Chemistry 2025 v1.0

General senior syllabus

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QCAA
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For all Queensland schools

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Queensland syllabuses for senior subjects

In Queensland, a syllabus for a senior subject is an official ‘map’ of a senior school subject. A syllabus’s function is to support schools in delivering the Queensland Certificate of Education (QCE) system through high-quality and high-equity curriculum and assessment.

Syllabuses are based on design principles developed from independent international research about how excellence and equity are promoted in the documents teachers use to develop and enliven the curriculum.

Syllabuses for senior subjects build on student learning in the Prep to Year 10 Australian Curriculum and include General, General (Extension), Senior External Examination (SEE), Applied, Applied (Essential) and Short Course syllabuses.

More information about syllabuses for senior subjects is available at www.qcaa.qld.edu.au/senior/senior-subjects and in the ‘Queensland curriculum’ section of the *QCE and QCIA policy and procedures handbook*.

Teaching, learning and assessment resources will support the implementation of a syllabus for a senior subject. More information about professional resources for senior syllabuses is available on the QCAA website and via the QCAA Portal.

Course overview

Rationale

At the core of all scientific endeavour is the inquiry into the nature of the universe. Science uses a systematic way of thinking, involving creative and critical reasoning, in order to acquire better and more reliable knowledge. Scientists recognise that knowledge is not fixed, but is fallible and open to challenge. As such, scientific endeavour is never conducted in isolation, but builds on and challenges an existing body of knowledge in the pursuit of more reliable knowledge. This collaborative process, whereby new knowledge is gained, is essential to the cooperative advancement of science, technology, health and society in the 21st century.

Tertiary study in any field will be aided by the transferable skills developed in this senior Science subject. It is expected that an appreciation of, and respect for, evidence-based conclusions and the processes required to gather, scrutinise and use evidence will be carried forward into all aspects of life beyond the classroom.

The purpose of senior Science subjects in Queensland is to introduce students to a scientific discipline. Students will be required to learn and apply aspects of the knowledge and skills of the discipline (thinking, experimentation, problem-solving and research skills), understand how it works and how it may impact society.

Upon completion of the course, students will have an appreciation for a body of scientific knowledge and the process that is undertaken to acquire this knowledge. They will be able to distinguish between claims and evidence, opinion and fact, and conjecture and conclusions.

In each of the senior Science subjects, students will develop:

- a deep understanding of a core body of discipline knowledge
- aspects of the skills used by scientists to develop new knowledge, as well as the opportunity to refine these skills through practical activities
- the ability to coordinate their understandings of the knowledge and skills associated with the discipline to refine experiments, verify known scientific relationships, explain phenomena with justification and evaluate claims by finding evidence to support or refute the claims.

Chemistry is the study of materials and their properties and structure. In Unit 1, students study atomic theory, chemical bonding, and the structure and properties of elements and compounds. In Unit 2, students explore intermolecular forces, gases, aqueous solutions, acidity and rates of reaction. In Unit 3, students study equilibrium processes and redox reactions. In Unit 4, students explore organic chemistry, synthesis and design to examine the characteristic chemical properties and chemical reactions displayed by different classes of organic compounds.

Chemistry aims to develop students':

- interest in and appreciation of chemistry and its usefulness in helping to explain phenomena and solve problems encountered in their ever-changing world
- understanding of the theories and models used to describe, explain and make predictions about chemical systems, structures and properties
- understanding of the factors that affect chemical systems and how chemical systems can be controlled to produce desired products
- appreciation of chemistry as an experimental science that has developed through independent and collaborative research, and that has significant impacts on society and implications for decision-making
- expertise in conducting a range of scientific investigations, including the collection and analysis of qualitative and quantitative data, and the interpretation of evidence
- ability to critically evaluate and debate scientific arguments and claims in order to solve problems and generate informed, responsible and ethical conclusions
- ability to communicate chemical understanding and findings to a range of audiences, including through the use of appropriate representations, language and nomenclature.

Syllabus objectives

The syllabus objectives outline what students have the opportunity to learn.

1. **Describe ideas and findings.**

   Students use scientific representations and language in appropriate genres to give a detailed account of scientific phenomena, concepts, theories, models and systems.

2. **Apply understanding.**

   Students use scientific concepts, theories, models and systems within their limitations. They use algebraic, visual and graphical representations of scientific relationships and data to determine unknown scientific quantities or features. They explain phenomena, concepts, theories, models, systems and modifications to methodologies.

3. **Analyse data.**

   Students consider scientific information from primary and secondary sources to identify trends, patterns, relationships, limitations and uncertainty. In qualitative data, they identify the essential elements, features or components. In quantitative data, they use mathematical processes and algorithms. They identify data to support ideas, conclusions or decisions.

4. **Interpret evidence.**

   Students use their understanding of scientific concepts, theories, models and systems and their limitations to draw conclusions and develop scientific arguments. They compare, deduce, extrapolate, infer, justify and make predictions based on their analysis of data.

5. **Evaluate conclusions, claims and processes.**

   Students critically reflect on the available evidence and make judgments about its application to research questions. They extrapolate findings to support or refute claims. They use the quality of the evidence to evaluate the validity and reliability of inquiry processes and suggest improvements and extensions for further investigation.

6. **Investigate phenomena.**

   Students develop rationales and research questions for experiments and investigations. They modify methodologies to collect primary data and select secondary sources. They manage risks, environmental and ethical issues and acknowledge sources of information.

Designing a course of study in Chemistry

Syllabuses are designed for teachers to make professional decisions to tailor curriculum and assessment design and delivery to suit their school context and the goals, aspirations and abilities of their students within the parameters of Queensland's senior phase of learning.

The syllabus is used by teachers to develop curriculum for their school context. The term *course of study* describes the unique curriculum and assessment that students engage with in each school context. A course of study is the product of a series of decisions made by a school to select, organise and contextualise subject matter, integrate complementary and important learning, and create assessment tasks in accordance with syllabus specifications.

It is encouraged that, where possible, a course of study is designed such that teaching, learning and assessment activities are integrated and enlivened in an authentic setting.

Course structure

Chemistry is a General senior syllabus. It contains four QCAA-developed units from which schools develop their course of study.

Each unit has been developed with a notional time of 55 hours of teaching and learning, including assessment.

Students should complete Unit 1 and Unit 2 before beginning Units 3 and 4. Units 3 and 4 are studied as a pair.

More information about the requirements for administering senior syllabuses is available in the 'Queensland curriculum' section of the *QCE and QCIA policy and procedures handbook*.

Curriculum

Senior syllabuses set out only what is essential while being flexible so teachers can make curriculum decisions to suit their students, school context, resources and expertise.

Within the requirements set out in this syllabus and the *QCE and QCIA policy and procedures handbook*, schools have autonomy to decide:

- how and when subject matter is delivered
- how, when and why learning experiences are developed, and the context in which learning occurs
- how opportunities are provided in the course of study for explicit and integrated teaching and learning of complementary skills.

These decisions allow teachers to develop a course of study that is rich, engaging and relevant for their students.

Assessment

Senior syllabuses set out only what is essential while being flexible so teachers can make assessment decisions to suit their students, school context, resources and expertise.

General senior syllabuses contain assessment specifications and conditions for the assessment instruments that must be implemented with Units 3 and 4. These specifications and conditions ensure comparability, equity and validity in assessment.

Within the requirements set out in this syllabus and the *QCE and QCIA policy and procedures handbook*, schools have autonomy to decide:

- specific assessment task details
- assessment contexts to suit available resources
- how the assessment task will be integrated with teaching and learning activities
- how authentic the task will be.

In Unit 1 and Unit 2, schools:

- develop at least two but no more than four assessments
- complete at least one assessment for each unit
- ensure that each unit objective is assessed at least once.

In Units 3 and 4, schools develop three assessments using the assessment specifications and conditions provided in the syllabus.

More information about assessment in senior syllabuses is available in 'The assessment system' section of the *QCE and QCIA policy and procedures handbook*.

Subject matter

Each unit contains a unit description, unit objectives and subject matter. Subject matter is the body of information, mental procedures and psychomotor procedures (see Marzano & Kendall 2007, 2008) that are necessary for students' learning and engagement with the subject. Subject matter itself is not the specification of learning experiences but provides the basis for the design of student learning experiences.

Subject matter has a direct relationship with the unit objectives and provides statements of learning that have been constructed in a similar way to objectives.

Aboriginal perspectives and Torres Strait Islander perspectives

The QCAA is committed to reconciliation. As part of its commitment, the QCAA affirms that:

- Aboriginal peoples and Torres Strait Islander peoples are the first Australians, and have the oldest living cultures in human history
- Aboriginal peoples and Torres Strait Islander peoples have strong cultural traditions and speak diverse languages and dialects, other than Standard Australian English
- teaching and learning in Queensland schools should provide opportunities for students to deepen their knowledge of Australia by engaging with the perspectives of Aboriginal peoples and Torres Strait Islander peoples
- positive outcomes for Aboriginal students and Torres Strait Islander students are supported by successfully embedding Aboriginal perspectives and Torres Strait Islander perspectives across planning, teaching and assessing student achievement.

Guidelines about Aboriginal perspectives and Torres Strait Islander perspectives and resources for teaching are available at www.qcaa.qld.edu.au/k-12-policies/aboriginal-torres-strait-islander-perspectives.

Where appropriate, Aboriginal perspectives and Torres Strait Islander perspectives have been embedded in the subject matter.

Complementary skills

Opportunities for the development of complementary skills have been embedded throughout subject matter. These skills, which overlap and interact with syllabus subject matter, are derived from current education, industry and community expectations and encompass the knowledge, skills, capabilities, behaviours and dispositions that will help students live and work successfully in the 21st century.

These complementary skills are:

- literacy — the knowledge, skills, behaviours and dispositions about language and texts essential for understanding and conveying English language content
- numeracy — the knowledge, skills, behaviours and dispositions that students need to use mathematics in a wide range of situations, to recognise and understand the role of mathematics in the world, and to develop the dispositions and capacities to use mathematical knowledge and skills purposefully
- 21st century skills — the attributes and skills students need to prepare them for higher education, work, and engagement in a complex and rapidly changing world. These skills include critical thinking, creative thinking, communication, collaboration and teamwork, personal and social skills, and digital literacy. The explanations of associated skills are available at www.qcaa.qld.edu.au/senior/senior-subjects/general-subjects/21st-century-skills.

It is expected that aspects of literacy, numeracy and 21st century skills will be developed by engaging in the learning outlined in this syllabus. Teachers may choose to create additional explicit and intentional opportunities for the development of these skills as they design the course of study.

Additional subject-specific information

Additional subject-specific information has been included to support and inform the development of a course of study.

Science understanding

The science understanding subject matter in each unit develops students' understanding of the key concepts, models and theories that underpin the subject, and of the strengths and limitations of different models and theories for explaining and predicting complex phenomena. It uses cognitions from Objectives 1–4.

The science understanding subject matter from Units 3 and 4 will be assessed by the external assessment.

Science as a human endeavour (SHE)

Each Queensland senior science subject requires students to learn and apply aspects of the knowledge and skill of the discipline. However, it is recognised that students should also develop an appreciation for the *nature* and *development* of science, and its *use* and *influence* on society.

While this appreciation is not directly assessed, the syllabus provides guidance as to where it may be developed. Importantly, this guidance draws students' attention to the way in which science operates, both in relation to the development of understanding and explanations about the world and to its influence on society.

Students should become familiar with the following SHE concepts:

- Science is a global enterprise that relies on clear communication, international conventions, peer review and reproducibility.
- Development of complex models and/or theories often requires a wide range of evidence from multiple individuals and across disciplines.
- Advances in science understanding in one field can influence other areas of science, technology and engineering.
- The use and acceptance of scientific knowledge is influenced by social, economic, cultural and ethical contexts.
- The use of scientific knowledge may have beneficial and/or harmful and/or unintended consequences.
- Scientific knowledge can enable scientists to offer valid explanations and make reliable predictions.
- Scientific knowledge can be used to develop and evaluate projected economic, social and environmental impacts and to design action for sustainability.
- ICT and other technologies have dramatically increased the size, accuracy and geographic and temporal scope of datasets with which scientists work.
- Models and theories are contested and refined or replaced when new evidence challenges them, or when a new model or theory has greater explanatory power.
- Scientific knowledge can be used to inform the monitoring, assessment and evaluation of risk.
- Science can be limited in its ability to provide definitive answers to public debate; there may be insufficient reliable data available, or interpretation of the data may be open to question.
- International collaboration is often required when investing in large-scale science projects or addressing issues for the Asia–Pacific region.

To support the development of these concepts, this syllabus identifies SHE subject matter in each unit. This highlights opportunities for teachers to contextualise the associated science understanding and science inquiry subject matter and provides stimulus for the development of claims and research questions for investigation.

Additional opportunities include:

- practicals provide opportunities for students to witness the *nature* of science
- the student experiment provides opportunity for students to experience how the *development* of new science knowledge is built upon existing knowledge
- the research investigation provides opportunity for students to appreciate the *use* and *influence* of scientific evidence to make decisions or to contribute to public debate about a claim.

Science inquiry

Defining *inquiry* in science education

In order to support the school's task of aligning their chosen pedagogical framework with the curriculum and assessment expectations outlined in this syllabus, some guidance has been provided in the form of clarification of the use of the term *inquiry* and the articulation of a framework to describe the process of inquiry. The purpose of this guidance is to prevent misunderstandings and problematic conflations and their subsequent negative impact on student learning. As Abrams, Southerland and Silva (2008, p. xv) stated in their book, *Inquiry in the Classroom: Realities and opportunities*:

> Inquiry in the classroom can be conceived as a complex set of ideas, beliefs, skills, and/or pedagogies. It is evident that attempting to select a singular definition of inquiry may be an insurmountable and fruitless task. Any single definition of inquiry in the classroom would necessarily reflect the thinking of a particular school of thought, at a particular moment in time, or a particular goal, and such a singular definition may serve to limit legitimate and necessary components of science learning. **However, operating without a firm understanding of the various forms of inquiry leaves science educators often 'talking past' one another, and often results in very muddled attempts in the classroom** [emphasis added].

Uses of the term *inquiry*

Common phrases involving the term *inquiry* have been listed below:

- science inquiry
- science inquiry skills
- the inquiry process
- inquiry-based learning.

This syllabus refers to the first three uses listed above. The first, *science inquiry*, defines the practical work of a scientist (Harlen 2013). The second, *science inquiry skills*, refers to the skills required to do the work of a scientist (Harlen 2013). The third, *the inquiry process*, is a framework that can be used to describe the process of asking a question and then answering it.

The final phrase, *inquiry-based learning*, refers to a variety of teaching and learning strategies an educator may choose to use within their school's pedagogical framework. Although a school may choose to adopt an inquiry-based pedagogy, this syllabus is *not* intended to endorse or recommend an inquiry-based learning approach.

Framework to describe the inquiry process

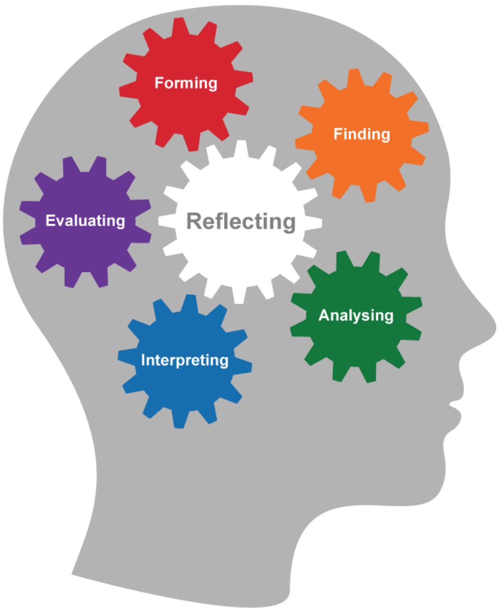
In order to support student engagement in activities involving inquiry, it is useful to establish a common language or framework to distinguish between stages of the process.

The stages involved in any inquiry are:

- forming and describing the inquiry activity
- finding valid and reliable evidence for the inquiry activity
- analysing the evidence collected
- interpreting the evidence selected
- evaluating the conclusions, processes or claims.

This framework uses reflection as the connection between, and driver of, all the stages. The progression through the inquiry process requires reflection on the decisions made and any new information that has emerged during the process to inform the next stage. Each stage of the inquiry process is worthy of reflection, the result of which may be the revision of previous stages (Marzano & Kendall 2007).

Figure 1: Stages of inquiry process



Science inquiry and science inquiry skills

Science inquiry involves identifying and posing questions and working to answer them. It is concerned with evaluating claims, investigating ideas, solving problems, reasoning, drawing valid conclusions and developing evidence-based arguments. It can easily be summarised as the 'work of a scientist' (Hackling 2005).

Within this syllabus, it is expected that students will engage in *aspects* of the work of a scientist by engaging in scientific inquiry (Tytler 2007). This expectation can be seen, for example, by the inclusion of practicals and investigations in the subject matter, and in the internal assessments for Units 3 and 4.

Science inquiry skills are the skills required to do the work of a scientist. They include writing research questions, planning, conducting, recording information, and reflecting on investigations; processing, analysing and interpreting evidence; evaluating conclusions, processes and claims; and communicating findings (ACARA 2015).

It is expected that students are explicitly taught science inquiry skills (Krajcik et al 2000), a number of which are outlined throughout the syllabus. Some science inquiry skills will be used to complete the listed practicals and investigations. The selection, application and coordination of science inquiry skills will be required in the student experiment and research investigation.

It is the prerogative of the educator to determine how listed practicals and investigations are used as opportunities to:

- develop, rehearse and refine science inquiry skills
- engage students in scaffolded or open-ended science inquiry tasks
- formatively assess science inquiry skills.

Science inquiry skills

Throughout the course of study, students will:

- identify, research and construct questions for investigation
- propose hypotheses and/or predict possible outcomes
- design investigations, including the procedure/s to be followed, the materials required, and the type and amount of primary and/or secondary data required to obtain valid and reliable evidence, e.g.
  - consider replicates, number of data points, and quality of sources
  - identify the types of errors, extraneous variables or confounding factors that are likely to influence results and implement strategies to minimise systematic and random error
- identify and implement strategies to manage risks, ethics and environmental impact, e.g.
  - cultural guidelines, protocols for working with the knowledges of First Nations peoples
  - material safety data sheets
  - workplace health and safety guidelines
  - appropriate disposal methods
  - standard operating procedures
  - acknowledgment of sources and referencing

- use appropriate equipment, techniques, procedures and sources to systematically and safely collect primary and secondary data, e.g.
  - laboratory and field techniques: measurement, and equipment calibration
  - ICTs, scientific texts, databases, simulations, online sources
- use scientific language and representations to systematically record information, observations, data and measurement error, e.g.
  - symbols, units and prefixes
  - tables, graphs and diagrams
  - indicators of measurement uncertainty and state measurement uncertainties as a range (±) to an appropriate precision, e.g. when adding or subtracting, the final answer should be given to the least number of decimal places, when multiplying or dividing, the final answer should be given to the least number of significant figures
  - identify that concentration can be represented in a variety of ways including, but not limited to, mol L^{-1}, g L^{-1} and ppm and that square brackets can be used to denote concentration.
  - logbooks
- translate information between graphical, numerical and/or algebraic forms, e.g.
  - units and measurement conversions
  - ratios and percentages
  - symbols and notation
- use mathematical techniques to summarise data in a way that allows for identification of relevant trends, patterns, relationships, limitations and uncertainty, e.g.
  - mean
  - gradient analysis
  - scatterplots (with maximum and minimum trendlines and R^2)
  - propagate random error in data processing to show the impact of measurement uncertainties on the final result
  - apply simple treatment of error analysis, e.g. for functions such as addition and subtraction, absolute uncertainties should be added, for multiplication, division and powers, percentage uncertainties should be added
  - calculate the measurement uncertainties in processed data, including the use of absolute uncertainties of the mean (Formula: $\Delta\bar{x} = \pm\frac{(X_{max} - x_{min})}{2}$) and percentage uncertainties (Formula: $\text{percentage uncertainty (\%)} = \frac{\text{absolute uncertainty}}{\text{measurement}} \times \frac{100}{1}$)
  - calculate the percentage error, when the experimental result can be compared with a theoretical or accepted result (value) (Formula: $\text{percentage error (\%)} = \left|\frac{\text{measured value} - \text{true value}}{\text{true value}}\right| \times \frac{100}{1}$)
  - discriminate between absolute uncertainty and percentage error

- select and construct appropriate representations to present data and communicate findings, e.g.
  - summary tables
  - apply appropriate graphical representations to analyse data and draw conclusions
  - analyse data to identify trends, patterns and relationships; recognising error, uncertainty and limitations of evidence
  - discriminate between precision and accuracy
  - identify that all measurements have limits to their precision and accuracy that must be considered when evaluating experimental results
  - interpret graphs in terms of the relationship between dependent and independent variables; draw and interpret best-fit lines or curves through data points, including evaluating when it can and cannot be considered as a linear function
  - identify that quantitative data obtained from measurements is associated with random error/measurement uncertainties
- select, synthesise and use evidence to construct scientific arguments and draw conclusions
- extrapolate findings to determine unknown values, predict outcomes and evaluate claims
- use data and reasoning to discuss and evaluate the validity and reliability of evidence, e.g.
  - discuss ways in which measurement error, instrumental uncertainty, the nature of the methodology or other factors influence uncertainty and limitations in the data
  - evaluate information sources and compare ideas, information and opinions presented within and between texts, considering aspects such as acceptance, bias, status, appropriateness and reasonableness
  - compare findings to theoretical models or expected values
  - discriminate between validity and reliability
- suggest improvements and extensions to minimise uncertainty, address limitations and improve the overall quality of evidence, e.g.
  - analyse the impact of random error/measurement uncertainties and systematic errors in experimental work and determine how these errors/measurement uncertainties can be reduced
  - discriminate between random and systematic errors
  - identify that experimental design and procedure usually leads to systematic errors in measurement, which causes a deviation in a direction and that repeated trials and measurements will reduce random error but not systematic error
- communicate to specific audiences and for specific purposes using appropriate language, nomenclature, genres and modes
- acknowledge sources of information and use standard scientific referencing conventions
- appreciate the role of peer review in scientific research.

Science inquiry subject matter uses cognitions from across all objectives, and is primarily assessed through the internal assessments for Units 3 and 4. To support the development of these science inquiry skills, this syllabus identifies suggested practicals and investigations for each unit. These highlight opportunities for students to directly experience the associated Science understanding subject matter and provide stimulus for student experiments and research investigations.

Safety and ethics

Workplace health and safety

Chemistry is designed to expose students to the practical components of science through practical experiences in the laboratory and the field. These experiences expose students to a variety of hazards, from biological and poisonous substances to injury from equipment. Besides a teacher's duty of care that derives from the *Education (General Provisions) Act 2006*, there are other legislative and regulatory requirements, for example the *Work Health and Safety Act 2011*, that will influence the nature and extent of practical work.

All practical work must be organised with student safety in mind. The *Department of Education and Training (DET) Policy and Procedure Register* (https://ppr.qed.qld.gov.au) provides guidance about current science safety protocols.

It is the responsibility of all schools to ensure that their practices meet current legislation requirements. References to relevant legislation and regulations are supported by the reference list located on the Chemistry subject page of the QCAA website.

Strategies for retaining and recalling information for assessment

The following practices[1] can support preparation for senior assessment in Chemistry.

The spacing effect

The spacing effect draws on research about forgetting and learning curves. By recalling and revisiting information at intervals, rather than at the end of a study cycle, students remember a greater percentage of the information with a higher level of accuracy. Exposing students to information and materials numerous times over multiple spaced intervals solidifies long-term memory, positively affecting retention and recall.

Teachers should plan teaching and learning sequences that allow time to revisit previously taught information and skills at several intervals. These repeated learning opportunities also provide opportunities for teachers to provide formative feedback to students.

The retrieval effect

The retrieval effect helps students to practise remembering through quick, regular, low-stakes questioning or quizzes that exercise their memories and develop their ability to engage in the deliberate act of recalling information. This has been shown to be more effective at developing long-term memories than activities that require students to search through notes or other resources.

Students may see an inability to remember as an obstacle, but they should be encouraged to understand that this is an opportunity for learning to take place. By trying to recall information, students exercise or strengthen their memory and may also identify gaps in their learning. The more difficult the retrieval practice, the better it can be for long-term learning.

Interleaving

Interleaving involves interspersing the concepts, categories, skills or types of questions that students focus on in class or revision. This is in contrast to blocking, in which these elements are grouped together in a block of time. For example, for concepts A, B and C:

- Blocking A A A A A B B B B B C C C C C
- Interleaving A B C B C A B A C A C B C A B

Studies have found that interleaving in instruction or revision produces better long-term recall of subject matter. Interleaving also ensures that spacing occurs, as instances of practice are spread out over time.

Additionally, because exposure to one concept is interleaved with exposure to another, students have more opportunities to distinguish between related concepts. This highlighting of differences may explain why studies have found that interleaving enhances inductive learning, where participants use exemplars to develop an understanding of broader concepts or categories. Spacing without interleaving does not appear to benefit this type of learning.

Interleaving can seem counterintuitive — even in studies where interleaving enhanced learning, participants often felt that they had learnt more with blocked study. Despite this, their performance in testing indicated greater learning through the interleaving approach.

[1] Based on Agarwal, Roediger, McDaniel & McDermott (2020); Birnbaum, Kornell, Ligon Bjork & Bjork (2013); Carpenter & Agarwal (2020); Chen, Paas & Sweller (2021); Ebbinghaus (1885); Rohrer (2012); Taylor & Rohrer (2010).

Reporting

General information about determining and reporting results for senior syllabuses is provided in the 'Determining and reporting results' section of the *QCE and QCIA policy and procedures handbook*.

Reporting standards

Reporting standards are summary statements that describe typical performance at each of the five levels (A–E).

A
The student accurately describes a variety of concepts, theories, models and systems, and their limitations. They give clear and detailed accounts of a variety of concepts, theories, models and systems by making relationships, reasons or causes evident. The student communicates effectively by using scientific representations and language accurately and concisely within appropriate genres. They efficiently collect, collate and process relevant evidence. The student accurately applies their understanding of scientific concepts, theories, models and systems within their limitations to explain a variety of phenomena, and predict outcomes, behaviours and implications. They accurately use representations of scientific relationships and data to determine a variety of unknown scientific quantities and perceptively recognise the limitations of models and theories when discussing results. The student analyses systematically and effectively by identifying the essential elements, features or components of qualitative data. They use relevant mathematical processes to appropriately identify trends, patterns, relationships, limitations and uncertainty in quantitative data. They interpret evidence insightfully by using their knowledge and understanding to draw justified conclusions based on their thorough analysis of evidence and established criteria. The student critically evaluates conclusions, claims and processes by insightfully scrutinising evidence, extrapolating credible findings, and discussing the reliability and validity of experiments. They investigate phenomena by carrying out effective experiments and research investigations.
B
The student accurately describes concepts, theories, models and systems, and their limitations. They give clear and detailed accounts of concepts, theories, models and systems by making relationships, reasons or causes evident. The student communicates accurately by using scientific representations and language within appropriate genres to present information. They collect, collate and process relevant evidence. The student accurately applies their understanding of scientific concepts, theories, models and systems within their limitations to explain phenomena and predict outcomes, behaviours and implications. They accurately use representations of scientific relationships and data to determine unknown scientific quantities, and accurately recognise the limitations of models and theories when discussing results. The student analyses effectively by identifying the essential elements, features or components of qualitative data. They use mathematical processes to appropriately identify trends, patterns, relationships, limitations and uncertainty in quantitative data. They interpret evidence by using their knowledge and understanding to draw reasonable conclusions based on their accurate analysis of evidence and established criteria. The student evaluate processes, claims and conclusions by scrutinising evidence, applying relevant findings and discussing the reliability and validity of experiments. They investigate phenomena by carrying out effective experiments and research investigations.

C
The student describes concepts, theories, models and systems, and their limitations. They give detailed accounts of concepts, theories, models and systems by making relationships, reasons or causes evident. The student communicates using scientific representations and language within appropriate genres to present information. They collect, collate and process evidence. The student applies their understanding of scientific concepts, theories, models and systems within their limitations to explain phenomena and predict outcomes, behaviours and implications. They use representations of scientific relationships and data to determine unknown scientific quantities and recognise the limitations of models and theories when discussing results. The student analyses by identifying the essential elements, features or components of qualitative data. They use mathematical processes to identify trends, patterns, relationships, limitations and uncertainty in quantitative data. They interpret evidence by using their knowledge and understanding to draw conclusions based on their analysis of evidence and established criteria. The student evaluates processes, claims and conclusions by describing the quality of evidence, applying findings, and describing the reliability and validity of experiments. They investigate phenomena by carrying out experiments and research investigations.
D
The student describes and gives accounts of aspects of concepts, theories, models and systems. The student uses scientific representations or language to present information. They use rudimentary representations of scientific relationships or data to determine unknown scientific quantities or variables. The student analyses by identifying the elements, features or components of qualitative data. They use parts of mathematical processes to identify trends, patterns, relationships, limitations or uncertainty in quantitative data. They interpret evidence by drawing conclusions based on evidence or established criteria. The student considers the quality of evidence and conclusions and discusses processes, claims or conclusions. They carry out aspects of experiments and research investigations.
E
The student describes scenarios and communicates by referring to representations of information. They discuss physical phenomena and evidence. They follow established methodologies in research situations. They discuss evidence. The student carries out elements of experiments and research investigations.

Determining and reporting results

Unit 1 and Unit 2

Schools make judgments on individual assessment instruments using a method determined by the school. They may use the reporting standards or develop an instrument-specific marking guide (ISMG). Marks are not required for determining a unit result for reporting to the QCAA.

The unit assessment program comprises the assessment instrument/s designed by the school to allow the students to demonstrate the unit objectives. The unit judgment of A–E is made using reporting standards.

Schools report student results for Unit 1 and Unit 2 to the QCAA as satisfactory (S) or unsatisfactory (U). Where appropriate, schools may also report a not rated (NR).

Units 3 and 4

Schools mark each of the three internal assessment instruments implemented in Units 3 and 4 using ISMGs.

Schools report a provisional mark by criterion to the QCAA for each internal assessment.

Once confirmed by the QCAA, these results will be combined with the result of the external assessment developed and marked by the QCAA.

The QCAA uses these results to determine each student's subject result as a mark out of 100 and as an A–E.

Units

Unit 1: Chemical fundamentals — structure, properties and reactions

In Unit 1, students relate matter and energy in chemical reactions as they consider the breaking and reforming of bonds as new substances are produced. The properties of a material depend on, and can be explained by, the material's structure. A range of models at the atomic and molecular scale enable explanation and prediction of the structure of materials, and how this structure influences properties and reactions.

Students conduct investigations to develop their understanding of patterns in the properties and composition of materials. They explore the structure of materials by describing physical and chemical properties at the macroscopic scale, and use models of structure and primary bonding at the atomic and subatomic scale to explain these properties. They are introduced to the mole concept as a means of quantifying matter in chemical reactions.

Contexts that could be investigated in this unit include history of atomic model development, use of radioisotopes, energy transfers in industry and the human body, and analysis of elements in living things. Students can also use materials that they encounter in their lives as a context for investigating the relationships between structure and properties.

Participation in a range of experiments and investigations will allow students to progressively develop their suite of science inquiry skills while gaining an enhanced appreciation of chemical structure and properties, and reaction enthalpy. Collaborative experimental work also helps students to develop communication, interaction, and self-management skills.

Throughout the unit, students develop skills in observation, experimentation and data analysis to describe and explain periodicity, material chemistry and energy transfers in chemical reactions.

Unit objectives

1. Describe ideas and findings about properties and structure of atoms and materials, and chemical reactions in terms of reactants, products and energy change.
2. Apply understanding of properties and structure of atoms and materials, and chemical reactions in terms of reactants, products and energy change.
3. Analyse data about properties and structure of atoms and materials, and chemical reactions in terms of reactants, products and energy change.
4. Interpret evidence about properties and structure of atoms and materials, and chemical reactions in terms of reactants, products and energy change.
5. Evaluate processes, claims and conclusions about properties and structure of atoms and materials, and chemical reactions in terms of reactants, products and energy change.
6. Investigate phenomena associated with properties and structure of atoms and materials, and chemical reactions in terms of reactants, products and energy change.

Subject matter

Topic 1: Properties and structure of atoms (20 hours)

Science understanding

Atomic structure

- Describe that atoms can be modelled as a nucleus surrounded by electrons in distinct energy levels.
- Discriminate between the terms *atomic number* (Z), *mass number* (A) and *isotopes of an element*.
- Apply the nuclear symbol notation $^{A}_{Z}M$ to determine the number of protons, neutrons and electrons in atoms, ions and isotopes.
- State the relative energies of the s, p and d orbitals.
- Apply the Aufbau principle, Hund's rule and the Pauli exclusion principle to write electron configurations for atoms and ions up to Z = 36.
- Determine full and condensed electron configurations for atoms and ions up to Z = 36. (e.g $1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^5$ and $[Ne]3s^2$ $3p^5$).
- Identify the electron configuration of Cr and Cu as exceptions.
- Explain how successive ionisation energy data is related to the electron configuration of an atom.

Isotopes

- Describe that isotopes are atoms of the same element that have different numbers of neutrons.
- State that isotopes can be represented in the form ^{A}X (IUPAC) or X-A.
- Identify that isotopes of an element have the same electron configuration and possess similar chemical properties but have different physical properties.
- Explain that the relative atomic mass of an element is the ratio of the weighted average mass per atom of the naturally occurring form of the element to 1/12 the mass of an atom of carbon-12.

Analytical techniques

- State that mass spectrometry involves the ionisation of substances and the separation and detection of the resulting ions. (The operation of the mass spectrometer is not required.)
- Analyse mass spectrometry spectra, to determine the isotopic composition of elements, the relative atomic mass of an element and percentage abundances of the isotopes of an element.
- Discriminate between absorption and emission line spectra.
- Explain that flame tests and atomic absorption spectroscopy (AAS) rely on electron transfer between atomic energy levels.
- Explain that the emission spectrum of hydrogen provides evidence for the existence of electrons in discrete energy levels (Bohr model), which converge at higher energies.
- Analyse flame tests and atomic absorption spectroscopy (AAS) to identify elements and determine the concentration of metallic ions in solution.

Periodic table and trends

- State that elements are represented by symbols.
- Identify that the structure of the periodic table based on increasing atomic number.
- Identify that the periodic table is arranged into four blocks associated with the four sub-levels — s, p, d and f.
- Describe the relationship between the structure of the periodic table and the electronic configuration of atoms.
- Explain that elements of the periodic table show trends in chemical and physical properties across periods and down groups as exemplified by groups 1, 2, 13–18 and period 3.
- Compare the metallic and non-metallic behaviours of elements, including group trends and the reactivity for the alkali metals (Li–Cs) and the halogens (F–I).
- Identify that oxides change from basic through amphoteric to acidic across period 3.
- Analyse data for atomic radii, valencies, ionic radii, 1st ionisation energy and electronegativities to determine periodic trends, patterns and relationships.

Introduction to bonding

- Explain that the ability of atoms to form chemical bonds, is related to the arrangement of electrons in the atom and the stability of the valence electron shell.
- Identify that the number of electrons lost, gained or shared is determined by the electron configuration of the atom.
- State that transitional elements can form more than one ion.
- Explain that ions are atoms or groups of atoms that are electrically charged due to an imbalance in the number of electrons and protons.
- Explain that chemical bonds are caused by electrostatic attractions that arise because of the sharing or transfer of electrons.
- Identify that the valency is a measure of the number of bonds that an atom can form.
- Determine the formula and IUPAC name of ionic and molecular compounds.
- Discriminate between the terms *empirical formula*, *molecular formula* and the *formula unit*.
- Determine Lewis (electron dot) structure of molecules and ions showing all valence electrons for up to four electrons pairs for each atom.
- Identify the numbers of bonding and lone pairs of electrons around each atom in a molecule.

Science as a human endeavour (SHE)

- Appreciate that experiments provided evidence that enabled scientists to develop models of the atom.
- Consider the role Geiger-Marsden's gold foil experiments and Maria Goeppert Mayer's nuclear shell model played in the development of atomic theory.
- Appreciate that radioisotopes require careful evaluation and monitoring because of the potential harmful effects to humans and/or the environment.
- Explore the use of radioisotopes for carbon dating and radiotherapy and Marie Curie's contribution to research on radioactivity.
- Appreciate that analysis of the distribution of elements in living things, Earth and the universe has informed a wide range of scientific understandings.
- Explore the composition of stars and Cecilia Payne-Gaposchkin's contribution to astrophysics.

Science inquiry

Investigate:

- flame tests to identify elements
- mass spectra and isotopes*
- atomic absorption spectroscopy (AAS) and the concentration of aqueous metallic ions.*

***Note:** Simulations may be used.

Topic 2: Properties and structure of materials (5 hours)

Science understanding

Compounds and mixtures

- State that pure substances may be elements or compounds.
- Identify that pure substances have distinct measurable properties (e.g. melting and boiling point, reactivity, strength, density) and mixtures have properties dependent on the identity and relative amounts of the substances that make them up.
- Discriminate between heterogeneous and homogeneous mixtures.
- Analyse data to determine the physical properties of pure substances and mixtures.

Bonding and properties

- Describe the properties of ionic, covalent and metallic compounds, e.g. melting and boiling point, thermal and electrical conductivity, strength and hardness.
- Explain that the type of bonding within ionic, metallic and covalent substances determines their physical properties.
- Explain the properties of ionic compounds by modelling ionic bonding as ions arranged in a crystalline lattice structure with strong electrostatic forces of attraction between oppositely charged ions.
- Discriminate between ionic and metallic bonding.
- Explain the properties of covalent compounds by modelling covalent bonding as the sharing of an electron pair in the region between two nuclei with a strong electrostatic force of attraction between both nuclei.
- Discriminate between covalent molecules, giant covalent networks and allotropes of carbon.
- Explain that hydrocarbons, including alkanes (saturated), alkenes (unsaturated) and benzene, have different chemical properties that are determined by the nature of the bonding within the molecules.
- Analyse data to determine the properties, structure and bonding of ionic, covalent and metallic compounds.

Science as a human endeavour (SHE)

- Appreciate that the development of nanomaterials is important to meet a range of contemporary needs and have specific properties related to the size of the particles (1–100 nm).
- Consider the benefits and potential risks associated with the use of nanomaterials in consumer products, health care, transportation, energy and agriculture.
- Appreciate that impurities can affect the physical and chemical properties of substances, resulting in inefficient or unwanted chemical reactions.
- Explore Ellen Swallow Richard’s contribution to developing water quality standards and the new discipline of home economics.
- Appreciate that carbon has a range of properties that allow a variety of interactions which are pivotal to the formation of biochemical molecules such as carbohydrates, proteins and DNA.
- Consider whether life exists elsewhere in the universe and if it could be carbon-based as it is on Earth.
- Explore Millicent Goldschmidt’s contribution to the development of astrobiology.

Science inquiry

Investigate:

- the separation of mixtures based on physical properties
- the properties of ionic, metallic, and covalent compounds
- tests to distinguish alkanes and alkenes.*

***Note:** Simulations may be used.

Topic 3: Chemical reactions — reactants, products and energy change (20 hours)

Science understanding

Chemical reactions

- Identify that chemical reactions and phase changes involve energy changes, commonly observable as changes in the temperature of the surroundings and/or the emission of light.
- Determine balanced chemical equations, including state symbols (s), (l), (g) and (aq), for a variety of reactions, e.g. single displacement, double-displacement, acid-base, combustion, combination, decomposition and simple redox reactions.

Exothermic and endothermic reactions

- State that heat is a form of energy, and that temperature is a measure of the average kinetic energy of the particles.
- Explain how endothermic and exothermic reactions relate to the law of conservation of energy and the breaking and reforming of bonds.
- Discriminate between exothermic and endothermic reactions.
- Sketch enthalpy level diagrams for exothermic and endothermic reactions.
- Analyse enthalpy level diagrams and thermochemical equations to determine the relative stabilities of reactants and products, and the sign of the enthalpy change (ΔH) for a reaction.
- Explain, in terms of average bond enthalpies, why reactions are exothermic or endothermic.
- Identify the limitations of using average bond enthalpies to calculate enthalpy change.
- Calculate the heat change (Q) for a substance given the mass, specific heat capacity and temperature change. (Formula: $Q = mc\Delta T$)
- Calculate the enthalpy change (ΔH) for a reaction given temperature changes, quantities of reactants and mass of water. (Formula: $\Delta H = H_{(products)} - H_{(reactants)}$)
- Analyse data for heat of combustion, heat of neutralisation and reactions in aqueous solutions to determine heat, mass, specific heat capacity, temperature and enthalpy change.

Mole concept and law of conservation of mass

- State that a mole is a precisely defined quantity of matter equal to Avogadro's number of particles.
- State the law of conservation of mass.
- Explain that the mole concept relates mass, moles and molar mass.
- Apply the mole concept to calculate the mass of reactants and products; amount of substance in moles; number of representative particles; and molar mass of atoms, ions, molecules and formula units. (Formula: $\text{moles (n)} = \frac{\text{mass(m)}}{\text{molar mass (M)}}$)
- Determine the percentage composition from relative atomic masses; empirical formula of a compound from the percentage composition by mass; and molecular formula of a compound from its empirical formula and molar mass.
- Determine limiting reactants.
- Discriminate between experimental and theoretical yield.
- Analyse data to determine percentage and theoretical yield.
  (Formula: $\text{percentage yield (\%)} = \frac{\text{experimental yeild}}{\text{theoretical yeild}} \times \frac{100}{1}$)

Science as a human endeavour (SHE)

- Appreciate that chemistry principles can be applied to industrial processes to reduce energy requirements.
- Explore how industries are reducing their energy requirements in order to save money and reduce greenhouse gas emissions.
- Appreciate that bodies rely on the exothermic reaction of respiration to provide us with sufficient energy.
- Explore how cells use food and convert it to energy and Gerty Cori's contribution to the treatment of diabetes.
- Appreciate that biofuels are more efficient and have less environmental impact than fossil fuels.
- Evaluate fuels, including fossil fuels and biofuels, in terms of their energy output, their suitability for purpose, and the nature of products of combustion.

Science inquiry

Investigate:

- types of chemical reactions
- limiting reagent/s and percentage yield
- the empirical formula of a compound from reactions involving mass change
- the enthalpy change of a reaction, e.g. calorimetry or Hess's Law.

Unit 2: Molecular interactions and reactions

In Unit 2, students develop their understanding of the physical and chemical properties of materials including gases, water, aqueous solutions, acids and bases. Students explore the characteristic properties of water that make it essential for physical, chemical and biological processes on Earth, including the properties of aqueous solutions. They investigate and explain the solubility of substances in water, and compare and analyse a range of solutions. They learn how rates of reaction can be measured and altered to meet particular needs, and use models of energy transfer and the structure of matter to explain and predict changes to rates of reaction. Students gain an understanding of how to control the rates of chemical reactions, including through the use of a range of catalysts.

Students conduct investigations of chemical reactions, including the prediction and identification of products, and the measurement of the rate of reaction. They investigate the behaviour of gases, and use the kinetic theory to predict the effects of changing temperature, volume and pressure in gaseous systems.

Contexts that could be investigated in this unit include forensic chemistry, and acids in the atmosphere and ocean, such as rain, blood chemistry, water quality and the importance of enzymes. Through appropriate contexts, students explore how evidence from multiple disciplines and individuals and the development of ICT, and other technologies have contributed to developing understanding of intermolecular forces and chemical reactions.

Participation in a range of experiments and investigations will allow students to progressively develop their suite of science inquiry skills while gaining an enhanced appreciation of materials, mixtures, reactions and underpinning models and theories. Collaborative experimental work also helps students to develop communication, interaction, and self-management skills.

Throughout the unit, students develop skills in observation, design, experimentation and data analysis to describe and explain material chemistry, solutions and rates of reactions.

Unit objectives

1. Describe ideas and findings about intermolecular forces and gases, aqueous solutions and acidity, and rates of chemical reactions.
2. Apply understanding of intermolecular forces and gases, aqueous solutions and acidity, and rates of chemical reactions.
3. Analyse data about intermolecular forces and gases, aqueous solutions and acidity, and rates of chemical reactions.
4. Interpret evidence about intermolecular forces and gases, aqueous solutions and acidity, and rates of chemical reactions.
5. Evaluate processes, claims and conclusions about intermolecular forces and gases, aqueous solutions and acidity, and rates of chemical reactions.
6. Investigate phenomena associated with intermolecular forces and gases, aqueous solutions and acidity, and rates of chemical reactions.

Subject matter

Topic 1: Intermolecular forces and gases (13 hours)

Science understanding

Intermolecular forces

- Apply the valence shell electron pair repulsion (VSEPR) theory to determine the shape and bond angles of linear, bent, trigonal planar, tetrahedral and pyramidal molecules. (Hybridization involving d-orbitals are not required.)
- Determine the polarity of molecules using molecular shape, understanding of symmetry, and comparison of the electronegativity of elements.
- Explain the relationship between vapour pressure, melting point, boiling point and solubility, and the nature and strength of intermolecular forces (e.g. dispersion forces, dipole-dipole attractions, and hydrogen bonding) within molecular covalent substances.

Chromatography techniques

- Identify that paper and thin layer chromatography can be used to determine the composition and purity of substances.
- Explain how variations in the strength of the interactions between atoms, molecules or ions in the mobile and stationary phases can be used to separate components.
- Analyse paper and thin layer (TLC) chromatographs to determine the composition and purity of substances, including calculating R_f values.

Gases

- State the relationship between the volume of a gas, number of moles and molar volume at standard temperature and pressure (STP).
- Apply the kinetic theory of gases to explain the relationships between pressure, temperature, and volume of a gas.
- Identify that the kinetic theory of gases applies to ideal gases.
- Apply the ideal gas equation to calculate the mass of chemicals and/or the volume of a gas (STP) involved in a chemical reaction. (Formula: $PV = nRT$)
- Analyse data to determine the relationships between pressure, temperature, and volume of a gas.

Science as a human endeavour (SHE)

- Appreciate that science relies on chemical processes to analyse materials in order to determine the identity, nature or source of the material.
- Explore how chromatography techniques, including gas and high-performance liquid chromatography, can be used to determine the composition and purity of substances.
- Appreciate that safe scuba diving requires knowledge of the behaviour of gases.
- Explore Jacques Cousteau and Emile Gagnan's role in the invention of SCUBA.
- Appreciate that two- and three-dimensional graphical models have been developed and adopted by chemists to represent and communicate the shapes of molecules.
- Consider the limitations associated with the VSEPR theory.

Science inquiry

Investigate:

- Boyle's law or the molar volume of a gas
- the separation of a mixture using paper or thin layer chromatography* (TLC)
- 3D models of linear, bent, trigonal planar, tetrahedral and pyramidal molecules.*

***Note:** Simulations may be used.

Topic 2: Aqueous solutions and acidity (22 hours)

Science understanding

Aqueous solutions and molarity

- Explain that the unique properties of water are related to molecular shape and hydrogen bonding between molecules.
- Discriminate between the terms *solute*, *solvent*, *solution*.
- Discriminate between the terms *strength* and *concentration*, e.g. acidic/basic solutions.
- State that square brackets ([ ]) are used to denote concentration.
- Discriminate between unsaturated, saturated and supersaturated solutions.
- Apply the mole concept to calculate moles of solute, concentration and volume of a solution. (Formula: Molarity/$\text{Concentration (c)} = \frac{\text{moles of solute (n)}}{\text{volume of solution (V)}}$)

Identifying ions in solution

- Apply ionic and chemical formulas to construct balanced ionic and chemical equations (including states) for precipitation reactions.
- Apply solubility rules to predict if a precipitation will be formed.
- Analyse data, including precipitation and acid-carbonate reactions, to determine the presence of specific ions in solutions.

Solubility

- Compare the solubility of ionic and molecular substance in water, and the intermolecular forces between species in the substances and water molecules.
- Identify that changes in solvent temperature can affect the solubility of solid and gaseous solutes (solids and gases).
- Analyse data, including solubility curves, to determine the solubility of ionic compounds and the concentration of ions in aqueous solutions.

pH

- State that pH is dependent on the concentration of hydrogen ions in solution.
- Identify that the pH scale is a logarithmic scale.
- Apply the pH scale to compare the levels of acidity or alkalinity of aqueous solutions.
- Apply the Arrhenius model to explain the behaviour of strong and weak acids and bases in aqueous solutions.

Reactions of acids

- Determine balanced chemical and ionic equation (including states) for the reactions of acids with bases, metals and carbonates.

Science as a human endeavour (SHE)

- Appreciate that most sulfur dioxide released to the atmosphere comes from burning coal or oil in electric power stations.
- Explore the chemistry of acid rain.
- Appreciate that blood plasma is an aqueous solution containing a range of ionic and molecular substances.
- Explore why blood is red and the chemistry of blood types.
- Appreciate that knowledge of the composition of water from different sources informs decisions about how that water is treated and used.
- Evaluate the measurable properties of water that are used to determine the water quality of a local water way.
- Explore the different water treatment methods used to provide safe drinking water.

Science inquiry

Investigate:

- precipitation reactions to identify cations and anions
- factors that affect solubility in aqueous solutions
- reactions of acids with bases, metals and carbonates.

Topic 3: Rates of chemical reactions (10 hours)

Science understanding

Rates of reactions

- Explain how temperature, surface area, pressure (gaseous systems), concentration and the presence of a catalyst can affect the rate of the reaction.
- Apply the collision theory to determine the effect of concentration, temperature, pressure and surface area on the rate of chemical reactions.
- Sketch Maxwell-Boltzmann distribution curves for reactions with and without catalysts.
- Describe activation energy (E_a).
- Explain the relationship between the strength and number of the existing chemical bonds, the magnitude of the activation energy and the rate of a chemical reaction.
- Sketch energy profile diagrams for reactions with and without catalysts.
- Analyse energy profile diagrams for reactions with and without catalysts, to determine the enthalpy change and activation energy.
- Explain how catalysts affect the rate of a chemical reaction.
- Calculate the rate of chemical reactions by measuring the rate of formation of products or the depletion of reactants. (Formula: $\text{rate of reaction} = \frac{\text{increase in product concentration } (\Delta[\text{P}])}{\text{time taken}}$ or $\frac{\text{decrease in reactant concentration } (-\Delta[\text{R}])}{\text{time taken}}$)
- Analyse data and graphical representations of relative changes in the concentration, volume and mass against time to determine rate of reaction. (Order of reaction is not required.)

Science as a human endeavour (SHE)

- Appreciate that catalysts work in a variety of ways, and knowledge of the structure of enzyme molecules helps scientists to explain and predict how they are able to lower the activation energy for reactions.
- Explore Mildred Cohn's use of isotopic tracers and NMR spectroscopy to study the mechanism of enzymatic catalysis.
- Appreciate that most contemporary methods of corrosion prevention rely on knowledge of chemical and electrochemical redox processes.
- Explore the historical theories on corrosion from the introduction of iron in Antiquity through to the impact of air pollution on the life span of modern metal structures.
- Appreciate that collision theory enables chemists to explain and predict the rates of a vast range of chemical reactions in many different contexts.
- Explore the history of collision theory, its uses and its limitations.

Science inquiry

- Investigate factors that affect the rate of chemical reactions.

Unit 3: Equilibrium, acids and redox reactions

In Unit 3, students explore the reversibility of reactions in a variety of chemical systems at different scales; acid-base equilibrium systems and their applications; the principles of oxidation and reduction reactions; and the production of electricity from electrochemical cells. Processes that are reversible will respond to a range of factors and can achieve a state of dynamic equilibrium, while contemporary models can be used to explain the nature of acids and bases, and their properties and uses.

Students conduct investigations on electrochemical cells and volumetric analysis applications. They examine qualitative and quantitative data about acids, equilibrium and redox to analyse trends and draw conclusions.

They participate in experiments and investigations related to the principles of dynamic chemical equilibrium and how these can be applied to chemical processes and systems; electrochemical cells, the choice of materials used and the voltage produced by these cells; pH scale and the extent of dissociation of acids and bases; and the concentrations of ions in an aqueous solution. Collaborative experimental work allows students to progressively develop their science inquiry skills, while gaining an enhanced appreciation of the importance of equilibrium and redox in the real world.

Contexts that could be investigated include environmental issues, such as acid rain and oceanic acidification; food or wine production; the historical development of theories about acids, corrosion and corrosion prevention; fuel cells; and uses of electrochemistry. Through the investigation of appropriate contexts, students explore the ways in which models and theories related to acid-base and redox reactions, and their applications, have developed over time, and the ways in which chemistry contributes to contemporary debate in industrial and environmental contexts, including the use of energy, evaluation of risk and action for sustainability.

Unit objectives

1. Describe ideas and findings about chemical equilibrium systems and oxidation and reduction.
2. Apply understanding of chemical equilibrium systems and oxidation and reduction.
3. Analyse data about chemical equilibrium systems and oxidation and reduction.
4. Interpret evidence about chemical equilibrium systems and oxidation and reduction.
5. Evaluate processes, claims and conclusions about chemical equilibrium systems and oxidation and reduction.
6. Investigate phenomena associated with chemical equilibrium systems and oxidation and reduction.

Subject matter

Topic 1: Chemical equilibrium systems (25 hours)

Science understanding

The following subject matter can be assessed in the external assessment.

Chemical equilibrium

- Discriminate between open or closed chemical systems.
- Identify that physical changes are usually reversible, whereas only some chemical reactions are reversible.
- Symbolise equilibrium equations using ⇋ in balanced chemical equations.
- Explain observable properties and the characteristics of physical and chemical systems in a state of equilibrium.
- Explain that, over time, physical change and reversible chemical reactions reach a state of dynamic equilibrium in a closed system, with the relative concentrations of products and reactants defining the position of equilibrium.
- Explain the reversibility of chemical reactions by considering the activation energies of the forward and reverse reactions.
- Analyse data and interpret graphical representations of relative changes in the concentration of reactants and product against time, to determine the position of equilibrium.

Factors that affect equilibrium

- Determine the effect of temperature change on chemical systems at equilibrium by considering the enthalpy change for the forward and reverse reactions.
- Explain the effect of changes of temperature, concentration and pressure on chemical systems at equilibrium by applying collision theory to the forward and reverse reactions.
- Apply Le Châtelier's principle to determine the effect changes of temperature, concentration of chemicals, pressure and the addition of a catalyst have on the position of equilibrium and on the value of the equilibrium constant.

Equilibrium constants

- Identify that the equilibrium constant (K_c) indicates the relationship between product and reactant concentrations at equilibrium.
- Identify that the solubility product (K_{sp}) gives a measure of the solubility of an ionic compound.
- Determine the equilibrium law expression for homogeneous and heterogeneous systems.
- Determine the extent of a reaction from the magnitude of the equilibrium constant (K_c).
- Calculate the reaction quotient (Q_c) for reversible reactions
  (Formula: $Q_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}$ for the reaction $aA + bB \leftrightharpoons cC + dD$)
- Calculate equilibrium constants (K_c) and the concentrations of reactants and products. Assume $[\text{reactants}]_{\text{initial}} = [\text{reactants}]_{\text{equilibrium}}$ when K_c is very small and state assumption when used. (Formula: $K_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}$ for the reaction $aA + bB \leftrightharpoons cC + dD$)

- Calculate solubility products (K_{sp}) and the concentrations of ions in aqueous solutions. (Formula: $Ksp = [C]^c[D]^d$ for the reaction aA(s) $\leftrightharpoons$ $cC(aq) + dD(AQ)$)
- Infer shifts in equilibrium reactions using equilibrium constants (K_c) and reaction quotients (Q_c).
- Analyse data to determine reaction quotients (Q_c), equilibrium constants (K_c), the concentrations of reactants and products and the concentration of ions in aqueous solutions.

Properties of acids and bases

- Identify that acids are substances that can act as proton (hydrogen ion) donors.
- Identify acids as monoprotic, diprotic or polyprotic.
- Identify hydrochloric, nitric and sulfuric acid as strong acids and group 1 hydroxides and barium hydroxide as strong bases.
- Identify carboxylic and carbonic acids as weak acids and ammonia and amines as weak bases.
- Discriminate between the terms strong, weak, concentrated and dilute for acids and bases.
- Discriminate between strong and weak acids and bases in terms of the extent of dissociation, rate of reaction, pH and electrical conductivity.
- Analyse data to determine the strength, concentration, pH and electrical conductivity of acids and bases.

pH

- Identify that water is a weak electrolyte and the self-ionisation of water is represented by $K_w = [H^+][OH^-]$.
- Apply K_w to calculate the concentration of hydrogen ions from the concentration of hydroxide ions in a solution.
- Calculate pH, hydrogen ion concentration $[H^+(aq)]$, pOH and hydroxide ion concentrations $[OH^-(aq)]$ for strong acids and bases. (Formula: $pH = -\log_{10} [H^+]$ and $pOH = -\log_{10} [OH^-]$)

Brønsted-Lowry model

- Describe acids and bases in equilibrium systems using the Brønsted-Lowry model.
- Explain the Brønsted-Lowry model using chemical equations that illustrate the transfer of hydrogen ions (protons) between conjugate acid-base pairs.
- Identify that amphiprotic species can act as Brønsted-Lowry acid (or base).
- Determine the formula of the conjugate acid (or base) of any Brønsted-Lowry base (or acid).
- Identify that buffers are solutions that are conjugate in nature and resist a change in pH when a small amount of an acid or base is added. (Buffer calculations are not required.)
- Apply Le Châtelier's principle to explain how buffer solutions respond to the addition of hydrogen ions and hydroxide ions.

Dissociation constants

- Explain that the strength of acids is related to the degree of ionisation at equilibrium in aqueous solution.
- Identify that the strength of acids can be represented with chemical equations and equilibrium constants (K_a).
- Determine the expression for the dissociation constant for weak acids (K_a) and weak bases (K_b) from balanced chemical equations.
- Calculate dissociation constants (K_a, K_b, and K_w), pK_a, pK_b, and the concentrations of reactants and products. (Formula: $K_\mathrm{a} = \frac{[\mathrm{H_3O^+}][\mathrm{A^-}]}{[\mathrm{HA}]}$; $K_\mathrm{b} = \frac{[\mathrm{BH^+}][\mathrm{OH^-}]}{[\mathrm{B}]}$; $K_w = K_\mathrm{a} \times K_\mathrm{b}$)
- Analyse data to compare the relative strengths of acids and bases.

Acid-base indicators

- Identify that acid-base indicators are a weak acid or a weak base where the conjugate acid-base pair have different colours and can be represented by $\mathrm{HIn(aq)} \leftrightharpoons \mathrm{H^+(aq)} + \mathrm{In^-(aq)}$ *or* $\mathrm{BOH(aq)} \leftrightharpoons \mathrm{B^+(aq)} + \mathrm{OH^-(aq)}$.
- Identify that indicators change colour when pH = pKa.
- Explain the relationship between the pH range, the end point and the pK_a value of an acid-base indicator.
- Analyse data to determine an appropriate indicator given the equivalence point of the titration and the pH range of the indicator (assuming indicators change colour over a range of pK_a ± 1).

Volumetric analysis

- Discriminate between the terms *end point* and *equivalence point*.
- Sketch the general shapes of conductometric and acid-base titration curves involving strong and weak acids and bases. (Titration of weak acids to weak bases is not required.)
- Interpret acid-base titration curves to determine the intercept with pH axis, equivalence point, buffer region and points where pK_a = pH or pK_b = pOH.
- Interpret conductometric titration curves to determine the intercept with conductivity axis, equivalence point and volume of titrant.
- Analyse volumetric data, including solubility, conductometric and acid-base titration curves, to determine moles, mass, volume and concentration.
- Analyse titration curves to calculate the concentration of a solution with reference to a standard solution.

Science as a human endeavour (SHE)

The following subject matter may be assessed in the internal assessments.

- Appreciate that the production of wine, along with that of many other food products, relies on the successful control of a range of reversible reactions in order to maintain the required chemical balance within the product.
- Explore the chemistry of wine.
- Appreciate that oceans contribute to the maintenance of steady concentrations of atmospheric carbon dioxide because the gas can dissolve in seawater through a range of reversible processes.
- Explore the absorption of heat by CO_2 and water vapour and the effect that changing amounts of CO_2 in the atmosphere have on climate.
- Explore Eunice Newton Foote's contribution to understanding climate change in 1856.
- Appreciate that 'superacids', such as carborane acids, have been found to be a million times stronger than sulfuric acid when their strength is extrapolated to aqueous solutions the position of equilibrium is considered.
- Explore the composition of 'superacids' and what makes them so strong.

Science inquiry

The following subject matter may be assessed in the internal assessments.

Investigate:

- factors that affect equilibrium (Le Châtelier's principle)
- solubility
- properties of acids and bases
- acid-base or conductometric titrations.

Topic 2: Oxidation and reduction (20 hours)

Science understanding

The following subject matter can be assessed in the external assessment.

Redox reactions

- Identify that displacement reactions of metals, combustion, corrosion and electrochemical processes, can be modelled as redox reactions involving oxidation of one substance and reduction of another substance.
- Determine the species oxidised and reduced, and the oxidising agent and reducing agent, in redox reactions.
- Explain that oxidation can be modelled as the loss of electrons from a chemical species, and reduction can be modelled as the gain of electrons by a chemical species; these processes can be represented using balanced half-equations and redox equations (acidic conditions only).
- Determine the oxidation state (represented with the sign given before the number) of an atom in an ion or compound, e.g. +2.
- Apply oxidation numbers (represented as roman numerals) to name transition metal compounds.

- Apply half-equations and oxidation numbers to balance redox equations and to discriminate between the species oxidised and reduced, and the oxidising agent and reducing agent.
- Analyse data, including displacement reactions of metals, combustion, corrosion and electrochemical processes to determine redox reactions.

Electrochemical cells

- Explain that electrochemical cells, including galvanic and electrolytic cells, consist of oxidation and reduction half-reactions connected via an external circuit that allows electrons to move from the anode (oxidation reaction) to the cathode (reduction reaction).
- Discriminate between a galvanic and an electrolytic cell.

Galvanic cells

- Identify that galvanic cells generate an electrical potential difference from a spontaneous redox reaction.
- Explain that galvanic cells can be represented as cell diagrams, including anode and cathode half-equations.
- Explain that oxidation occurs at the negative electrode (anode) and reduction occurs at the positive electrode (cathode).
- Explain that two half-cells can be connected by a salt bridge to create a galvanic cell, e.g. Mg, Zn, Fe and Cu and their solutions of ions.
- Identify the essential components of a galvanic cell, including the oxidation and reduction half-cells, the positive and negative electrodes and their solutions of their ions, the flow of electrons and the movement of ions, and the salt bridge.
- Sketch a galvanic cell and label the essential components.

Standard electrode potential

- Describe the standard hydrogen electrode.
- Explain the term *standard electrode (reduction) potential*, E^{θ}.
- Identify the limitations associated with standard electrode (reduction) potentials, E^{θ}.
- Calculate cell potential, E^{θ}_{cell} (Formula: $E^{\theta}_{\text{cell}} = E^{\theta}_{\text{reduction half-cell}} - E^{\theta}_{\text{oxidation half-cell}}$)
- Apply standard electrode potentials to determine the relative strength of oxidising and reducing agents.
- Analyse data, including standard electrode potentials, to make predictions about the spontaneity of a reaction and to compare electrochemical cells.

Electrolytic cells

- Identify that electrolytic cells use an external electrical potential difference to provide the energy to allow a non-spontaneous redox reaction to occur.
- Identify the essential components of an electrolytic cell, including source of electric current and conductors, positive and negative electrodes, and the electrolyte.
- State the factors that affect the products in electrolysis.
- Determine the products of the electrolysis of a molten salt.
- Explain the products of the electrolysis of aqueous solutions, e.g. dilute and concentration sodium chloride(aq) and copper sulfate(aq).
- Describe that electrolytic cells can be used in small-scale and industrial situations, including metal plating and the purification of copper.
- Calculate moles of electrons, current, time, mass of substance or volume of gas produced or used during electrolysis. (Formula: $\mathrm{Q} = \mathrm{n}(\mathrm{e}^{-}) \times \mathrm{F}$)
- Analyse data to determine the relative amounts of product produced at each electrode in electrolysis.

Science as a human endeavour (SHE)

The following subject matter may be assessed in the internal assessments.

- Appreciate that the level of alcohol in the body can be measured by testing breath or blood alcohol concentrations.
- Explore the chemistry of breath tests for alcohol, drugs and disease.
- Appreciate that fuel cells are a potential lower-emission alternative to the internal combustion engine and are already being used to power buses, boats, trains and cars.
- Explore battery technologies that could power the future.
- Appreciate that electrochemistry has a wide range of uses, ranging from industrial scale metal extraction to personal cosmetic treatments.
- Explore the desalination process to product of fresh water.

Science inquiry

The following subject matter may be assessed in the internal assessments.

Investigate:

- displacement reactions
- galvanic cells
- factors that affect electrolysis
- electroplating using an electrolytic cell.

Unit 4: Structure, synthesis and design

In Unit 4, students explore the ways in which models and theories relate to chemical synthesis, structure and design, and associated applications; and the ways in which chemistry contributes to contemporary debate regarding current and future uses of local, regional and international resources. Students focus on the principles and application of chemical synthesis, particularly in organic chemistry, and consider where and how functional groups can be incorporated into already existing carbon compounds in order to generate new substances with properties that enable them to be used in a range of contexts. Current and future applications of chemistry include the development of specialised techniques to create or synthesise new substances to meet the specific needs of society, such as pharmaceuticals, fuels, polymers and nanomaterials.

Contexts that could be investigated in this unit include green polymer chemistry, insecticides and herbicides, biofuels and molecular synthesis. Through the investigation of these contexts, students may explore the contradiction between organic chemistry advances and the environmental impact accompanying these practices.

Participation in a range of experiments and investigations will allow students to progressively develop their suite of science inquiry skills while gaining an enhanced appreciation of organic structure, reactions and syntheses. Collaborative experimental work also helps students to develop communication, interaction, character and management skills.

Throughout the unit, students develop skills in experimental methodology, qualitative and quantitative data analysis and current organic developments to describe and explain the importance of this branch of chemistry to society.

Unit objectives

1. Describe ideas and findings about properties and structure of organic materials and chemical synthesis and design.
2. Apply understanding of properties and structure of organic materials and chemical synthesis and design.
3. Analyse data about properties and structure of organic materials and chemical synthesis and design.
4. Interpret evidence about properties and structure of organic materials and chemical synthesis and design.
5. Evaluate processes, claims and conclusions about properties and structure of organic materials and chemical synthesis and design.
6. Investigate phenomena associated with properties and structure of organic materials and chemical synthesis and design.

Subject matter

Topic 1: Properties and structure of organic materials (30 hours)

Science understanding

The following subject matter can be assessed in the external assessment.

Structure of organic compounds

- Identify organic molecules including alkanes, alkenes, alkynes, alcohols, aldehydes, ketones, carboxylic acids, haloalkanes, esters, amines and amides.
- Discriminate between class and functional groups, e.g. for OH, hydroxyl is the functional group and alcohol is the class.
- Describe the features of a homologous series.
- Discriminate between saturated and unsaturated organic molecules.
- Discriminate between empirical, molecular and structural formulas.
- Determine molecular and structural formulas for organic compounds, up to C10, including simple methyl and ethyl branched chains, for
  - alkanes, alkenes and alkynes
  - alcohols (primary, secondary and tertiary)
  - aldehydes and ketones
  - carboxylic acids
  - amines and amides
  - haloalkanes (primary, secondary and tertiary)
  - esters.
- Apply IUPAC rules in the nomenclature of organic compounds, up to C10, including simple methyl and ethyl branched chains, for
  - alkanes, alkenes and alkynes
  - alcohols (primary, secondary and tertiary)
  - aldehydes and ketones
  - carboxylic acids
  - haloalkanes (primary, secondary and tertiary)
  - esters.
- Identify structural and stereoisomers, including geometrical (*cis* and *trans*) and optical isomers.
- Deduce the structural formula of geometrical (*cis* and *trans*) isomers (non-cyclic alkenes), of and optical isomers and isomers of the non-cyclic alkanes up to C_6.
- Sketch the structural formula and apply IUPAC rules in the nomenclature for isomers of alkanes (non-cyclic) and alkenes (straight chain) up to C_6, and for the geometrical (*cis* and *trans*) isomers of simple alkenes (non-cyclic).
- Determine the structural formula of optical isomers for simple organic compounds.
- Identify chiral carbon atoms.
- Analyse data to determine the structural, molecular and empirical formula of organic compound and the percentage composition of elements in organic compounds.

Physical properties and trends

- Explain the trends (melting point, boiling point, volatility, solubility in water and organic solvents) within and between homologous series (alkanes, alkenes, alcohols, carboxylic acids) in term of intermolecular and intramolecular bonding, e.g. dispersion forces, dipole-dipole interactions and hydrogen bonds.
- Analyse data to determine the physical properties of an homologous series, trends in melting point, boiling point, volatility and the solubility alkanes, alkenes, alcohols and carboxylic acids.

Organic reactions and reaction pathways

- Identify that an organic compound displays characteristic chemical properties and undergoes specific reactions based on the functional group present.
- Determine, using equations, the reaction of
  - alkanes with halogens (X_2)
  - haloalkanes with halogens (X_2), sodium hydroxide and ammonia
  - alkenes with water, halogens(X_2), hydrogen (H_2) and hydrogen halides (HX)
  - alcohols with hydrogen halides (HX)
  - carboxylic acid with alcohol to form esters, and with amines to form amides.
- Determine, using equations, reactions including the
  - oxidation of alcohols
  - combustion of alkanes and alcohols
  - addition of alkenes to form poly(alkenes)
  - reduction of alkynes and alkenes to form alkanes
  - elimination of haloalkanes to form alkenes.
- Identify reactions as addition, elimination, substitution or redox (oxidation-reduction). (Reaction mechanism for substitution and elimination reactions are not required.)
- Determine the primary, secondary and tertiary carbon atoms in haloalkanes and alcohols.
- Describe the acid-base properties of carboxylic acids and amines.
- Explain that esterification is a reversible reaction.
- Discriminate between
  - alkanes and alkenes using bromine water
  - primary, secondary and tertiary alcohols using acidified potassium dichromate (VI) and potassium manganate (VII).
- Apply Markovnikov's rule to determine the products for addition reactions of alkenes with hydrogen halides (HX) and water.
- Determine reaction pathways, including reagents, condition and chemical equations, given the starting materials and the product/s formed. (Reaction pathways are based on, but not limited to, the summary diagram in the QCAA Chemistry formula and data book.)
- Interpret chemical tests to distinguish between alkanes and alkenes; and primary, secondary and tertiary alcohols.

Organic materials: structure and function

- Describe the structural features of
  - amino acids, tripeptides, monosaccharides and disaccharides
  - polyethene (LDPE and HDPE), polypropene (syntactic, isotactic and atactic) and polytetrafluorethene (Teflon).
  - polylactic acid (PLA), polyamide (nylon) and polyester.
- Explain how properties, including strength, density and biodegradability of polymers can be related to the structures of the materials.
- Explain the acid-base properties of 2-amino acids, including the formation of zwitterions.

Analytical techniques

- Explain how amino acids can be separated and identified by paper/TLC chromatography, including intermolecular forces/solubility in mobile and stationary phase and retention (R_f) values.
- Explain how amino acids can be separated and analysed by electrophoresis, including pH of buffer, isoelectric points, and movement of charged ions.
- Analyse data, including paper/TLC chromatograms and electrophoresis to determine the identity of amino acids and retention factors. (Formula: $R_\mathrm{f} = \frac{\text{distance moved by the amino acid}}{\text{distance moved by the solvent}}$)
- Analyse data from spectra, including mass spectroscopy and infraredred to determine the identity and structure of organic molecules.

Science as a human endeavour (SHE)

The following subject matter may be assessed in the internal assessments.

- Appreciate that the developments in computer modelling enabled more accurate visualisation and prediction of three-dimensional organic structures, such as proteins, which is critical in drug design and biotechnology.
- Recognise that enzymes are proteins and explore characteristics of biological catalysts (enzymes), including activity, depends on the structure and the specificity of the enzyme action.
- Consider that triglycerides (lipids) are esters, and that saturated and unsaturated fatty acids have difference structures and properties.
- Appreciate that synthetic polymers often have large ‘ecological footprints’ as they are synthesised from fossil fuels and do not biodegrade. Therefore, sustainable polymers, produced from renewable sources such as plants, waste products and waste gases are ‘greener’.
- Explore the principles of green chemistry and recognise that the higher the atom economy, the ‘greener’ the process.
- Appreciate that organochlorine compounds, such as DDT, chlordane and lindane, were identified as powerful insecticides in the 1950s because their structure makes them chemically unreactive.
- Explore the relationship between the chemical structure of insecticides, their effectiveness as an insecticide, and their persistent and bioaccumulation in the environment.

Science inquiry

The following subject matter may be assessed in the internal assessments.

Investigate:

- properties of homogenous series*
- 3D models of organic molecules.
- paper/TLC chromatography to separate amino acids*
- electrophoresis to separate amino acids*
- mass spectroscopy and infrared red spectra.*

***Note:** Simulations may be used.

Topic 2: Chemical synthesis and design (15 hours)

Science understanding

The following subject matter can be assessed in the external assessment.

Chemical synthesis

- Explain that reagents and reaction conditions are chosen to optimise the yield and rate for chemical synthesis processes, including the production of ammonia (Haber process) and sulfuric acid (contact process).
- Describe, using equations, the
  - production of ammonia by the Haber process
  - production of sulfuric acid using the contact process
  - production of ethanol from fermentation and the hydration of ethene
  - operation of a hydrogen fuel cell under acidic and alkaline conditions.
- Calculate the yield of chemical synthesis reactions by comparing stoichiometric quantities with actual quantities and by determining limiting reagents and/or reaction conditions.
- Analyse and interpret data to determine the impact of reagents and reaction conditions on yield and rate of chemical synthesis processes.

Macromolecules: polymers, proteins and carbohydrates

- Describe, using equations, how
  - addition polymers, including polyethene (LDPE and HDPE), polypropene and polytetrafluorethene, can be produced from their monomers
  - condensation polymers, including polysaccharides (carbohydrates), polylactic acid (PLA), polyamide (proteins and nylon) and polyester, can be produced from their monomers.
- Apply amino acid symbols to construct and name tripeptides.
- Identify that tripeptides are formed when amino acid monomers are joined by peptide bonds.
- Identify that disaccharides are formed when monosaccharides monomers are joined by glycosidic bonds.

Science as a human endeavour (SHE)

The following subject matter may be assessed in the internal assessments.

- Appreciate that green chemistry aims to increase the atom economy of chemical processes by designing novel reactions that can maximise the desired products and minimise by-products.
- Explore important developments in sustainable chemical industries, such as new synthetic schemes that can simplify operations in chemical productions and greener solvents that are inherently environmentally and ecologically benign.
- Consider the principles of green chemistry, including the design of chemical synthesis processes that use renewable raw materials, limiting the use of potentially harmful solvents and minimising the amount of unwanted products. Atom economy can be calculated and used to draw conclusions about the economic and environmental impact of chemical synthesis processes.
- Appreciate that dwindling supplies of economically viable sources of fossil fuels and concerns related to carbon emissions have prompted research into the synthesis of biofuels.
- Explore the development of biofuels from plant feedstocks, such as algae, oil seeds and wood waste, or from waste materials, such as food industry waste oils.
- Appreciate that molecular manufacturing (or molecular assembly) involves building objects to atomic precision using robotic mechanisms to position and react molecules and has the potential to quickly develop products (such as stronger materials, and smaller, faster and more energy-efficient computers) and address a range of global issues through provision of vital materials and products at a greatly reduced cost and environmental impact.
- Explore how enzymes can be used on an industrial scale for chemical synthesis to achieve an economically viable rate, including fermentation to produce ethanol and lipase-catalysed transesterification to produce biodiesel.
- Consider that molecular manufacturing processes involve the positioning of molecules to facilitate a specific chemical reaction; such methods have the potential to synthesise specialised products, including proteins, carbon nanotubes, nanorobots and chemical sensors used in medicine.

Science inquiry

The following subject matter may be assessed in the internal assessments.

Investigate:

- the Haber and contact processes*
- the properties of polymers.

***Note:** Simulations may be used.

Assessment

Internal assessment 1: Data test (10%)

Students respond to items using qualitative data and/or quantitative data derived from practicals, activities or case studies from Unit 3.

Assessment objectives

2. Apply understanding of chemical equilibrium systems or oxidation and reduction to given algebraic, visual or graphical representations of scientific relationships and data to determine unknown scientific quantities or features.
3. Analyse data about chemical equilibrium systems or oxidation and reduction to identify trends, patterns, relationships, limitations or uncertainty in datasets.
4. Interpret evidence about chemical equilibrium systems or oxidation and reduction to draw conclusions based on analysis of datasets.

Specifications

The teacher provides an examination that may ask students to respond using:

- single words
- sentences (up to 150 words per question)
- calculations.

Question specifications

The examination must be aligned to the specifications provided in the table below.

Focus of question	Mark allocation (± 2%)	Objective	In these questions, students:
Unknown scientific quantities or features of datasets	~ 30%	2	calculate using algorithms, determine, identify, use
Trends, patterns, relationships, limitations or uncertainty in datasets	~ 30%	3	categorise, classify, compare, contrast, identify, organise, sequence
Conclusions based on analysis of datasets	~ 40%	4	deduce, determine, draw (a conclusion), extrapolate, infer, interpolate, justify, predict

Stimulus specifications

The teacher provides unseen stimulus that:

- uses qualitative data and/or quantitative data from the listed practicals, activities or case studies from Unit 3
- contains between two and four datasets.

Conditions

- Time allowed
  - Perusal time: 5 minutes
  - Working time: 60 minutes
- This is an individual supervised task.
- Students are permitted a QCAA-approved graphics or scientific calculator.

Mark allocation

Criterion	Assessment objectives	Marks
Data test	2, 3, 4	10
	Total marks:	10

Instrument-specific marking guide

Data test	Cut-off	Marks
The student response has the following characteristics:		
• consistent demonstration, across a range of scenarios, of – selection and correct application of scientific concepts, theories, models and systems to predict outcomes, behaviours and implications – correct calculation of quantities through the use of algebraic, visual and graphical representations of scientific relationships and data – correct and appropriate use of analytical techniques to correctly identify trends, patterns, relationships, limitations and uncertainty – correct interpretation of evidence to draw valid conclusions	> 90%	10
	> 80%	9
• consistent demonstration of – selection and correct application of scientific concepts, theories, models and systems to predict outcomes, behaviours and implications – correct calculation of quantities through the use of algebraic, visual and graphical representations of scientific relationships and data – correct use of analytical techniques to correctly identify trends, patterns, relationships, limitations and uncertainty – correct interpretation of evidence to draw valid conclusions	> 70%	8
	> 60%	7
• adequate demonstration of – selection and correct application of scientific concepts, theories, models and systems to predict outcomes, behaviours and implications – correct calculation of quantities through the use of algebraic, visual and graphical representations of scientific relationships and data – correct use of analytical techniques to correctly identify trends, patterns, relationships, limitations and uncertainty – correct interpretation of evidence to draw valid conclusions	> 50%	6
	> 40%	5
• demonstration of elements of – selection and correct application of scientific concepts, theories, models and systems to predict outcomes, behaviours and implications – correct calculation of quantities through the use of algebraic, visual or graphical representations of scientific relationships or data – correct use of analytical techniques to correctly identify trends, patterns, relationships, limitations or uncertainty – correct interpretation of evidence to draw valid conclusions	> 30%	4
	> 20%	3
• demonstration of elements of – application of scientific concepts, theories, models or systems to predict outcomes, behaviours or implications – calculation of quantities through the use of algebraic or graphical representations of scientific relationships and data – use of analytical techniques to identify trends, patterns, relationships, limitations or uncertainty – interpretation of evidence to draw conclusions.	> 10%	2
	> 1%	1
The student response does not match any of the descriptors above.	≤ 1%	0

Internal assessment 2: Student experiment (20%)

Students modify (i.e. refine, extend or redirect) an experiment relevant to Unit 3 subject matter to address their own related hypothesis or question. This assessment provides opportunities to assess science inquiry skills.

Assessment objectives

1. Describe ideas and experimental findings about chemical equilibrium systems or oxidation and reduction.
2. Apply understanding of chemical equilibrium systems or oxidation and reduction to modify experimental methodologies and process data.
3. Analyse experimental data about chemical equilibrium systems or oxidation and reduction.
4. Interpret experimental evidence about chemical equilibrium systems or oxidation and reduction.
5. Evaluate experimental processes and conclusions about chemical equilibrium systems or oxidation and reduction.
6. Investigate phenomena associated with chemical equilibrium systems or oxidation and reduction through an experiment.

Specifications

This task requires students to:

- identify an experiment to modify
- develop a research question to be investigated
- research relevant background scientific information to inform the modification of the research question and methodology
- conduct a risk assessment and account for risks in the methodology
- conduct the experiment
- collect relevant qualitative data and/or quantitative data to address the research question
- process and present the data appropriately
- analyse the evidence to identify trends, patterns or relationships
- analyse the evidence to identify uncertainty and limitations
- interpret the evidence to draw conclusion/s to the research question
- evaluate the reliability and validity of the experimental process
- suggest possible improvements and/or extensions to the experiment
- communicate findings in an appropriate scientific genre, e.g. report, poster presentation, journal article, conference presentation.

Scientific inquiry is a non-linear, iterative process. Students will not necessarily complete these steps in the stated order; some steps may be repeated or revisited.

It is recommended that this task is designed so that students can develop a response in approximately 10 hours of class time.

Conditions

- Students can develop their responses in class time and their own time.
- This is an individual task.
- The following aspects of the task may be completed as a group
  - identifying an experiment
  - developing a research question
  - conducting a risk assessment
  - conducting the experiment
  - collecting data.
- Students use a practical or simulation performed in class as the basis for their methodology and research question.

Response requirements

One of the following:

- Multimodal (at least two modes delivered at the same time): up to 11 minutes
- Written: up to 2000 words

Mark allocation

Criterion	Assessment objectives	Marks
Forming	1, 2, 6	5
Finding	6	5
Analysing	2, 3	5
Interpreting and Evaluating	4, 5	5
	Total marks:	20

Instrument-specific marking guide

Forming	Marks
The student response has the following characteristics:	
• a considered rationale for the experiment • justified modifications to the methodology • a specific and relevant research question • appropriate use of genre and referencing conventions • fluent and concise use of scientific language and representations	4–5
• a reasonable rationale for the experiment • feasible modifications to the methodology • a relevant research question • use of basic genre and referencing conventions • competent use of scientific language and representations	2–3
• a vague or irrelevant rationale for the experiment • inappropriate modifications to the methodology • an inappropriate research question • inadequate use of genre and referencing conventions • simplistic use of language and representations.	1
The student response does not match any of the descriptors above.	0

Finding	Marks
The student response has the following characteristics:	
• a methodology that enables the collection of sufficient, relevant data • considered management of risks/ethical issues/environmental issues • collection of sufficient and relevant raw data	4–5
• a methodology that enables the collection of relevant data • management of risks/ethical issues/environmental issues • collection of relevant raw data	2–3
• a methodology that causes the collection of insufficient and irrelevant data • inadequate management of risks/ethical issues/environmental issues • collection of insufficient and irrelevant raw data.	1
The student response does not match any of the descriptors above.	0

Analysing	Marks
The student response has the following characteristics:	
• correct and relevant processing of data • thorough identification of relevant trends/patterns/relationships • thorough and appropriate identification of the uncertainty and limitations of evidence	4–5
• basic processing of data • identification of obvious trends/patterns/relationships • basic identification of uncertainty/limitations of evidence	2–3
• incorrect or irrelevant processing of data • identification of incorrect or irrelevant trends/patterns/relationships • incorrect or insufficient identification of uncertainty/limitations of evidence.	1
The student response does not match any of the descriptors above.	0

Interpreting and Evaluating	Marks
The student response has the following characteristics:	
• justified conclusion/s linked to the research question • justified discussion of the reliability and validity of the experimental process • suggested improvements and extensions to the experiment that are logically derived from the analysis of evidence	4–5
• reasonable conclusion/s relevant to the research question • reasonable description of the reliability and validity of the experimental process • suggested improvements and/or extensions to the experiment that are related to the analysis of evidence	2–3
• inappropriate or irrelevant conclusion/s • cursory or simplistic statements about the reliability and validity of the experimental process • ineffective or irrelevant suggestions.	1
The student response does not match any of the descriptors above.	0

Internal assessment 3: Research investigation (20%)

Students gather evidence related to a research question to evaluate a claim relevant to Unit 4 subject matter. This assessment provides opportunities to assess science inquiry skills and science as a human endeavour (SHE) subject matter.

Assessment objectives

1. Describe ideas and findings about the properties and structure of organic materials or chemical synthesis and design.
2. Apply understanding of the properties and structure of organic materials or chemical synthesis and design to develop research questions.
3. Analyse research data about the properties and structure of organic materials or chemical synthesis and design.
4. Interpret research evidence about the properties and structure of organic materials or chemical synthesis and design.
5. Evaluate research processes, claims and conclusions about the properties and structure of organic materials or chemical synthesis and design.
6. Investigate phenomena associated with the properties and structure of organic materials or chemical synthesis and design through research.

Specifications

This task requires students to:

- select a claim to be evaluated, from a list provided by the teacher
- identify the relevant scientific concepts associated with the claim
- conduct research to gather evidence from scientifically credible sources to evaluate the claim
- pose a research question that addresses an aspect of the claim
- identify relevant evidence to answer the research question
- identify the trends, patterns or relationships in the evidence
- analyse the evidence to identify limitations
- interpret the evidence to construct scientific arguments
- interpret the evidence to form a conclusion to the research question
- discuss the quality of the evidence
- evaluate the claim by applying the findings of the research to the claim
- suggest improvements and/or extensions to the investigation
- communicate findings in an appropriate scientific genre, e.g. report, journal article, essay, conference presentation.

Scientific inquiry is a non-linear, iterative process. Students will not necessarily complete these steps in the stated order; some steps may be repeated or revisited.

Evidence must be obtained by researching scientifically credible sources, such as:

- books and podcasts by well-credentialed scientists
- 'popular' science websites or magazines
- websites of governments, universities, independent research bodies or science and technology manufacturers
- scientific journals.

It is recommended that this task is designed so that students can develop a response in approximately 10 hours of class time.

Conditions

- Students can develop their responses in class time and their own time.
- This is an individual task.
- The following aspects of the task may be completed as a group
  - selecting a claim
  - identifying the relevant scientific concepts associated with the claim
  - conducting research.

Response requirements

One of the following:

- Multimodal (at least two modes delivered at the same time): up to 11 minutes
- Written: up to 2000 words

Mark allocation

Criterion	Assessment objectives	Marks
Forming and Finding	1, 2, 6	5
Analysing	3	5
Interpreting	4, 5	5
Evaluating	5, 1	5
	Total marks:	20

Instrument-specific marking guide

Forming and Finding	Marks
The student response has the following characteristics:	
• a considered rationale identifying clear development of the research question from the claim • a specific and relevant research question • selection of sufficient and relevant sources • acknowledgment of sources of information through appropriate use of referencing conventions • fluent and concise use of scientific language/representations	4–5
• a reasonable rationale that links the research question and the claim • a relevant research question • selection of relevant sources • use of basic referencing conventions • competent use of scientific language/representations	2–3
• a vague or irrelevant rationale for the investigation • an inappropriate research question • selection of insufficient or irrelevant sources • inadequate acknowledgment of sources • incorrect use of language/representations.	1
The student response does not match any of the descriptors above.	0

Analysing	Marks
The student response has the following characteristics:	
• the identification of sufficient and relevant evidence • thorough identification of relevant trends/patterns/relationships in evidence • thorough and appropriate identification of limitations of evidence	4–5
• the identification of relevant evidence • identification of obvious trends/patterns/relationships in evidence • basic identification of limitations of evidence	2–3
• the identification of insufficient and irrelevant evidence • identification of incorrect or irrelevant trends/patterns/relationships in evidence • incorrect or insufficient identification of limitations of evidence.	1
The student response does not match any of the descriptors above.	0

Interpreting	Marks
The student response has the following characteristics:	
• justified scientific argument/s • justified conclusion linked to the research question • justified discussion of the quality of evidence	4–5
• reasonable scientific argument/s • reasonable conclusion relevant to the research question • reasonable description of the quality of evidence	2–3
• inappropriate or irrelevant argument/s • inappropriate or irrelevant conclusion • cursory or simplistic statements about the quality of evidence.	1
The student response does not match any of the descriptors above.	0

Evaluating	Marks
The student response has the following characteristics:	
• extrapolation of credible findings of the research to the claim • suggested improvements and extensions to the investigation that are considered and relevant to the claim • appropriate use of genre conventions	4–5
• application of relevant findings of the research to the claim • suggested improvements and/or extensions to the investigation that are relevant to the claim • use of basic genre conventions	2–3
• application of insufficient or inappropriate findings of the research to the claim • ineffective or irrelevant suggestions • inadequate use of genre conventions.	1
The student response does not match any of the descriptors above.	0

External assessment: Examination — combination response (50%)

External assessment is developed and marked by the QCAA. The external assessment in Chemistry is common to all schools and administered under the same conditions, at the same time, on the same day.

Assessment objectives

1. Describe ideas and findings about chemical equilibrium systems, oxidation and reduction, properties and structure of organic materials, and chemical synthesis and design.
2. Apply understanding of chemical equilibrium systems, oxidation and reduction, properties and structure of organic materials, and chemical synthesis and design.
3. Analyse data about chemical equilibrium systems, oxidation and reduction, properties and structure of organic materials, and chemical synthesis and design to identify trends, patterns, relationships, limitations or uncertainty.
4. Interpret evidence about chemical equilibrium systems, oxidation and reduction, properties and structure of organic materials, and chemical synthesis and design to draw conclusions based on analysis.

Specifications

This examination:

- includes two papers. Each paper consists of a number of different types of questions relating to Units 3 and 4
- may ask students to respond using
  - multiple choice
  - single words
  - sentences or paragraphs
- may ask students to
  - calculate using algorithms
  - interpret unseen stimulus, including graphs, tables or diagrams.

Conditions

Paper 1

- Time allowed
  - Perusal time: 5 minutes
  - Working time: 90 minutes
- Students may use a QCAA-approved graphics or scientific calculator.
- The QCAA provides the QCAA Chemistry formula and data book.

Paper 2

- Time allowed
  - Perusal time: 5 minutes
  - Working time: 90 minutes
- Students may use a QCAA-approved graphics or scientific calculator.
- The QCAA provides the QCAA Chemistry formula and data book.

Glossary

The syllabus glossary is available at www.qcaa.qld.edu.au/downloads/senior-qce/common/snr_glossary_cognitive_verbs.pdf.

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Version history

Version	Date of change	Information
1.0	January 2024	Released for familiarisation and planning (with implementation starting in 2025)