRY

10.1 Fundamentals of organic chemistry

Essential Idea: Organic chemistry focuses on the chemistry of compounds containing carbon **Nature of science**:

- Serendipity and scientific discoveries—PTFE and superglue.
- Ethical implications-drugs, additives and pesticides can have harmful effects on both people and the environment.

Asses	sment statement	Teacher's notes	
10.1a	Distinguish between empirical, molecular and structural formulas.	 Structural formulas can be represented in full and condensed format. Skeletal formulas should be used to differentiate between hydrocarbon structures. Hydrocarbons consist of chains of carbons bonded to hydrogen atoms. 	
10.1b	Explain trends in boiling points of members of a homologous series.	A homologous series is a series of compounds of the same family, with the same general formula, which differ from each other by a common structural unit.	
10.1c	Describe the differences between constitutional (structural) isomers using structural formulas	Structural isomers are compounds with the same molecular formula but different arrangements of atoms.	
10.1d	Use IUPAC rules in the nomenclature of straight-chain and branched-chain isomers containing saturated and unsaturated structures.	 Saturated compounds (alkanes) contain single bonds only and unsaturated compounds (alkenes & alkynes) contain double or triple bonds. The following nomenclature should be covered: alkenes up to hexene and alkynes up to hexyne. 	
10.1e	Identify common functional groups in organic molecules by structure and name, e.g. phenyl, hydroxyl, carbonyl (aldehyde & ketone), carboxyl, carboxamide, ester, ether, amine, nitrile, alkyl, alkenyl and alkynyl.	Functional groups consist of a collection of specific atoms which when bonded to a hydrocarbon creates a defined set of properties, commonly considered the reactive parts of organic molecules	
10.1f	Differentiate between the classes or organic compounds based on hydrocarbon structure, bonding and functional groups: alkanes, alkenes, alkynes, halogenoalkanes, alcohols, ethers, aldehydes, ketones, esters, carboxylic acids, amines, amides, nitriles and arenes.	The general formulas (eg C_nH_{2n+2}) of alkanes, alkenes, alkynes, ketones, alcohols, aldehydes and carboxylic acids should be known. The distinction between class names and functional group names needs to be made, e.g. for OH, hydroxyl is the functional group whereas alcohol is the class name.	
10.1g	Construct 3-D models (real or virtual) of organic molecules.		
10.1h	Identify primary, secondary and tertiary carbon atoms in halogenoalkanes and alcohols and primary, secondary and tertiary nitrogen atoms in amines.		
10.1i	Apply IUPAC rules in the nomenclature of organic molecules containing hydroxyls, ethers, carbonyls (axial & terminal), halogens, esters, and carboxyl groups.	 The following nomenclature should be covered: compounds up to six carbon atoms (in the basic chain for nomenclature purposes) containing only one of the classes of functional groups: alcohols, ethers, aldehydes, halogenoalkanes, ketones, esters and carboxylic acids. non-cyclic alkanes and halogenoalkanes up to halohexanes. 	
10.1j	Discuss the structure of benzene using physical and chemical evidence.	Benzene is an aromatic, unsaturated hydrocarbon	
Intern	International-mindedness:		

- A small proportion of nations have control over the world's oil resources. The interdependence of the countries that are net importers and those that are net exporters is an important factor in shaping global policies and economic developments.
- The octane rating (octane number) can be described as a standard measure of the performance of the fuel used in cars and aircraft. Octane ratings often vary quite widely regionally throughout the globe, and are complicated by the fact that different countries use different means of expressing the values.

Theory of knowledge:

- The label "organic chemistry" originates from a misconception that a vital force was needed to explain the chemistry of life. Can you think of examples where vocabulary has developed from similar misunderstandings? Can and should language ever be controlled to eliminate such problems?
- Kekulé claimed that the inspiration for the cyclic structure of benzene came from a dream. What role do the less analytical ways of knowledge play in the acquisition of scientific knowledge?

Utilization:

Fractional distillation makes great use of many petrochemicals.

Dyes, pesticides, herbicides, explosives, soap, cosmetics, synthetic scents and flavorings.

Syllabus and cross-curricular links:

Topic 1.2—empirical and molecular formulas

Topics 4.2 and 4.3—Lewis (electron dot) structures, multiple bonds, VSEPR theory, resonance and bond and molecular polarity

Topic 4.4—intermolecular forces

Topic 5.3-exothermic reactions and bond enthalpies

Topic 8.4—weak acids

Options B.2 and B.7-proteins

Aim 6: Either use model kits or suitable computer-generated molecular graphics programs to construct three-dimensional models of a wide range of organic molecules.

Aim 6: Experiments could include distillation to separate liquids or the use of a rotary evaporator to remove a solvent from a mixture. Aim 8: There are consequences in using fossil fuels as our main source of energy. Many products can be obtained from fossil fuels due to the inherently rich chemistry of carbon. This raises some fundamental questions—are fossil fuels too valuable to burn and how do they affect the environment? Who should be responsible for making decisions in this regard?

Aim 8: Discuss the use of alcohols and biofuels as fuel alternatives to petrol (gasoline) and diesel.

10.2 Functional group chemistry & 20.3 Stereoisomerism

Essential Idea:

- Structure, bonding and chemical reactions involving functional group inter-conversions are key strands in organic chemistry.
- Stereoisomerism involves isomers which have different arrangements of atoms in space but do not differ in connectivity or bond multiplicity (i.e. whether single, double or triple) between the isomers themselves

Nature of science:

- Use of data—much of the progress that has been made to date in the developments and applications of scientific research can be mapped back to key organic chemical reactions involving functional group inter-conversions.
- Transdisciplinary—the three-dimensional shape of an organic molecule is the foundation pillar of its structure and often its properties. Much of the human body is chiral.

Assessment statement		Teacher's notes
10.2a	Write balanced chemical equations for the complete and incomplete combustion of hydrocarbons.	Alkanes have low reactivity and undergo free-radical substitution reactions.
10.2b	Describe the reactions of methane and ethane with halogens in terms of a free-radical substitution mechanism involving photochemical homolytic fission.	 Reference should be made to initiation, propagation and termination steps in free-radical substitution reactions. Free radicals should be represented by a single dot.
10.2c	Write balanced chemical equations for the electrophilic addition reactions of alkenes. These include hydrogenation, halogenation, hydrohalogenation and hydration.	Alkenes are more reactive than alkanes and undergo addition reactions. Bromine water can be used to distinguish between alkenes and alkanes.
10.2d	Outline of the addition polymerization of alkenes.	
10.2e	Describe the relationship between the structure of the monomer to the polymer and repeating unit.	Addition polymers consist of a wide range of monomers and form the basis of the plastics industry.
10.2f	Write balanced chemical equations for the complete combustion of alcohols.	
10.2g	Write balanced equations for the oxidation reactions of primary and secondary alcohols (using acidified potassium dichromate(VI) or potassium manganate(VII) as oxidizing agents).	
10.2h	Explain the processes of distillation and reflux in the isolation of the aldehyde and carboxylic acid products.	
10.2i	Write the equation for the condensation reaction of an alcohol with a carboxylic acid, in the presence of a catalyst (eg concentrated sulfuric acid) to form an ester.	Alcohols undergo nucleophilic substitution reactions with acids (also called esterification or condensation) and some undergo oxidation reactions

10.2j	Write the equation for the substitution reactions of halogenoalkanes with aqueous sodium hydroxide.	Halogenoalkanes are more reactive than alkanes. They can undergo (nucleophilic) substitution reactions. A nucleophile is an electron-rich species containing a lone pair that it donates to an electron-deficient carbon.
10.2k	Write equations for the electrophilic substitution reactions of aromatic (arene) molecules.	Benzene does not readily undergo addition reactions but does undergo electrophilic substitution reactions.
20.3a	Describe the structural differences between stereoisomers.	Stereoisomers are subdivided into two classes—conformational isomers, which interconvert by rotation about a σ bond and configurational isomers that interconvert only by breaking and reforming a bond.
20.3b	Construct 3-D models (real or virtual) of a wide range of stereoisomers.	Wedge-dash type representations involving tapered bonds should be used for representations of optical isomers.
20.3c	Predict structural formulas for different stereoisomers of non-cyclic alkenes and C3 and C4 cycloalkanes.	 <i>Cis</i>-trans isomers can occur in alkenes or cycloalkanes (or heteroanalogues) and differ in the positions of atoms (or groups) relative to a reference plane. According to IUPAC, E/Z isomers refer to alkenes of the form R1R2C=CR3R4 (R1 ≠ R2, R3 ≠ R4) where neither R1 nor R2 need be different from R3 or R4. The term geometric isomers as recommended by IUPAC is now obsolete and <i>cis</i>-trans isomers and E/Z isomers should be used instead. In the E/Z system, the group of highest Cahn–Ingold–Prelog priority attached to one of the terminal doubly bonded atoms of the alkene (ie R1 or R2) is compared with the group of highest precedence attached to the other (ie R3 or R4). The stereoisomer is Z if the groups lie on the same side of a reference plane passing through the double bond and perpendicular to the plane containing the bonds linking the groups to the double-bonded atoms; the other stereoisomer is designated as E.
20.3d	Explain how the existence of chirality in organic molecules leads to the formation of enantiomers	A chiral carbon is a carbon joined to four different atoms or groups.
20.3e	Compare the physical and chemical properties of enantiomers.	
20.3f	Explain how to distinguish between optical isomers using a polarimeter.	 An optically active compound can rotate the plane of polarized light as it passes through a solution of the compound. Optical isomers are enantiomers. Enantiomers are non-superimposeable mirror images of each other. Diastereomers are not mirror images of each other. A racemic mixture (or racemate) is a mixture of two enantiomers in equal amounts and is optically inactive.

• Methane is a greenhouse gas, and its release from ruminants in countries such as Brazil, Uruguay, Argentina and New Zealand contributes significantly to total greenhouse gas emissions. Landfills are also a source of methane, and technologies are developing in some countries to capture the gas as a source of energy for electricity and heat generation.

• Alcohol misuse is a growing problem in many countries and can have an impact on their economies and social structures.

• Have drugs and medicines in some countries been sold and administered as racemates instead of as the desired enantiomer with the associated therapeutic activity? Can you think of any drugs or medicines which may serve as good case studies for this?

Theory of knowledge:

- The existence of optical isomers provides indirect evidence for a tetrahedrally bonded carbon atom. Which ways of knowing allow us to connect indirect evidence to our theories?
- Stereoisomerism can be investigated by physical and computer models. What is the role of such models in other areas of knowledge?
- One of the challenges for the scientist and the artist is to represent the three-dimensional world in two dimensions. What are the similarities and differences in the two approaches? What is the role of the different ways of knowing in the two approaches?

Utilization:

- Alkane usage as fuels.
- The role of ethene in fruit ripening.
- Alcohols, usage as fuel additives.
- Alcohols, role in the breathalyzer.
- Esters, varied uses-perfumes, food flavorings, solvents, nitroglycerin, biofuels and painkillers.
- Many of the drugs derived from natural sources are chiral and include nicotine, dopamine, thyroxine and naproxen.
- The role of stereochemistry in vision science and food science.
- In many perfumes, stereochemistry often can be deemed more important than chemical composition.

Syllabus and cross-curricular links:

Topic 9.1—redox processes

Option B.3—lipids

Option B.4-carbohydrates

Option B.10-stereochemistry in biomolecules

Aim 6: Experiments could include distinguishing between alkanes and alkenes, preparing soap and the use of gravity filtration, filtration under vacuum (using a Buchner flask), purification including recrystallization, reflux and distillation, melting point determination and extraction. **Aim 8**: Discuss the significance of the hydrogenation of alkenes in the food production including *trans*-fats as by-products.

Aim 6: Experiments could include the synthesis and characterization of an enantiomer (eg (-) menthol) or the resolution of a racemic mixture.

20.1 Organic chemistry & 20.2 Synthetic routes

Essential Idea:

- Key organic reaction types include nucleophilic substitution, electrophilic addition, electrophilic substitution and redox reactions. Reaction mechanisms vary and help in the understanding the different types of reaction taking place.
- Organic synthesis is the systematic preparation of a compound from widely available starting materials or the synthesis of a compound via a synthetic route that often can involve a series of different steps.

Nature of science:

- Looking for trends and discrepancies—by understanding different types of organic reactions and their mechanisms, it is possible to synthesize new compounds with novel properties which can then be used in several applications. Organic reaction types fall into a number of different categories.
- Collaboration and ethical implications—scientists have collaborated to work on investigating the synthesis of new pathways and have considered the ethical and environmental implications of adopting green chemistry.
- Scientific method—in synthetic design, the thinking process of the organic chemist is one which invokes retro-synthesis and the ability to think in a reverse-like manner.

Assessment statement		Teacher's notes
20.1a	Outline of the mechanism of electrophilic addition reactions of alkenes with halogens/interhalogens and hydrogen halides.	 An electrophile is an electron-deficient species that can accept electron pairs from a nucleophile. Electrophiles are Lewis acids. Markovnikov's rule can be applied to predict the major product in electrophilic addition reactions of unsymmetrical alkenes with hydrogen halides and interhalogens. The formation of the major product can be explained in terms of the relative stability of possible carbocations in the reaction mechanism. The difference between curly arrows and fish-hooks in reaction mechanisms should be emphasized. Use of partial charges (δ+ and δ-) and wedge-dash three-dimensional representations (using tapered bonds as shown below) should be encouraged where appropriate in explaining reaction mechanisms. Typical conditions and reagents of all reactions should be known (eg catalysts, reducing agents, reflux etc.).
20.16	Outline the mechanism of the nucleophilic substitution reactions of halogenoalkanes with aqueous sodium hydroxide in terms of S_N1 and S_N2 mechanisms.	• S_N1 represents a nucleophilic unimolecular substitution reaction and S_N2 represents a nucleophilic bimolecular substitution reaction. S_N1 involves a carbocation intermediate. S_N2 involves a concerted reaction with a transition state.

		 For tertiary halogenoalkanes the predominant mechanism is S_N1 and for primary halogenoalkanes it is S_N2. Both mechanisms occur for secondary halogenoalkanes. The rate determining step (slow step) in an S_N1 reaction depends only on the concentration of the halogenoalkane, rate = <i>k</i>[halogenoalkane]. For S_N2, rate = <i>k</i>[halogenoalkane][nucleophile]. S_N2 is stereospecific with an inversion of configuration at the carbon. S_N2 reactions are best conducted using aprotic, non-polar solvents and S_N1 reactions. Reference should be made to heterolytic fission for S_N1 reactions. The difference between homolytic and heterolytic fission should be understood.
20.1c	Explain why hydroxide is a better nucleophile than water when outlining nucleophilic substitution reactions.	
20.1d	Explain of how the rate of a nucleophilic reaction depends on the identity of the halogen (i.e. the leaving group), whether the halogenoalkane is primary, secondary or tertiary and the choice of solvent.	
20.1e	Describe of the difference between protic and aprotic solvents.	
20.1f	Outline the mechanism of the nitration (electrophilic substitution) reaction of benzene (using a mixture of concentrated nitric acid and sulfuric acid).	Benzene is the simplest aromatic hydrocarbon compound (or arene) and has a delocalized structure of π bonds around its ring. Each carbon to carbon bond has a bond order of 1.5. Benzene is susceptible to attack by electrophiles.
20.1g	Outline the reduction reactions of carbonyl containing compounds: aldehydes and ketones to primary and secondary alcohols and carboxylic acids to aldehydes, using suitable reducing agents.	Carboxylic acids can be reduced to primary alcohols (via the aldehyde). Ketones can be reduced to secondary alcohols. Typical reducing agents are lithium aluminium hydride (used to reduce carboxylic acids) and sodium borohydride.
20.1h	Write the equation for the conversion of nitrobenzene to phenylamine via a two-stage reaction	
20.2a	Outline multi-step synthetic routes given starting reagents and the product(s).	 The synthesis of an organic compound stems from a readily available starting material via a series of discrete steps. Functional group interconversions are the basis of such synthetic routes. Retro-synthesis of organic compounds. Reaction types can cover any of the reactions covered in topic 10 and sub-topic 20.1

- What role does green and sustainable chemistry, in relation to organic chemistry, play in a global context?
- How important are natural products to developing countries? Explore some specific examples of natural products available in developing countries which are important to the developed world.

Theory of knowledge: A retro-synthetic approach is often used in the design of synthetic routes. What are the roles of imagination, intuition and reasoning in finding solutions to practical problems?

Utilization:

- Organic synthesis plays a vital role in drug design and drug uptake in medicine and biochemistry.
- Nutrition, food science and biotechnology also are underpinned by organic chemistry.
- Natural products are compounds isolated from natural sources and include taxol, mescaline and capsaicin.

Syllabus and cross-curricular links:

Topics 10.1 and 10.2-organic chemistry

Topic 14.1—covalent bonding

Topic 14.2-hybridization

Aim 6: Three-dimensional visualization of organic compounds using molecular models could be covered.

Aim 6: A range of experiments of organic synthetic reactions exploring various types of reactions and functional group interconversions could be done. Core techniques of organic chemistry could include reflux, distillation, filtration, purification (including chromatographic techniques), separations and extractions.

Aim 6: Synthesis (or reaction) in the laboratory of an example of a widely used drug or medicine (eg aspirin) or a household product (eg fading of tomato ketchup—electrophilic addition reaction of bromine).

Aim 6: Multiple stage organic synthetic route series of experiments (up to a maximum of four stages).

11.3 & 21.1 Spectroscopic identification of organic compounds

Essential Idea:

- Analytical techniques can be used to determine the structure of a compound, analyze the composition of a substance or determine the purity of a compound. Spectroscopic techniques are used in the structural identification of organic and inorganic compounds.
- Although spectroscopic characterization techniques form the backbone of structural identification of compounds, typically no one technique results in a full structural identification of a molecule.

Nature of science:

- Improvements in instrumentation—mass spectrometry, proton nuclear magnetic resonance and infrared spectroscopy have made identification and structural determination of compounds routine. (1.8)
- Models are developed to explain certain phenomena that may not be observable—for example, spectra are based on the bond vibration model • Improvements in modern instrumentation—advances in spectroscopic techniques (IR, ¹H NMR and MS) have resulted in detailed knowledge

of the structure of compounds.

	Assessment statement	Teacher's notes
11.3a	Determine the IHD from a molecular formula.	The degree of unsaturation or index of hydrogen deficiency (IHD) can be used to determine from a molecular formula the number of rings or multiple bonds in a molecule.
11.3b	Deduction of information about the structural features of a compound from percentage composition data, MS, ¹ H NMR or IR.	 Mass spectrometry (MS), proton nuclear magnetic resonance spectroscopy (¹H NMR) and infrared spectroscopy (IR) are techniques that can be used to help identify compounds and to determine their structure. The electromagnetic spectrum (EMS) is given in the data booklet in section 3. The regions employed for each technique should be understood. The data booklet contains characteristic ranges for IR absorptions (section 26), ¹H NMR data (section 27) and specific MS fragments (section 28). For ¹H NMR, only the ability to deduce the number of different hydrogen (proton) environments and the relative numbers of hydrogen atoms in each environment is required. Integration traces should be covered but splitting patterns are not required.
21.1a	Deduction of the structure of a compound given information from a range of analytical characterization techniques (X-ray crystallography, IR, ¹ H NMR and MS).	 Students should be able to interpret the following from ¹H NMR spectra: number of peaks, area under each peak, chemical shift and splitting patterns. Treatment of spin-spin coupling constants will not be assessed but students should be familiar with singlets, doublets, triplets and quartets. High resolution ¹H NMR should be covered. The precise details of single crystal X-ray crystallography need not be known in detail, but students should be aware of the existence of this structural technique in the wider context of structural identification of both inorganic and organic compounds. The operating principles are not required for any of these methods. Structural identification of compounds involves several different analytical techniques including IR, ¹H NMR and MS. In a high resolution ¹H NMR spectrum, single peaks present in low resolution can split into further clusters of peaks. The structural technique of single crystal X-ray crystallography can be used to identify the bond lengths and bond angles of crystalline compounds.
21.1b	Explanation of the use of tetramethylsilane (TMS) as the reference standard.	

International-mindedness:

- Monitoring and analysis of toxins and xenobiotics in the environment is a continuous endeavor that involves collaboration between scientists in different countries.
- The chemical community often shares chemical structural information on the international stage. The Cambridge Crystallographic Database, ChemSpider developed by the *Royal Society of Chemistry* and the *Protein Data Bank (RCSB PDB)* (at Brookhaven National Laboratory, USA) are examples which highlight the international nature of the scientific community.

Theory of knowledge:

- Electromagnetic waves can transmit information beyond that of our sense perceptions. What are the limitations of sense perception as a way of knowing?
- The intensity ratio of the lines in the high resolution NMR spectrum is given by the numbers in Pascal's triangle, a mathematical pattern known independently over a thousand years ago by a number of different cultures. Why is mathematics such an effective tool in science? Is mathematics the science of patterns?

Utilization:

- IR spectroscopy is used in heat sensors and remote sensing in physics.
- Protons in water molecules within human cells can be detected by magnetic resonance imaging (MRI), giving a three-dimensional view of organs in the human body.
- Protons in water molecules within human cells can be detected by magnetic resonance imaging (MRI), giving a three-dimensional view of organs in the human body. Why is MRI replacing computerized tomography (CT) scans for some applications but is used as a complementary technique for others?
- MS (and other techniques such as TLC, GC, GC-MS and HPLC) can be used in forensic investigations at crime scenes.
- Analytical techniques can be used to test for drug abuse by high-performance athletes.

Syllabus and cross-curricular links:

Topic 1.2—determination of the empirical formula from percentage composition data or from other experimental data and determination of the molecular formula from both the empirical formula and experimental data.

Topic 2.1—the nuclear atom

Topic 5.3—bond enthalpies

Topic 11.3—spectroscopic identification of compounds

Option B.2-chromatography and protein separation

Option B.9—chromatography and pigments

Aim 7: Spectral databases can be used here.

Aim 8: The effects of the various greenhouse gases depend on their abundance and their ability to absorb heat radiation

OPTION B: BIOCHEMISTRY

B.1 Introduction to biochemistry

Essential Idea: Metabolic reactions involve a complex interplay between may different components in highly controlled environments **Nature of science:** Use of data—biochemical systems have a large number of different reactions occurring in the same place at the same time. As technologies have developed, more data has been collected leading to the discovery of patterns of reactions in metabolism.

	Assessment statement	Teacher's notes
B.1a	Describe the role biochemistry plays in our understanding of metabolism in living systems.	 The diverse functions of biological molecules depend on their structures and shapes. Metabolic reactions take place in highly controlled aqueous environments. Reactions of breakdown are called catabolism and reactions of synthesis are called anabolism.
B.1b	Explain the difference between condensation and hydrolysis reactions.	Biopolymers form by condensation reactions and are broken down by hydrolysis reactions.
B.1c	Using the equations of photosynthesis and respiration, explain the potential balancing of oxygen and carbon dioxide in the atmosphere.	 Photosynthesis is the synthesis of energy-rich molecules from carbon dioxide and water using light energy. Respiration is a complex set of metabolic processes providing energy for cells.

International-mindedness: Metabolic reactions in the human body are dependent on the supply of nutrients through a regular balanced diet. Globally there are significant differences in the availability of nutritious food, which have major and diverse impacts on human health. **Utilization:** Biochemistry is fundamental to the study of many other subjects, including genetics, immunology, pharmacology, nutrition and agriculture.

Syllabus and cross-curricular links:

Topic 10.2—S_N reactions (condensation and hydrolysis)

Topic 13.2 and Option B.9-metal complexes and light absorption

B.2 Proteins & enzymes & B.7 Proteins & enzymes (Additional HL topic)

Essential idea:

• Proteins are the most diverse of the biopolymers responsible for metabolism and structural integrity of living organisms.

· Analyses of protein activity and concentration are key areas of biochemical research

- Nature of science:
- Collaboration and peer review—several different experiments on several continents led to the conclusion that DNA, and not protein as originally thought, carried the information for inheritance.
- Theories can be superseded—"lock and key" hypothesis to "induced fit" model for enzymes.
- Collaboration and ethical considerations—scientists collaborate to synthesize new enzymes and to control desired reactions (ie waste control).

	Assessment statement	Teacher's notes
B.2a	Describe the structure and properties of the 21 "common" amino acids.	Amino acids are amphoteric and can exist as zwitterions, cations and anions
B.2b	Differentiate the solubilities and melting points of amino	

	acids in terms of zwitterions.	
B.2c	Describe the relationships between charge, pH and isoelectric point for amino acids and proteins.	
B.2d	Outline the changes in structural of reactants and products in condensation reactions of amino acids, and hydrolysis reactions of peptides.	Proteins are polymers of 2-amino acids, joined by amide links (also known as peptide bonds).
B.2e	Describe of the four levels of protein structure, including the origin and types of bonds and interactions involved.	 Protein structures are diverse and are described at the primary, secondary, tertiary and quaternary levels A protein's three-dimensional shape determines its role in structural components or in metabolic processes. Reference should be made to alpha helix and beta pleated sheet, and to fibrous and globular proteins with examples of each. Include all bonds and interactions (both intramolecular and intermolecular) responsible for the protein structure.
B.2f	Analyze graphs of enzyme activity involving changes in substrate concentration, pH and temperature	 Most enzymes are proteins that act as catalysts by binding specifically to a substrate at the active site. As enzyme activity depends upon the conformation, it is sensitive to changes in temperature and pH and the presence of heavy metal ions.
B.2g	Explain the processes of paper chromatography and gel electrophoresis in amino acid and protein separation and identification.	Chromatography separation is based on different physical and chemical principles. In paper chromatography the use of R_f values and locating agents should be covered
B.7a	Determine the maximum rate of reaction (V_{max}) and the value of the Michaelis constant (K_m) for an enzyme by graphical means, and explain their significance.	Michealis-Menten kinetics describes the reaction rates of enzyme-catalyzed reactions relative to substrate concentrations [S]. Lineweaver-Burk graphs provide a linear relationship between the inverse of reaction rate (1/v) and the inverse of substrate (1/[S]).
B.7b	Compare competitive and non-competitive inhibition of enzymes with reference to protein structure, the active site and allosteric site.	 Inhibitors play an important role in regulating the activities of enzymes. The effects of competitive and non-competitive inhibitors on K_m and V_{max} values should be covered
B.7c	Explain the concept of product inhibition in metabolic pathways (feedback inhibition/control)	
B.7d	Calculate the pH of buffer solutions, such as those used in protein analysis and in reactions involving amino acids in solution.	Amino acids and proteins can act as buffers in solution. The Henderson–Hasselbalch equation is given in the data booklet in section 1 and is used to calculate pH values of buffered solutions.
B.7e	Determine the concentration of a protein in solution from a calibration curve using the Beer–Lambert law.	Protein assays commonly use UV-vis spectroscopy and a calibration curve based on known standards.
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• The Universal Protein Resource (UniProt) is a consortium of bioinformatics institutes. Its mission is to act as a resource for the scientific community by providing comprehensive, high-quality and freely accessible data on protein sequence and functional information.

• Technologies based on enzyme activity go back to ancient times in many parts of the world.

• Brewing and cheese-making are often associated with particular place names.

Theory of knowledge: The term "lock-and-key" is an effective metaphor but the "induced fit" model is a better model. How are metaphors and models used in the construction of knowledge?

Utilization:

- Many synthetic materials are polyamides. Examples include nylon and Kevlar®.
- Electrophoresis is used in some medical diagnostics to identify patterns of unusual protein content in blood serum or urine.
- The first protein to be sequenced was insulin by Frederick Sanger in 1951, in a process that took over ten years. Today, protein sequencing is a routine and very efficient process, and is a major part of the study known as proteomics.
- Enzymes are widely used in industrial and domestic applications. Examples include biological detergents, textiles, foods and beverages, and biodegradable plastics. Advances in protein engineering have led to the synthesis of enzymes that are effective in a wide range of conditions **Syllabus and cross-curricular links**:

Topics 8.3 and 18.2—pH and pK_a and pK_b values

Topic 20.3—stereoisomerism

Topic 6.1—chemical kinetics

Topics 8.1, 8.3 and 8.4—the pH scale and conjugate acids and bases

Topics 18.2 and 18.3-acid-base calculations and pH curves

Option B.9—chromatography

Aim 6: Experiments could involve hydrolysis of a protein, separation and identification of amino acid mixtures by paper chromatography, or gel electrophoresis of proteins and DNA.

Aim 7: Data logging experiments involving absorption/concentration studies for protein content using the Biuret reagent.

Aim 7: Simulations can be used for gel electrophoresis.

Aim 6: Experiments could include measuring enzyme activity with changing conditions of temperature, pH and heavy metal ion concentration. Aim 7: Data-logging experiments with temperature or pH probes to investigate enzyme activity under different conditions; or computer modelling of enzyme–substrate interactions.

Aim 8: Many enzyme technologies help mitigate damaging environmental effects of chemicals, such as from leather, paper and oil industries.

B.4 Carbohydrates

Essential Idea: Carbohydrates are oxygen-rich biomolecules which play a central role in the metabolic reactions of energy transfer **Nature of science**:

- Construct models/visualizations- understanding the stereochemistry of carbohydrates is essential to understanding their structural roles in cells.
- Haworth projections help focus on the nature and position of attached groups by making carbon and hydrogen implicit.
- Obtaining evidence for scientific theories—consider the structural role of carbohydrates.

	Assessment statement	Teacher's notes
B.4a	Describe the structural features of monosaccharides.	Carbohydrates have the general formula $C_x(H_2O)_y$. Monosaccharides contain either an aldehyde group (aldose) or a ketone group (ketose) and several –OH groups. Straight chain forms of sugars cyclize in solution to form ring structures containing an ether linkage. Haworth projections represent the cyclic structures of monosaccharides.
B.4b	Describe the structural formulas of disaccharides and polysaccharides from given monosaccharides.	Glycosidic bonds form between monosaccharides forming disaccharides and polysaccharides.
B.4c	Relate the properties and functions of monosaccharides and polysaccharides to their chemical structures.	Carbohydrates are used as energy sources and energy reserves.

International-mindedness:

- Sugar is a major international commodity and is produced in about 130 different countries. Approximately three-quarters of production comes from sugar cane in tropical and subtropical regions and the remainder comes from sugar beet which is cultivated in temperate climates.
- Diabetes is a chronic disease that occurs when the body cannot effectively regulate blood sugar, due to a failure in the production or functioning of insulin. The World Health Organization projects that deaths from diabetes will double between 2005 and 2030.
- Lactose intolerance is a condition in which the individual is not able to digest lactose, the sugar found in milk and dairy products. It is due to a failure to produce sufficient levels of lactase, the enzyme that hydrolyses lactose into glucose and galactose. Globally lactose intolerance is the norm. It is an example of a Western perspective invading science.

Theory of knowledge:

The use of aspartame as an artificial sweetener has been controversial for many years as the side effects are not fully investigated. Should scientists be held morally responsible for the adverse consequences of their work?

Utilization:

Carbohydrates are used in the pharmaceutical industry to bind preparations into tablets.

Ethanol is produced as a biofuel from the fermentation of carbohydrates in crops such as corn or sugar cane.

Syllabus and cross-curricular links:

Topics 10.1 and 10.2—organic functional groups

Topic 20.1—organic reactions

Topic 20.3—stereoisomerism

Aim 6: Experiments could include using Benedict's or Fehling's solution tests to distinguish between reducing sugars and non-reducing sugars or using iodine solution to test for the presence of starch.

Aim 8: The production of biofuels from crops raises many questions about related issues such as deforestation, soil erosion and sustainability. The "food vs fuel" debate refers to the controversies arising from developments that divert agricultural crops into biofuel production.

B.3 Lipids

Essential Idea: Lipids are a broad group of biomolecules that are largely non-polar and therefore insoluble in water **Nature of science**: Significance of science explanations to the public—long-term studies have led to knowledge of the negative effects of diets high in saturated fat, cholesterol, and *trans*-fat. This has led to new food products

	Assessment statement	Teacher's notes
B.3a	Summarize the chemical structures and properties of different lipid classes, including fatty acids, triacylglycerols (triglycerides), phospholipids, and	Fatty acids are long-chain carboxylic acids, some fatty acids are given in the data booklet in section 34. Fatty acids can be saturated, monounsaturated or polyunsaturated.

	steroids.	Lipids act as structural components of cell membranes, in energy storage, thermal and electrical insulation, as transporters of lipid soluble vitamins and as hormones.
B.3b	Compare carbohydrates and lipids as energy storage molecules with respect to their solubility and energy density.	Fats are more reduced than carbohydrates and so yield more energy when oxidized.
B.3c	Describe the structural formulas of reactants and products in condensation and hydrolysis reactions between glycerol and fatty acids and/or phosphate.	Triglycerides are produced by condensation of glycerol with three fatty acids and contain ester links. Phospholipids are derivatives of triglycerides. Hydrolysis of triglycerides and phospholipids can occur using enzymes or in alkaline or acidic conditions.
B.3d	Predict the relative melting points of fats and oils from their structures.	
B.3e	Compare the processes of hydrolytic and oxidative rancidity in fats with respect to the site of reactivity in the molecules and the conditions that favor the reaction.	
B.3f	Using the concept of iodine number, determine the unsaturation of a fat.	
B.3g	Describe the chemical structure of steroids	Steroids have a characteristic fused ring structure, known as a steroidal backbone.
B.3h	Discuss the impact of lipids on health, including the roles of dietary high-density lipoprotein (HDL) and low- density lipoprotein (LDL) cholesterol, saturated, unsaturated and <i>trans</i> -fat and the use and abuse of steroids.	 Important roles include: energy storage insulation and protection of organs steroid hormones structural component of cell membrane omega-3 poly-unsaturated fatty acids reduce the risk of heart disease poly-unsaturated fats may lower levels of LDL cholesterol. Negative effects include: increased risk of heart disease from elevated levels of LDL cholesterol and <i>trans</i> fatty acids; the major source of LDL cholesterol is saturated fats, in particular lauric (C₁₂), myristic (C₁₄) and palmitic (C₁₆) acids obesity.

International-mindedness: There are large global and cultural differences in the dietary sources of lipids and methods used to prevent rancidity. **Theory of knowledge:**

- Different countries have very different standards towards food labelling. Is access to information a human right? What knowledge should be universally available?
- What are the different responsibilities of government, industry, the medical profession and the individual in making healthy choices about diet? Public bodies can protect the individual but also limit their freedom. How do we know what is best for society and the individual?

Utilization:

Alkaline hydrolysis of fats is used in the process of soap-making, known as saponification.

Steroid abuse, especially in sports, and methods for detection.

Syllabus and cross-curricular links:

Topics 10.1 and 10.2—functional groups, hydrogenation of alkenes

Topic 10.2-free radical mechanisms

Topic 20.3—configurational isomerism

Aim 6: Experiments could include the calculation of the iodine number of fats to measure degree of unsaturation, calorimetric experiments on different fats and oils, or the separation of lipids from common food sources using different solvents and a separating funnel.

B.5 Vitamins

Essential idea: Vitamins are organic micronutrients with diverse functions that must be obtained from the diet. **Nature of science:** Making observations and evaluating claims—the discovery of vitamins (*vital amines*) is an example of scientists seeking a cause for specific observations. This resulted in the explanation of deficiency diseases (eg scurvy and beriberi).

	Assessment statement	Teacher's notes
B.5a	Describe the roles that vitamins perform in biochemical processes.	Vitamins are organic micronutrients which (mostly) cannot be synthesized by the body but must be obtained from suitable food sources.
B.5b	Compare of the structures and properties of different vitamins.	Specific attention is paid to vitamins A, C and D. The solubility (water or fat) of a vitamin can be predicted from its structure. Most vitamins are sensitive to heat.

B.5c	Discuss the causes and effects of vitamin deficiencies in different countries and suggestion of solutions	Vitamin deficiencies in the diet cause particular diseases and affect millions of people worldwide
	different countries and suggestion of solutions.	Micronutrient deficiencies include:
		• retinol (vitamin A)—xerophthalmia, night blindness
		 niacin (vitamin B₃)—pellagra
		• thiamin (vitamin B ₁)—beriberi
		• ascorbic acid (vitamin C)—scurvy
		• calciferol (vitamin D)—rickets.
		Macronutrient deficiencies include:
		 protein—marasmus and kwashiorkor.

- The food supplements industry, especially the sale of vitamin pills, has become very lucrative in many countries.
- Vitamin D deficiency is increasing, partly as a result of greater protection of the skin from sunlight.

Theory of knowledge:

- What are the ethical considerations in adding supplements to commonly consumed foods, such as fluoride to water or iodine to salt? Public bodies can protect the individual but also limit their freedom. How do we know what is best for society and the individual?
- Linus Pauling is the only man to win two individual Nobel Prizes. His claim that vitamin C supplements could prevent diseases such as the common cold led to their widespread use. What is the role of authority in communicating scientific knowledge to the public?

Syllabus and cross-curricular links:

Topics 4.1, 4.2 and 4.3—structure and physical properties

Topic 10.1—organic functional groups Topic 20.3—configurational isomerism

Aim 6: Experiments could include the DCPIP determination of vitamin C levels in foods.

B.6 Biochemistry and the environment

Essential idea: Our increasing knowledge of biochemistry has led to several environmental problems, while also helping to solve others. Nature of science: Risk assessment, collaboration, ethical considerations-it is the responsibility of scientists to consider the ways in which products of their research and findings negatively impact the environment, and to find ways to counter this. For example, the use of enzymes in biological detergents and to break up oil spills, and green chemistry in general.

	Assessment statement	Teacher's notes
B.6a	Discuss the increasing problem of xenobiotics such as antibiotics in sewage treatment plants.	Xenobiotics refer to chemicals that are found in an organism that are not normally present there.
B.6b	Describe the role of starch in biodegradable plastics.	Biodegradable/compostable plastics can be consumed or broken down by bacteria or other living organisms.
B.6c	Discuss the use of host–guest chemistry for the removal of a specific pollutant in the environment.	 Host-guest chemistry involves the creation of synthetic host molecules that mimic some of the actions performed by enzymes in cells, by selectively binding to specific guest species, such as toxic materials in the environment. Enzymes have been developed to help in the breakdown of oil spills and other industrial wastes. Enzymes in biological detergents can improve energy efficiency by enabling effective cleaning at lower temperatures. The emphasis in explanations of host-guest chemistry should be on non-covalent bonding within the supramolecule.
B.6d	Describe the process of biomagnification citing specific examples, including the chemical source of the substance. Examples could include heavy metals or pesticides.	Biomagnification is the increase in concentration of a substance in a food chain.
B.6e	Discuss the challenges and criteria in assessing the "greenness" of a substance used in biochemical research, including the atom economy.	Green chemistry, also called sustainable chemistry, is an approach to chemical research and engineering that seeks to minimize the production and release to the environment of hazardous substances.

International-mindedness:

• The term green chemistry was first coined in 1991, and acceptance of its philosophy has led to developments in education and legislation in many countries.

• Use of the pesticide DDT is banned in most countries due to its toxic effects and biomagnification. Its use continues, however, in countries where malaria remains a major public health challenge.

Utilization:

Syllabus and cross-curricular links:

Topic 4.4—intermolecular forces

Topic 10.1—natural and synthetic organic compounds

Aim 6: Experiments could include the comparison of the breakdown of biodegradable and non-biodegradable plastics in the environment. **Aim 6**: Risk assessment, including the risks to the environment, is an essential part of all experimental work.

Aim 8: The development of the science of green chemistry has raised awareness of the environmental and ethical implications of using science and technology.

B.8 Nucleic acids

Essential idea: DNA is the genetic material that expresses itself by controlling the synthesis of proteins by the cell. **Nature of science:**

- Scientific method—the discovery of the structure of DNA is a good example of different approaches to solving the same problem. Scientists used models and diffraction experiments to develop the structure of DNA.
- Developments in scientific research follow improvements in apparatus—double helix from X-ray diffraction provides explanation for known functions of DNA.

	Assessment statement	Teacher's notes	
B.8a	Describe the structure of nucleotides and their condensation polymers (nucleic acids or polynucleotides).	Nucleotides are the condensation products of a pentose sugar, phosphoric acid and a nitrogenous base—adenine (A), guanine (G), cytosine (C), thymine (T) or uracil (U). Polynucleotides form by condensation reactions. Nucleic acids are polymers made up of nucleotides. A nucleotide contains a phosphate group, a pentose sugar and an organic nitrogenous base. Students should recognize, but do not need to recall, the structures of the five bases: adenine (A), cytosine (C), guanine (G), thymine (T) and uracil (U). Nucleic acids are joined by covalent bonds between the phosphate of one nucleotide and the sugar of the next, resulting in a backbone with a repeating pattern of sugar–phosphate–sugar–phosphate. Nitrogenous bases are attached to	
		the sugar of the backbone.	
B.8b	Describe structure of DNA and stability in terms of the interactions between its hydrophilic and hydrophobic components.	DNA is a double helix of two polynucleotide strands held together by hydrogen bonds.	
		he structure has two nucleic acid strands that spiral around an axis. Students should describe the hydrogen bonding between specific pairs of nucleotide bases.	
B.8c	Distinguish between the structures of DNA and RNA.	RNA is usually a single polynucleotide chain that contains uracil in place of thymine, and a sugar ribose in place of deoxyribose.	
		RNA has ribose as its pentose sugar; DNA has deoxyribose. Deoxyribose lacks an oxygen atom on C2. RNA has uracil instead of thymine as its base. RNA is a single-strand nucleic acid; DNA is a double-strand nucleic acid.	
B.8d	Explain the origin of the negative charge on DNA and its association with basic proteins (histones) in chromosomes.		
B.8e	Explain how the complementary pairing between bases enables DNA to replicate itself exactly.		
B.8f	Predict the nucleotide sequence in a complementary strand of DNA or a molecule of RNA from a given polynucleotide DNA sequence.		
B.8g	Describe how the sequence of DNA within a gene codes for a specific sequence of amino acids in a protein.	The sequence of bases in DNA determines the primary structure of proteins synthesized by the cell using a triplet code, known as the genetic code, which is universal.	
B.8h	Discuss the benefits and concerns of using genetically modified foods.	Genetically modified organisms have genetic material that has been altered by genetic engineering techniques, involving transferring DNA between species.	
Inter	ternational-mindedness:		

• The Human Genome Project was an international research program whose goal was to complete the mapping and sequencing of all the genes in

- The policies on the labelling of genetically modified (GM) foods vary greatly in different countries.
- Most of the genetically modified organisms are protected by international patents. What effect does this have on the global economy and scientific community?

Theory of knowledge:

- DNA stores information but not knowledge.
- What are the differences between information and knowledge?
- The Nobel Prize in Physiology or Medicine 1962 was awarded jointly to Crick, Watson and Wilkins "for their discoveries concerning the molecular structure of nucleic acids and its significance for information transfer in living material". What is the role of collaboration in advancing knowledge?
- The existence of DNA databases opens up questions of individual privacy and the extent to which government has the right of access to personal information. Who has the right to access knowledge of an individual's DNA?

Utilization:

- Knowledge of DNA sequencing has transformed several aspects of legal enquiry, including forensics and paternity cases. It is also widely used in studies of ancestry and human migration.
- DNA sequencing is an important aspect of the study of biochemical evolution.

Syllabus and cross-curricular links:

- Topic 4.4—hydrogen bonding, intermolecular interactions
- Topic 8.1-acid-base interactions

Aim 5: The story of the rivalry between the different teams involved in the elucidation of DNA structure in the 1950s is an example of a failure of effective collaboration and communication during scientific activities.

Aim 6: Experiments could include DNA extraction from cells and investigation of its physical properties, and model building exercises of DNA structure, including the specific base pairings between a purine and a pyrimidine.

Aim 7: Databases exist of genetic sequences from different organisms.

Aim 8: Many ethical questions are raised by our knowledge of the human genome, including cloning, genetic engineering, gene therapy, and so on.

B.9 Biological pigments

Essential idea: Biological pigments include a variety of chemical structures with diverse functions which absorb specific wavelengths of light. **Nature of science:** Use of data—quantitative measurements of absorbance are a reliable means of communicating data based on color, which was previously subjective and difficult to replicate.

	Assessment statement	Teacher's notes
B.9a	Explain the chemical nature of biological pigments	 Biological pigments are colored compounds produced by metabolism. The color of pigments is due to highly conjugated systems with delocalized electrons, which have intense absorption bands in the visible region. The structures of chlorophyll, heme B and specific examples of anthocyanins and carotenoids are given in the data booklet in section 35; details of other pigment names and structures are not required. Knowledge of specific color changes with changing conditions is not required.
B.9b	Describe how the sigmoidal shape of hemoglobin's oxygen dissociation curve in based on the cooperative binding of hemoglobin to oxygen.	 Porphyrin compounds, such as hemoglobin, myoglobin, chlorophyll and many cytochromes are chelates of metals with large nitrogen-containing macrocyclic ligands. Hemoglobin and myoglobin contain heme groups with the porphyrin group bound to an iron(II) ion. Cytochromes contain heme groups in which the iron ion interconverts between iron(II) and iron(III) during redox reactions. Explanation of cooperative binding in hemoglobin should be limited to conformational changes occurring in one polypeptide when it becomes oxygenated.
B.9c	Discuss the factors that influence oxygen saturation of hemoglobin, including temperature, pH and carbon dioxide.	
B.9d	Explain why there is greater affinity for oxygen by fetal hemoglobin as compared to maternal (parental) hemoglobin.	
B.9e	Explain the binding action of carbon monoxide as a competitive inhibitor of oxygen binding for hemoglobin.	
B.9f	Outline the factors that affect the stabilities of anthocyanins, carotenoids and chlorophyll in relation to their structures.	Carotenoids are lipid-soluble pigments, and are involved in harvesting light in photosynthesis. They are susceptible to oxidation, catalyzed by light.

B.9g	Explain the ability of anthocyanins to act as indicators based on their sensitivity to pH.	Anthocyanins are aromatic, water-soluble pigments widely distributed in plants. Their specific colour depends on metal ions and pH.
B.9h	Describe the function of photosynthetic pigments in trapping light energy during photosynthesis.	
B.9i	Investigate biological pigments through paper and thin layer chromatography.	

International-mindedness: Artificial colors are commonly added during the commercial preparation and processing of food. The list of approved food colours varies greatly by country, which raises questions for international trade.

Theory of knowledge: Experiments show that our appreciation of food is based on an interaction between our senses. How do the different senses interact in giving us empirical knowledge about the world?

Utilization:

- Different tones of skin, eye and hair colour are the result of differences in the concentration of the pigment melanin.
- People whose ancestors have lived at high altitude for many generations have developed hemoglobin with a higher affinity for oxygen.
- The purplish-red colour of meat is largely due to the presence of myoglobin. The change in colour to brown on cooking occurs as the iron ion becomes oxidized to Fe³⁺.
- Anthocyanins and carotenoids provide visible signals for plants to attract insects and birds for pollination and seed dispersal. They also
 protect plants from damage caused by UV light.

Aim 6: Experiments could include the extraction and isolation of pigments from plant sources using solvents and separating funnel or the use of anthocyanins as pH indicators.

Aim 7: Use of data loggers for collecting absorption data.

B.10 Stereochemistry in biomolecules

Essential Idea: Most biochemical processes are stereospecific and involve only molecules with certain configuration of chiral carbon atoms. **Nature of science:** Theories used to explain natural phenomena/evaluate claims—biochemistry involves many chiral molecules with biological activity specific to one enantiomer. Chemical reactions in a chiral environment act as a guiding distinction between living and non-living matter.

	Assessment statement	Teacher's notes			
B.10a	Explain how biomolecules form stereoisomers based on the geometric differences about chiral carbons	 With one exception, amino acids are chiral, and only the L-configuration is found in proteins. D and L stereoisomers of sugars refer to the configuration of the chiral carbon atom furthest from the aldehyde or ketone group, and D forms occur most frequently in nature. Ring forms of sugars have isomers, known as α and β, depending on whether the position of the hydroxyl group at carbon 1 (glucose) or carbon 2 (fructose) lies below the plane of the ring (α) or above the plane of the ring (β). 			
B.10b	Description of the hydrogenation and partial hydrogenation of unsaturated fats, including the production of <i>trans</i> -fats, and a discussion of the advantages and disadvantages of these processes.	Naturally occurring unsaturated fat is mostly in the <i>cis</i> form, but food processing can convert it into the <i>trans</i> form. Relative melting points of saturated and <i>cis</i> -/ <i>trans</i> -unsaturated fats should be covered.			
B.10c	Explanation of the structure and properties of cellulose, and comparison with starch.				
B.10d	Discussion of the importance of cellulose as a structural material and in the diet.				
B.10e	Outline of the role of vitamin A in vision, including the roles of opsin, rhodopsin and <i>cis-</i> and <i>trans-</i> retinal.	Vision chemistry involves the light activated interconversion of <i>cis</i> - and <i>trans</i> -isomers of retinal.			
Interi	International-mindedness: Different countries have very different standards of food labelling with respect to its chemical content, including the				

type of fats present.

Aim 8: Ethical questions arise through the use of saturated and trans-fats, particularly in the fast-food industry.