Diploma Programme

Chemistry guide

First assessment 2025

International Baccalaureate®
Baccalauréat International
Bachillerato Internacional

Diploma Programme

Chemistry guide

First assessment 2025

International Baccalaureate®
Baccalauréat International
Bachillerato Internacional

Diploma Programme
Chemistry guide

Published February 2023
Updated May 2023

Published on behalf of the International Baccalaureate Organization, a not-for-profit educational foundation of 15 Route des Morillons, 1218 Le Grand-Saconnex, Geneva, Switzerland by the

International Baccalaureate Organization (UK) Ltd
Peterson House, Malthouse Avenue, Cardiff Gate
Cardiff, Wales CF23 8GL
United Kingdom
Website: ibo.org

The International Baccalaureate Organization (known as the IB) offers four high-quality and challenging educational programmes for a worldwide community of schools, aiming to create a better, more peaceful world. This publication is one of a range of materials produced to support these programmes.

The IB may use a variety of sources in its work and check information to verify accuracy and authenticity, particularly when using community-based knowledge sources such as Wikipedia. The IB respects the principles of intellectual property and makes strenuous efforts to identify and obtain permission before publication from rights holders of all copyright material used. The IB is grateful for permissions received for material used in this publication and will be pleased to correct any errors or omissions at the earliest opportunity.

IB merchandise and publications can be purchased through the IB Store (email: sales@ibo.org). Any commercial use of IB publications (whether fee-covered or commercial) by third parties acting in the IB's ecosystem without a formal relationship with the IB (including but not limited to tutoring organizations, professional development providers, educational publishers and operators of curriculum mapping or teacher resource digital platforms, etc.) is prohibited and requires a subsequent written licence from the IB. Licence requests should be sent to copyright@ibo.org. More information can be obtained on the IB public website.

IB mission statement

The International Baccalaureate aims to develop inquiring, knowledgeable and caring young people who help to create a better and more peaceful world through intercultural understanding and respect.

To this end the organization works with schools, governments and international organizations to develop challenging programmes of international education and rigorous assessment.

These programmes encourage students across the world to become active, compassionate and lifelong learners who understand that other people, with their differences, can also be right.

IB learner profile

The aim of all IB programmes is to develop internationally minded people who, recognizing their common humanity and shared guardianship of the planet, help to create a better and more peaceful world.

As IB learners we strive to be:

INQUIRERS

We nurture our curiosity, developing skills for inquiry and research. We know how to learn independently and with others. We learn with enthusiasm and sustain our love of learning throughout life.

KNOWLEDGEABLE

We develop and use conceptual understanding, exploring knowledge across a range of disciplines. We engage with issues and ideas that have local and global significance.

THINKERS

We use critical and creative thinking skills to analyse and take responsible action on complex problems. We exercise initiative in making reasoned, ethical decisions.

COMMUNICATORS

We express ourselves confidently and creatively in more than one language and in many ways. We collaborate effectively, listening carefully to the perspectives of other individuals and groups.

PRINCIPLED

We act with integrity and honesty, with a strong sense of fairness and justice, and with respect for the dignity and rights of people everywhere. We take responsibility for our actions and their consequences.

OPEN-MINDED

We critically appreciate our own cultures and personal histories, as well as the values and traditions of others. We seek and evaluate a range of points of view, and we are willing to grow from the experience.

CARING

We show empathy, compassion and respect. We have a commitment to service, and we act to make a positive difference in the lives of others and in the world around us.

RISK-TAKERS

We approach uncertainty with forethought and determination; we work independently and cooperatively to explore new ideas and innovative strategies. We are resourceful and resilient in the face of challenges and change.

BALANCED

We understand the importance of balancing different aspects of our lives—intellectual, physical, and emotional—to achieve well-being for ourselves and others. We recognize our interdependence with other people and with the world in which we live.

REFLECTIVE

We thoughtfully consider the world and our own ideas and experience. We work to understand our strengths and weaknesses in order to support our learning and personal development.

The IB learner profile represents 10 attributes valued by IB World Schools. We believe these attributes, and others like them, can help individuals and groups become responsible members of local, national and global communities.

International Baccalaureate®
Baccalauréat International
Bachillerato Internacional

Contents

Purpose of this document

This publication is intended to guide the planning, teaching and assessment of chemistry in schools. Subject teachers are the primary audience, although it is expected that teachers will use the guide to inform students and parents about the subject.

This guide can be found on the subject page of the Programme Resource Centre at resources.ibo.org, a password-protected International Baccalaureate (IB) website designed to support IB teachers. It can also be purchased from the IB store at store.ibo.org.

Additional resources

Additional publications such as specimen papers and markschemes, teacher support material (TSM), subject reports and grade descriptors can also be found on the Programme Resource Centre. Past examination papers as well as markschemes can be purchased from the IB store.

Teachers are encouraged to check the Programme Resource Centre for additional resources created or used by other teachers. Teachers can provide details of useful resources, for example: websites, books, videos, journals or teaching ideas.

Acknowledgement

The IB wishes to thank the educators and associated schools for generously contributing time and resources to the production of this guide.

First assessment 2025

The Diploma Programme

The Diploma Programme (DP) is a rigorous pre-university course of study designed for students in the 16 to 19 age range. It is a broad-based two-year course that aims to encourage students to be knowledgeable and inquiring, but also caring and compassionate. There is a strong emphasis on encouraging students to develop intercultural understanding, open-mindedness, and the attitudes necessary for them to respect and evaluate a range of points of view.

The Diploma Programme model

The course is presented as six academic areas enclosing a central core (see figure 1). It encourages the concurrent study of a broad range of academic areas. Students study two modern languages (or a modern language and a classical language), a humanities or social science subject, an experimental science, mathematics and one of the creative arts. It is this comprehensive range of subjects that makes the DP a demanding course of study designed to prepare students effectively for university entrance. In each of the academic areas students have flexibility in making their choices, which means they can choose subjects that particularly interest them and that they may wish to study further at university.

Figure 1

Diploma Programme model

Choosing the right combination

Students are required to choose one subject from each of the six academic areas, although they can, instead of an arts subject, choose two subjects from another area. Normally, three subjects (and not more than four) are taken at higher level (HL), and the others are taken at standard level (SL). The IB recommends 240 teaching hours for HL subjects and 150 hours for SL. Subjects at HL are studied in greater depth and breadth than at SL.

At both levels, many skills are developed, especially those of critical thinking and analysis. At the end of the course, students' abilities are measured by means of external assessment. Many subjects contain some element of coursework assessed by teachers.

The core of the Diploma Programme model

All DP students participate in the three course elements that make up the core of the model.

Theory of knowledge (TOK) is a course that is fundamentally about critical thinking and inquiry into the process of knowing rather than about learning a specific body of knowledge. The TOK course examines the nature of knowledge and how we know what we claim to know. It does this by encouraging students to analyse knowledge claims and explore questions about the construction of knowledge. The task of TOK is to emphasize connections between areas of shared knowledge and link them to personal knowledge in such a way that an individual becomes more aware of their own perspectives and how they might differ from others.

In TOK, students explore the means of producing knowledge within the core theme of "knowledge and the knower" as well as within various optional themes (knowledge and technology, knowledge and politics, knowledge and language, knowledge and religion, and knowledge and indigenous societies) and areas of knowledge (the arts, natural sciences, human sciences, history and mathematics). The course also encourages students to make comparisons between different areas of knowledge and reflect on how knowledge is arrived at in the various disciplines, what the disciplines have in common, and the differences between them.

Creativity, activity, service (CAS) is at the heart of the DP. The emphasis in CAS is on helping students to develop their own identities, in accordance with the ethical principles embodied in the IB mission statement and the IB learner profile. It involves students in a range of activities alongside their academic studies throughout the DP. The three strands of CAS are creativity (arts and other experiences that involve creative thinking), activity (physical exertion contributing to a healthy lifestyle) and service (an unpaid and voluntary exchange that has a learning benefit for the student). Possibly, more than any other component in the DP, CAS contributes to the IB's mission to create a better and more peaceful world through intercultural understanding and respect.

The extended essay (EE), including the world studies extended essay, offers the opportunity for IB students to investigate a topic of special interest, in the form of a 4,000-word piece of independent research. The area of research undertaken is chosen from one of the students' six DP subjects, or in the case of the interdisciplinary world studies essay, two subjects, and acquaints them with the independent research and writing skills expected at university. This leads to a major piece of formally presented, structured writing, in which ideas and findings are communicated in a reasoned and coherent manner, appropriate to the subject or subjects chosen. It is intended to promote high-level research and writing skills, intellectual discovery and creativity. An authentic learning experience, it provides students with an opportunity to engage in personal research on a topic of choice, under the guidance of a supervisor.

Approaches to teaching and approaches to learning

Approaches to teaching and approaches to learning (ATL) across the DP refers to deliberate strategies, skills and attitudes that permeate the teaching and learning environment. These approaches and tools, intrinsically linked with the learner profile attributes, enhance student learning and assist student preparation for the DP assessment and beyond. The aims of approaches to teaching and learning in the DP are to:

- empower teachers as teachers of learners as well as teachers of content
- empower teachers to create clearer strategies for facilitating learning experiences in which students are more meaningfully engaged in structured inquiry and greater critical and creative thinking
- promote both the aims of individual subjects (making them more than course aspirations) and linking previously isolated knowledge (concurrency of learning)
- encourage students to develop an explicit variety of skills that will equip them to continue to be actively engaged in learning after they leave school, and to help them not only obtain university admission through better grades but also prepare for success during tertiary education and beyond
- enhance further the coherence and relevance of the students' DP experience
- allow schools to identify the distinctive nature of an IB DP education, with its blend of idealism and practicality.

The five ATL (developing thinking skills, social skills, communication skills, self-management skills and research skills) along with the six approaches to teaching (teaching that is inquiry-based, conceptually focused, contextualized, collaborative, differentiated and informed by assessment) encompass the key values and principles that underpin IB pedagogy.

The IB mission statement and the IB learner profile

The DP aims to develop in students the knowledge, skills and attitudes they will need to fulfil the aims of the IB, as expressed in the organization's mission statement and the learner profile. Teaching and learning in the DP represent the reality in daily practice of the organization's educational philosophy.

Academic integrity

Academic integrity in the DP is a set of values and behaviours informed by the attributes of the learner profile. In teaching, learning and assessment, academic integrity serves to promote personal integrity, engender respect for the integrity of others and their work, and ensure that all students have an equal opportunity to demonstrate the knowledge and skills they acquire during their studies.

All coursework—including work submitted for assessment—is to be authentic, based on the student's individual and original ideas with the ideas and work of others fully acknowledged. Assessment tasks that require teachers to provide guidance to students or that require students to work collaboratively must be completed in full compliance with the detailed guidelines provided by the IB for the relevant subjects.

For further information on academic integrity in the IB and the DP, please consult the IB publications *Academic integrity policy*, *Effective citing and referencing*, *Diploma Programme: From principles into practice* and the general regulations in *Diploma Programme Assessment procedures* (updated annually). Specific information regarding academic integrity as it pertains to external and internal assessment components of this DP subject can be found in this guide.

Acknowledging the ideas or work of another person

Coordinators and teachers are reminded that candidates must acknowledge all sources used in work submitted for assessment. The following is intended as a clarification of this requirement.

DP candidates submit work for assessment in a variety of media that may include audiovisual material, text, graphs, images and/or data published in print or electronic sources. If a candidate uses the work or ideas of another person, the candidate must acknowledge the source using a standard style of referencing in a consistent manner. A candidate's failure to acknowledge a source will be investigated by the IB as a potential breach of regulations that may result in a penalty imposed by the IB final award committee.

The IB does not prescribe which style(s) of referencing or in-text citation should be used by candidates; this is left to the discretion of appropriate faculty/staff in the candidate's school. The wide range of subjects, response languages and the diversity of referencing styles make it impractical and restrictive to insist on particular styles. In practice, certain styles may prove most commonly used, but schools are free to choose a style that is appropriate for the subject concerned and the language in which candidates' work is written. Regardless of the reference style adopted by the school for a given subject, it is expected that the minimum information given includes: name of author, date of publication, title of source, and page numbers as applicable.

Candidates are expected to use a standard style and use it consistently so that credit is given to all sources used, including sources that have been paraphrased or summarized. When writing text candidates must clearly distinguish between their words and those of others by the use of quotation marks (or other method, such as indentation) followed by an appropriate citation that denotes an entry in the bibliography. If an electronic source is cited, the date of access must be indicated. Candidates are not expected to show faultless expertise in referencing, but are expected to demonstrate that all sources have been acknowledged. Candidates must be advised that audiovisual material, text, graphs, images and/or data published in print or in electronic sources that is not their own must also attribute the source. Again, an appropriate style of referencing/citation must be used.

Learning diversity and learning support requirements

Schools must ensure that equal access arrangements and reasonable adjustments are provided to candidates with learning support requirements that are in line with the IB documents *Access and inclusion policy* and *Learning diversity and inclusion in IB programmes: Removing barriers to learning.*

The publications *Meeting student learning diversity in the classroom* and *The IB guide to inclusive education: a resource for whole school development* are available to support schools in the ongoing process of increasing access and engagement by removing barriers to learning.

Programme standards and practices

The programme standards and practices are a set of principles for schools to ensure quality and fidelity in the implementation of IB programmes. Teaching and learning are important markers of quality and effective practice in schools; thus the expectations teachers and learners share across all IB programmes can be found in the programme standards and practices.

The programme standards and practices provide a framework to help teachers understand their rights and responsibilities in IB World Schools as they develop learning environments and experiences for their students. The IB recognizes that in order for effective teaching to take place, teachers must be supported in their understanding, well-being, environment and resources. Teachers use the core tenets of IB philosophy and pedagogy (approaches to teaching, ATL, the learner profile and international-mindedness) to design learning experiences that prepare learners to fulfil the aims and objectives outlined in this guide.

To learn more about teachers' rights and responsibilities, please see the IB publication *Programme standards and practices* on the Programme Resource Centre.

Nature of science

What is nature of science?

Nature of science (NOS) is an overarching theme in the biology, chemistry and physics courses that seeks to explore conceptual understandings related to the purpose, features and impact of scientific knowledge.

What do we want to know in science?

Nobel laureate and influential popularizer of science, Richard Feynman, once described the process of science using the analogy of watching an unknown board game being played "... and you don't know the rules of the game, but you're allowed to look at the board from time to time. And from these observations, you try to figure out what the rules are of the game, [and] the rules of the pieces moving" (Feynman et al., 1963).

What is the scientific endeavour?

Classifying such observations and underlying patterns in the natural world is the essence of what scientists do, underpinned by the assumption that the universe exists as an external reality accessible to the human experience. The varied and often non-linear processes used in scientific methodologies have several key features in common to maximize the validity and reliability of knowledge produced. The development of falsifiable hypotheses, a requirement for replicable data, and the utilization of peer-review may be among the most essential of these and help differentiate a scientific process from a pseudoscientific one. The communal and collaborative nature of this approach further strengthens the objectivity of science by ensuring the inclusion of diverse perspectives and shared responsibility for its outcomes.

What type of knowledge do we produce?

Formal scientific knowledge may encompass several categories including representative models, explanatory theories and descriptive laws. As the focus of each discipline of natural science differs, so too does the balance of their contributions to each category. What remains constant, however, is the acknowledgement of assumptions, exceptions and limitations of scientific knowledge to provide realistic parameters to our understanding of the natural world. Claims of certainty are treated with caution given the presence of paradigmatic shifts throughout the history of science.

What is the impact of scientific knowledge?

As well as the pursuit of knowledge for its own sake, it is useful to consider the interplay of science with other areas of society. Although advances in technology traditionally fuelled great leaps in scientific understanding, in recent times it may be more common to see science as a driver of technological development. In addition, the implications of science within environmental, political, social, cultural and economic domains can also be profound. These connections illustrate the importance of local, national and international scientific bodies that engage with the public understanding of science and heighten the responsibility of scientists to adhere to principles of academic integrity in their research.

Table 1

Aspects of nature of science

Aspects	How are scientific knowledge claims generated, tested, communicated, evaluated and used? What issues arise from these actions?
Observations	Scientists act as observers, looking at Earth and all other parts of the universe, to obtain data about natural phenomena. Observations can be made directly using human senses, or with the aid of instruments such as electronic sensors. Unexpected or unplanned observations can open up new research fields.
Patterns and trends	Scientists analyse their observations, looking for patterns or trends, and try to draw general conclusions by inductive reasoning. They also look for discrepancies. Scientists classify objects through pattern recognition. A trend may take the form of a positive or negative correlation between variables. Correlations may be based on a causal relationship, but correlation does not prove causation.
Hypotheses	Scientists make provisional explanations for the patterns that they have observed in natural phenomena. These hypotheses can be tested, with further observations or experiments, to obtain support for a hypothesis or show that it is false.
Experiments	Scientists design and perform experiments to obtain data, which can be used to test hypotheses. The quality of experimental evidence depends on careful control of variables and on the quantity of data generated. Progress in science often follows technological developments that allow new experimental techniques. Creativity and imagination play a role in experimental design, interpretation and conclusion.
Measurement	Quantitative measurements are more objective than qualitative observations, but all measurements are limited in precision and accuracy. Measurements are repeated to strengthen the reliability of data. Random errors in measurement due to unknown or unpredictable differences lead to imprecision and uncertainty, whereas systematic errors lead to inaccuracy.
Models	Scientists construct models as artificial representations of natural phenomena. They are useful when direct observation or experimentation is difficult. Models are simplifications of complex systems and can be physical representations, abstract diagrams, mathematical equations or algorithms. All models have limitations that need to be considered in their application.
Evidence	Scientists adopt a sceptical attitude to claims and evaluate them using evidence. Some claims cannot be tested using verifiable evidence, so cannot be falsified. They are therefore not scientific. Scientific knowledge must be supported by evidence.
Theories	Scientists develop general explanations that are widely applicable, based on observed patterns or tested hypotheses. Predictions can be generated from these theories by deductive reasoning. If these predictions are tested, they may corroborate a theory or show that it is false and should be rejected. Paradigm shifts take place when a new theory replaces an old one. The term "law" is sometimes used for statements that allow predictions to be made about natural phenomena without explaining them.
Falsification	Scientists can use evidence to falsify a claim formulated as a hypothesis, theory or model, but they cannot prove with certainty that such a claim is true. There is therefore inherent uncertainty in all scientific knowledge. Nonetheless, many theories in science are corroborated by strong evidence and allow for prediction and explanation. Scientists must remain open-minded with respect to new evidence.

Aspects	How are scientific knowledge claims generated, tested, communicated, evaluated and used? What issues arise from these actions?
Science as a shared endeavour	Scientists communicate and collaborate throughout the world. Agreed conventions and common terminology facilitate unambiguous communication. Peer review is essential to verify the research methods of knowledge claims prior to their publication in journals.
Global impact of science	Scientists have an obligation to assess the risks associated with their work and must aim to do no harm. Developments in science may have ethical, environmental, political, social, cultural and economic consequences that must be considered during decision-making. The pursuit of science may have unintended consequences. Research proposals are often filtered through ethics boards. Scientists have a responsibility to communicate their findings to the public with honesty and clarity.

How is NOS different from TOK?

In contrast to the specificity of understanding of science, the TOK course encourages students to think critically about the concepts that underpin knowledge production. For example, peer review is used as a tool to support objectivity in scientific research. Through the study of TOK, students question the limitations of the peer review process and extend their thinking to an assessment of objectivity in other areas of knowledge.

Nature of chemistry

What is the purpose of studying chemistry?

As one of the three natural sciences in the IB Diploma Programme, chemistry is primarily concerned with identifying patterns that allow us to explain matter at the microscopic level. This then allows us to predict and control matter's behaviour at a macroscopic level. The subject therefore emphasizes the development of representative models and explanatory theories, both of which rely heavily on creative but rational thinking. Given the pattern-seeking nature of chemistry, the development of generalized rules and principles also plays an important part in knowledge production, as do the concrete statements provided by mathematical laws.

How is knowledge acquired in chemistry?

With its roots in the practice of alchemy, chemistry maintains a strong emphasis on empirical experimentation. However, with advances in technology, it now extends its reach beyond the limits of the human senses at a macroscopic level and into fields such as spectroscopy and computer molecular modelling. Insights from these technologies often require thorough mathematical analysis before being accepted as valid justifications for scientific claims. In all their investigative work, chemists must qualify confidence in their discoveries by considering potential errors related to methodology or limitations in measuring equipment.

What is the impact of chemistry?

As outlined in the "Nature of science" section, the pursuit of scientific knowledge does not occur in isolation. In chemistry, developments in fields such as biofuels or catalysis often have impacts far beyond the boundaries of academic research. Honest and clear communication to audiences beyond the scientific domain is therefore essential. The retraction of a 2019 research paper by Dr Frances Arnold, a Nobel laureate in chemistry, due to unreproducible data is a good example of embracing this ethical responsibility.

How is the nature of chemistry engaged with?

The Diploma Programme chemistry course supports teaching through:

- approaches to learning
- nature of science
- skills in the study of chemistry.

The Diploma Programme chemistry course supports learning in several ways.

- It offers a balanced experimental programme—Students are encouraged to become familiar with traditional experimentation techniques, as well as the application of technology where possible. These opportunities help them to develop their investigative skills and evaluate the impact of error in scientific inquiry.
- The scientific investigation—This places a specific emphasis on inquiry-based skills and the formal communication of scientific knowledge.
- The collaborative sciences project—This extends the development of scientific communication in a collaborative and interdisciplinary context, allowing students to work together beyond the confines of one specific syllabus.

Distinction between SL and HL

Students at SL and HL share the following.

- An understanding of science through a stimulating experimental programme
- The nature of science as an overarching theme
- The study of a concept-based syllabus
- One piece of internally assessed work, the scientific investigation
- The collaborative sciences project

The SL course provides students with a fundamental understanding of chemistry and experience of the associated skills. The HL course requires students to increase their knowledge and understanding of the subject, including additional mathematical skills, and so provides a solid foundation for further study at university level.

The SL course has a recommended 150 teaching hours, compared to 240 hours for the HL course. This difference is reflected in the additional content studied by HL students. Some of the HL content is conceptually more demanding and explored in greater depth. The distinction between SL and HL is therefore one of both breadth and depth. The increased breadth and depth at HL result in increased networked knowledge, requiring the student to make more connections between diverse areas of the syllabus.

Chemistry and the core

Chemistry and theory of knowledge

The TOK course plays a special role in the DP by providing opportunities for students to reflect on the nature, scope and limitations of knowledge and the process of knowing through an exploration of knowledge questions.

The areas of knowledge (AOK) are specific branches of knowledge, each of which can be seen to have a distinct nature and sometimes use different methods of gaining knowledge. In TOK, students explore five compulsory AOK: history, the human sciences, the natural sciences, mathematics and the arts.

There are several different ways in which aspects of the chemistry course can be connected to the exploration of knowledge. During the teaching and learning of the chemistry course, teachers and students evaluate knowledge claims by exploring questions concerning their validity, reliability, credibility and certainty, as well as individual and cultural perspectives on them.

Exploration of the relationship between knowledge and TOK concepts can help students to deepen their understanding and make connections between disciplines. For example, while discussing the depletion of energy sources and the constant need for new energy resources to meet energy demands, students can explore the concepts of responsibility, power and justification.

Many aspects of the chemistry course lend themselves to the exploration of knowledge questions. Some examples are provided in the following table.

Table 2

Examples of knowledge questions

Learning opportunities	Knowledge question
Chemical equations	Can all knowledge be expressed in words or symbols?
Development in our understanding of atomic theory	How can it be that scientific knowledge changes over time? What role do paradigm shifts play in the progression of scientific knowledge?
Acids and bases or the periodic table	To what extent do the classification systems we use in the pursuit of knowledge affect the conclusions that we reach?

Learning opportunities	Knowledge question
Analytic and spectroscopic techniques	How do the tools that we use shape the knowledge that we produce?
Structure of benzene and the origin of the “ring-like” model	What is the role of imagination and intuition in the creation of hypotheses in the natural sciences?

For more information, please refer to the *Theory of knowledge guide* and the *Theory of knowledge teacher support material.*

Chemistry and the extended essay

Students who choose to write an EE in chemistry undertake independent research as part of an in-depth study of a focused topic. The topic for study may be generated from the chemistry course or may relate to a subject area beyond the syllabus content. This detailed study will help develop research, thinking, self-management and communication skills, which will support students’ learning in the chemistry course, and in further studies.

Examples of areas for research topics

- Environmental chemistry—removing heavy metals or pesticides from the soil or water sources; measuring the amount of and effects of acid deposition.
- Food chemistry—investigating the stability of certain pigments or vitamins and the shelf life of certain molecules in food.
- Materials chemistry—assessing the durability or other chemical/physical properties of compounds, mixtures or metals.

Students and supervisors must ensure that an EE does not duplicate other work submitted for the diploma.

For more information, please refer to the *Extended essay guide* and the *Extended essay teacher support material.*

Chemistry and creativity, activity, service

The CAS component of the DP core provides many opportunities for students to link science concepts and topics to practical experiences. Teachers can highlight how knowledge and understanding developed through the course might inform meaningful experiences. Outside the classroom, CAS experiences might also ignite students’ passion for addressing topics inside the chemistry classroom.

Some examples of relevant CAS experiences are as follows.

- Organizing a science club for students in lower years
- Implementing environmental initiatives within the school or local community, such as recycling, composting and roof gardens
- Organizing or participating in a social media outreach or advocacy campaign, for example, on an environmental or health concern

CAS experiences can be a single event or may be an extended series of events. It is important that CAS experiences be distinct from and not submitted as part of a chemistry assessment.

For more information, please refer to the *Creativity, activity, service guide* and the *Creativity, activity, service teacher support material.*

Chemistry and international-mindedness

Science has been, and continues to be, a truly international endeavour. From the beginnings of seismology in China, through material science in Mesopotamia to astronomy in the Islamic Golden Age, the search for an objective understanding of the natural world transcends the limitations imposed by national boundaries. The scientific process, requiring curiosity, insight and an open-minded approach, benefits from the widest possible participation across genders and cultures through inclusivity and diversity.

Given the global nature of many scientific issues, international organizations often have a focus on the engagement of science with the public domain. The World Health Organization and the Intergovernmental Panel on Climate Change are two well-known examples that model a responsibility to inform nations of scientific progress on an equitable basis. Underlying this responsibility is the interest of promoting a peaceful and sustainable future.

Advancements in technology, along with the cost of modern research facilities, continues to reinforce the role of international collaborative work. The project between the Joint Institute of Nuclear Research in Russia and the Lawrence Livermore National Laboratory in the USA to provide evidence for the existence of element 118, oganesson, is a good example of international collaboration.

The importance of collaboration in contemporary science is reflected by the large number of international organizations tasked with collating and sharing data with the scientific community. Access to shared knowledge through websites and databases must be integrated into classroom teaching as it plays an important role in validating experimental work.

In addition to integrating technology and collaborative work, the collaborative sciences project provides an excellent opportunity for students to engage with global issues.

Teachers are encouraged to consider the questions posed in the “Teaching in context” section in the TSM, to allow students to reflect on where and how science might interact with society. These conversations may also introduce ethical questions such as those identified in the TOK syllabus.

Chemistry and the IB learner profile

Each box provides an example of how each learner profile attribute could be modelled by learners and teachers.

Example attribute

- Learners who best embody the attribute with reference to science.
- Directing teachers with possible routes to develop the attribute in the classroom.
- Practical ways in which learners demonstrate the attribute in the process of “doing” science.

Attributes of the IB learner profile

Inquirer

- Inquirers are curious, they actively use research skills, work independently and show enthusiasm about the world around them.
- Teachers facilitate skill development and promote inquiry; they provide students with opportunities to ask questions, search for answers, and experiment.
- Learners use their inquiry skills to extend their scientific knowledge and engage with research.

Knowledgeable

- Learners explore concepts, ideas and issues related to science in order to broaden and deepen their understanding of factual and procedural knowledge.
- Access to a variety of resources and opportunities provides learner agency to develop scientific knowledge and understanding.
- Learners apply their knowledge to unfamiliar contexts and make connections between concepts and facts to illustrate their understanding of science.

Thinker

- Learners are eager to solve complex problems and reflect on their thinking strategies.

Thinker
• Teachers provide opportunities for learners to critically analyse their approaches and methods and deepen their understanding of science, allowing them to be creative in finding solutions to problems. • Learners practise reasoning and critical thinking by testing assumptions, formulating hypotheses, interpreting data and drawing conclusions from the evidence provided.

Communicator
• Learners collaborate effectively with others and use a variety of modes of communication to express their ideas and opinions. • Teachers facilitate group work, encourage open discussions and the use of the scientific language to provide models for successful communication. • Learners demonstrate effective communication skills as part of collaborative activities through listening to others and sharing ideas.

Principled
• Learners take responsibility for their work, promote shared values and act in an ethical manner. • Teachers can provide opportunities to model principled behaviour including acknowledging the work of others and citing sources. The collaborative sciences project provides opportunities for learners to take a principled stance. • Learners appreciate the importance of integrity in data collection and consider all data, even that which does not match their original hypothesis.

Open-minded
• Open-minded learners accept that different perspectives, models or hypotheses exist, and these can be used to enhance scientific understanding. • Teachers can provide models that were at the time supported by data or observations, but through reasoning, deduction or falsification may be rejected or refined. • Learners need to be prepared to have their perspectives and ideas challenged through the study of science.

Caring
• Learners act to protect the environment and to improve the lives of others. • Teachers can draw attention to how daily choices have consequences by challenging learners to adopt sustainable practice and providing support to help fellow learners. Reference should be made to the *Sciences experimentation guidelines*. • Learners can connect curriculum content to global challenges such as healthcare, energy supply or food production. The collaborative sciences project provides an opportunity for learners to support each other to enable their group to achieve their goal successfully.

Risk-taker
• Risk-takers seek new opportunities to develop their learning and explore new approaches to solve problems. They actively thrive on challenges. • Teachers can provide support and guidance for learners, encouraging them to explore new techniques or methods of learning. This might include scaffolds for the use of language, the design of experiments and the analysis of data. As learners grow in confidence, these supports can be phased out giving them more freedom to choose their own approach.

Risk-taker

- Learners should be prepared for the next set of experimental data to falsify their ideas as uncertainty is a feature of science. They understand that this is a step forward in their understanding.

Balanced

- Balanced learners look holistically at all aspects of their development and ensure that various tasks are given appropriate attention without focusing on one to the detriment of others.
- Teachers should encourage learners to consider a balanced perspective on scientific issues without bias.
- Learners need to organize their own time effectively, giving themselves sufficient time to complete all parts of their learning without negatively impacting on the emotional and social aspects of their lives.

Reflective

- Reflective learners consider why and how they achieve success, and also how they could change their approach when learning is difficult.
- Teachers provide opportunities for learners to continually review strategies, methods, techniques and approaches to problem-solving in order to improve their conceptual understandings in science. Assessment criteria or checklists can help learners to consider the quality of their work in a guided way.
- Learners develop skills and concepts throughout the course, networking their knowledge by continually reflecting on their understanding.

Approaches to the teaching and learning of chemistry

The approaches to learning framework

What are approaches to learning skills and why do we teach them?

The approaches to learning (ATL) framework seeks to develop in students affective, cognitive and metacognitive skills that will support their learning processes during and beyond their IB experience. The development of ATL skills is closely connected with the IB learner profile attributes and therefore helps to advance the IB mission. The ATL skills are an integral part of IB learning and teaching that should be developed across the whole programme—it is not expected that a single course should ever address all of them.

How are they organized?

The ATL framework for IB programmes consists of five general skill categories: thinking skills, communication skills, social skills, research skills and self-management skills. Each of these categories covers a broad range, as shown by the examples presented in the table below. The ATL skill categories are closely linked and interrelated and therefore individual skills may be relevant to more than one category.

How do we teach them?

ATL skills can be learned and taught, improved with practice and developed incrementally. The table below illustrates, through a number of examples, how the chemistry course can support ATL skill development. The examples shown in the table are not exhaustive. Teachers are encouraged to adapt them for use in their school context and collaboratively identify further examples of ATL skill development.

Further information on the ATL framework and strategies for the development of the ATL skills can be found in the *Chemistry teacher support material* and the *Diploma Programme Approaches to teaching and learning website*.

Table 3

ATL skills and development

Skill category	Examples of ATL skill development in the classroom
Thinking skills	• Being curious about the natural world • Asking questions and framing hypotheses based upon sensible scientific rationale • Designing procedures and models • Reflecting on the credibility of results • Providing a reasoned argument to support conclusions • Evaluating and defending ethical positions • Combining different ideas in order to create new understandings • Applying key ideas and facts in new contexts • Engaging with, and designing, linking questions • Experimenting with new strategies for learning • Reflecting at all stages of the assessment and learning cycle
Communication skills	• Practising active listening skills

Skill category	Examples of ATL skill development in the classroom
	• Evaluating extended writing in terms of relevance and structure • Applying interpretive techniques to different forms of media • Reflecting on the needs of the audience when creating engaging presentations • Clearly communicating complex ideas in response to open-ended questions • Using digital media for communicating information • Using terminology, symbols and communication conventions consistently and correctly • Presenting data appropriately • Delivering constructive criticism appropriately
Social skills	• Working collaboratively to achieve a common goal • Assigning and accepting specific roles during group activities • Appreciating the diverse talents and needs of others • Resolving conflicts during collaborative work • Actively seeking and considering the perspective of others • Reflecting on the impact of personal behaviour or comments on others • Constructively assessing the contribution of peers
Research skills	• Evaluating information sources for accuracy, bias, credibility and relevance • Explicitly discussing the importance of academic integrity and full acknowledgement of the ideas of others • Using a single, standard method of referencing and citation • Comparing, contrasting and validating information • Using search engines and libraries effectively
Self-management skills	• Breaking down major tasks into a sequence of stages • Being punctual and meeting deadlines • Taking risks and regarding setbacks as opportunities for growth • Avoiding unnecessary distractions • Drafting, revising and improving academic work • Setting learning goals and adjusting them in response to experience • Seeking and acting on feedback

Experimental programme

Integral to the student experience of a chemistry course is the learning that takes place through scientific inquiry within the classroom or laboratory. Experimentation through a variety of forms can be used to introduce a topic, address a phenomenon or allow students to consider and examine authentic questions and curiosities.

A school's experimental programme should allow students to experience the full breadth and depth of the course, develop scientific skills and demonstrate safe, competent and methodical use of a range of tools, techniques and equipment. Students should therefore be encouraged to develop investigations to support their learning through open-ended inquiry with a focus on laboratory experiments, databases, simulations and modelling.

Conceptual learning

Concept-based teaching and learning is encouraged across the continuum of IB programmes.

Concepts are mental representations of categories. They are constructed, modified and activated by the learner through learning experiences. Concepts do not exist in isolation but are interrelated. Conceptual understanding is always a work in progress—it is continually being developed and refined.

Conceptual understanding is therefore an outcome of a non-linear, ongoing process of evolving understandings, adapting previous understandings, and identifying and dispelling misconceptions. It consists of making connections between prior and new knowledge to construct and build an awareness of this network of knowledge.

Concepts vary in their level of abstraction and universality.

- They can be organizing ideas that are applicable in many contexts and have relevance both within and across subject areas.
- They can provide a deep understanding of specific knowledge fields (or fields of knowledge) and help to organize knowledge further, as well as reveal connections between different areas of the subject.

For example, consider the following sequence of three concepts, which shows the more specific focus of each concept.

Change > Reactivity > Collision theory

In other words, collision theory is a component in understanding chemical reactivity, which in turn helps to develop an understanding of change in chemistry. The sequence could be extended further to look at concepts such as particle, collision and reaction, all of which provide a basis for understanding collision theory.

Outcomes of a concept-based approach

Fostering critical thinking, the outcome of a concept-based approach is that students are able to:

- identify examples of a concept
- organize, reflect on, modify and expand their network of knowledge
- apply concepts to existing and future knowledge
- apply their conceptual understanding as a scientific thinking tool for predicting outcomes, justifying conclusions and evaluating knowledge claims.

Structure of the syllabus and conceptual understanding

The structure of this chemistry syllabus is intended to promote concept-based teaching and learning.

There are two organizing concepts in the chemistry roadmap: **structure** and **reactivity**. Each of these concepts is subdivided into topics and subtopics, which are all connected through the idea that structure determines reactivity, which in turn transforms structure.

Each of the 22 subtopics is headed by a guiding question to give a sense of what is covered. The purpose of these guiding questions is to promote inquiry—they are therefore not straightforward and best answered once the associated understandings have been acquired. Teachers and students are encouraged to create their own guiding questions to capture the content of units of study.

Several linking questions are associated with understandings throughout this guide. Linking questions are intended to promote the skills in the study of chemistry and highlight links between the course understandings, encouraging students to look at an understanding from a different perspective, originating in a different part of the course. They are designed to facilitate these connections and their ideal outcome is to promote a highly networked understanding of chemistry.

For example, the trend in reactivity down group 1 is connected to several parts of the course—it illustrates the organization of elements in the periodic table, can be explained in terms of ionization energies, is related to the electron configuration and exemplifies the tendency of metals to be oxidized. The linking questions found in the guide are not exhaustive. Students and teachers may encounter other connections between understandings and concepts in the syllabus, leading them to create their own linking questions.

Teaching chemistry in context

The study of chemistry enables constructive engagement with topical scientific issues. By contextualizing chemical concepts, scientific knowledge claims can be evaluated more effectively, and informed choices on such issues as human health and the environment can be made. Chemical research has brought innovation and benefit to many fields and continues to be at the heart of seeking effective solutions to many global challenges. It is therefore important to explore applications of chemistry in our world while teaching the course to elicit interest, understanding and curiosity.

Teaching the content of the course in relation to specific contexts supports the pedagogical principle of teaching in local and global contexts as part of the approaches to teaching framework and offers a number of advantages. First, it helps students relate their learning to genuine applications of chemistry, highlighting the relevance to global issues as well as the significance in students' own contexts. Second, it develops an appreciation for the interaction between scientific solutions and their implications, be it ethical, environmental or economic. Third, it helps to illustrate some of the NOS aspects underpinning the course.

The *Chemistry teacher support material* highlights possible areas that could be visited throughout the course and that may provide context for some topics to stimulate the application of ideas and problem-solving skills. Consideration of these and related areas may help provide ideas for the scientific investigation, the collaborative sciences project, TOK exhibition, CAS, or an EE in chemistry or world studies.

Engaging with sensitive topics

Students and teachers are encouraged to engage with exciting, stimulating and personally relevant topics and issues that may be, at times, sensitive or personally challenging. Teachers should be aware of this and provide guidance on how to engage with such topics in a responsible manner. Consideration should be given to the personal, political and spiritual values of others.

Prior learning

Past experience shows that students will be able to study chemistry at SL successfully with no background in, or previous knowledge of, science. Their approach to learning, characterized by the IB learner profile attributes, will be significant here.

However, for most students considering the study of chemistry at HL, while there is no intention to restrict access, some previous exposure to formal science education would be necessary. Specific topic details are not specified, but students who have undertaken the IB Middle Years Programme (MYP) or studied an equivalent national science qualification or a school-based science course would be well prepared for an HL subject.

Links to the Middle Years Programme

The MYP sciences courses seek to promote skills and attitudes needed to apply scientific knowledge in theoretical, experimental and authentic contexts. A strong foundation is established for DP sciences in which learners will capitalize on—and continue advancing—their skills and attitudes to develop knowledge and understanding commensurate with pre-university level science.

The MYP offers a framework for learning and teaching while maintaining flexibility with curriculum content. The content in MYP sciences courses can therefore vary greatly from one school to another. Content in DP sciences courses is more prescribed, and this is one of the main differences teachers will notice when comparing the two programmes.

A connected, conceptual curriculum where learning is inquiry-based and contextualized is the pedagogical principle that underpins both programmes and indeed the entire IB continuum (International Baccalaureate, 2019).

Conceptual learning focuses on organizing ideas and their interconnections. A conceptual approach is encouraged in IB programmes because it promotes deep learning and facilitates the construction of further knowledge. Conceptual understanding aids the application of knowledge in unfamiliar and novel contexts. This skill is reflected in the aims and assessment objectives of both programmes.

Broad concepts frame MYP learning and teaching with the purpose of unifying ideas across subject areas. Discipline-specific related concepts are intended to provide disciplinary depth (International Baccalaureate, 2014). Key and related concepts are not required in the DP, although some teachers may find that they wish to continue developing a curriculum around them. In DP sciences, overarching concepts are manifested in the course roadmaps and the NOS. DP sciences seek to highlight the interconnectedness of the course understandings. The intention is to promote conceptual understanding and further the construction of learners' knowledge networks.

Both MYP and DP teaching involve inquiry-based approaches, which foster a high degree of student engagement, collaboration and interaction. The inquiry, design, experimental, analysis, evaluation and communication skills encouraged by criteria B and C will serve students well as they prepare to undertake the scientific investigation for the internal assessment (IA). In addition, MYP students will gain familiarity with criterion-related assessment and the use of assessment criteria, which will further support their understanding of the DP sciences IA criteria.

IB programmes encourage the exploration of scientific principles in connection to local and global contexts. Doing so helps students ground abstract concepts in more concrete local and global real-world situations as well as cultivating international-mindedness (see the "Approaches to teaching" section in *Diploma Programme Approaches to teaching and learning website*). Teachers should therefore weave opportunities for contextualization into the curriculum. MYP sciences criterion D analyses the real-world application of science. In the DP, sciences teachers are encouraged to frequently anchor their teaching in real-world applications that are invoked throughout the course of the programme.

In addition to equipping students with scientific knowledge and skills, the MYP and DP sciences courses share similar guiding principles that seek to develop in students the learner profile attributes.

Links to the Career-related Programme

In the Career-related Programme (CP), students study at least two DP subjects, a core consisting of four components and a career-related study, which is determined by the local context and aligned with student needs. The CP has been designed to add value to the students' career-related studies. This provides the context for the choice of DP courses. The chemistry course can assist CP students planning careers in a variety of professional fields where, for example, a sound understanding of science and mathematical skills are important. This includes healthcare, technological and manufacturing industries, and engineering. While chemistry helps students understand the underlying science in the contemporary world, it also encourages the development of strong problem-solving, critical thinking and ethical approaches that will assist students in the global workplace.

Collaborative sciences project

The collaborative sciences project is an interdisciplinary sciences project, providing a worthwhile challenge to DP and CP students, addressing real-world problems that can be explored through the sciences. The nature of the challenge should allow students to integrate factual, procedural and conceptual knowledge developed through the study of their disciplines.

Through the identification and research of complex issues, students can develop an understanding of how interrelated systems, mechanisms and processes impact a problem. Students will then apply their collective understanding to develop solution-focused strategies that address the issue. With a critical lens they will evaluate and reflect on the inherent complexity of solving real-world problems.

Students will develop an understanding of the extent of global interconnectedness between regional, national, and local communities, which will empower them to become active and engaged citizens of the world. While addressing local and global issues, students will appreciate that the issues of today exist across national boundaries and can only be solved through collective action and international cooperation.

The collaborative sciences project supports the development of students' ATL skills, including teambuilding, negotiation and leadership. It facilitates an appreciation of the environment, and the social and ethical implications of science and technology.

Full details of the requirements are in the *Collaborative sciences project guide*.

Aims

The course enables students, through the overarching theme of the NOS, to:

1. develop conceptual understanding that allows connections to be made between different areas of the subject, and to other DP sciences subjects
2. acquire and apply a body of knowledge, methods, tools and techniques that characterize science
3. develop the ability to analyse, evaluate and synthesize scientific information and claims
4. develop the ability to approach unfamiliar situations with creativity and resilience
5. design and model solutions to local and global problems in a scientific context
6. develop an appreciation of the possibilities and limitations of science
7. develop technology skills in a scientific context
8. develop the ability to communicate and collaborate effectively
9. develop awareness of the ethical, environmental, economic, cultural and social impact of science.

Assessment objectives

The assessment objectives for chemistry reflect those parts of the aims that will be formally assessed either internally or externally. It is the intention of this course that students are able to fulfil the following assessment objectives.

1. Demonstrate knowledge of:
    a. terminology, facts and concepts
    b. skills, techniques and methodologies.
2. Understand and apply knowledge of:
    a. terminology and concepts
    b. skills, techniques and methodologies.
3. Analyse, evaluate, and synthesize:
    a. experimental procedures
    b. primary and secondary data
    c. trends, patterns and predictions.
4. Demonstrate the application of skills necessary to carry out insightful and ethical investigations.

Assessment objectives in practice

Assessments align with the course's aims, objectives and conceptual approach; the NOS and subject-specific skills are also assessed. This allows students to demonstrate learning effectively through varied tasks that are reliably and accurately marked or moderated by subject-area educators and experts.

Assessment objective	Which component addresses this assessment objective?	How is the assessment objective addressed?
AO1 Demonstrate knowledge	Paper 1 Paper 2 Scientific investigation	Students respond to a range of multiple-choice, short-answer questions and extended-response questions. Students investigate and answer a research question that is their own.
AO2 Understand and apply knowledge	Paper 1 Paper 2 Scientific investigation	Students respond to a range of multiple-choice, short-answer, data-based and extended-response questions. Students investigate and answer a research question that is their own.
AO3 Analyse, evaluate, and synthesize	Paper 1 Paper 2 Scientific investigation	Students respond to a range of multiple-choice, short-answer, data-based and extended-response questions. Students investigate and answer a research question that is their own.
AO4 Demonstrate the application of skills necessary to carry out insightful and ethical investigations	Scientific investigation	Students investigate and answer a research question that is their own.

Component	Approximate weighting of assessment objectives (%)	
	AO1 + AO2	AO3
Paper 1	50	50
Paper 2	50	50
Internal assessment	Covers AO1, AO2, AO3 and AO4	

Syllabus outline

Syllabus component	Teaching hours	
	SL	HL
Syllabus content	**110**	**180**
Structure 1. Models of the particulate nature of matter	17	21
Structure 2. Models of bonding and structure	20	30
Structure 3. Classification of matter	16	31
Reactivity 1. What drives chemical reactions?	12	22
Reactivity 2. How much, how fast and how far?	21	31
Reactivity 3. What are the mechanisms of chemical change?	24	45
Experimental programme	**40**	**60**
Practical work	20	40
Collaborative sciences project	10	10
Scientific investigation	10	10
Total teaching hours	**150**	**240**

The recommended teaching time is 150 hours to complete SL courses and 240 hours to complete HL courses as stated in the general regulations (in *Diploma Programme Assessment procedures*).

Syllabus roadmap

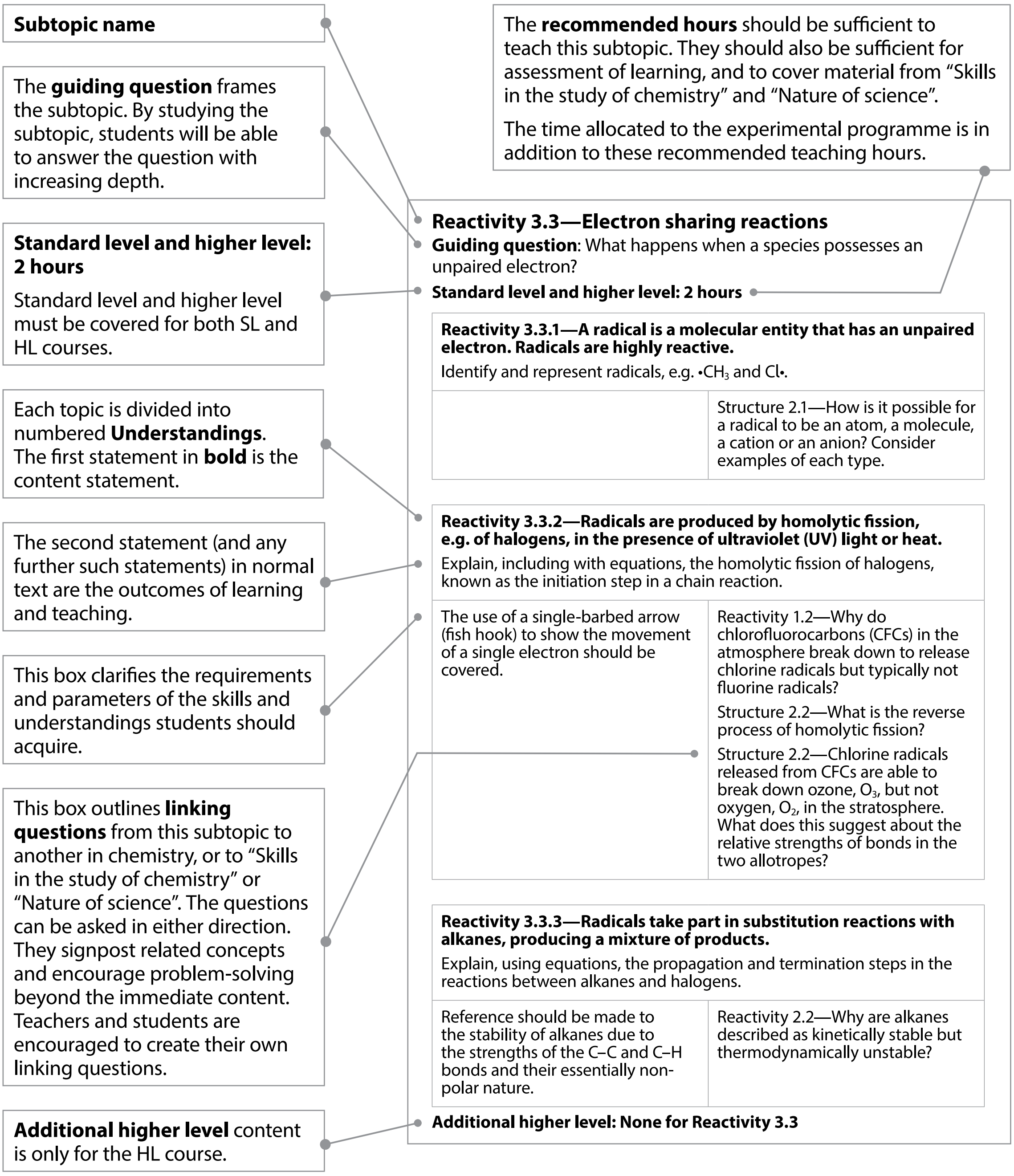
The aim of the syllabus is to integrate concepts, topic content and the NOS through inquiry. Students and teachers are encouraged to personalize their approach to the syllabus according to their circumstances and interests.

Table 4

Chemistry roadmap via structure and reactivity

Skills in the study of chemistry			
Structure Structure refers to the nature of matter from simple to more complex forms		Reactivity Reactivity refers to how and why chemical reactions occur	
Structure determines reactivity, which in turn transforms structure			
Structure 1. **Models of the particulate nature of matter**	Structure 1.1—Introduction to the particulate nature of matter	**Reactivity 1.** **What drives chemical reactions?**	Reactivity 1.1—Measuring enthalpy changes
	Structure 1.2—The nuclear atom		Reactivity 1.2—Energy cycles in reactions
	Structure 1.3—Electron configurations		
	Structure 1.4—Counting particles by mass: The mole		Reactivity 1.3—Energy from fuels
	Structure 1.5—Ideal gases		Reactivity 1.4—Entropy and spontaneity (Additional higher level)
Structure 2. **Models of bonding and structure**	Structure 2.1—The ionic model	**Reactivity 2.** **How much, how fast and how far?**	Reactivity 2.1—How much? The amount of chemical change
	Structure 2.2—The covalent model		Reactivity 2.2—How fast? The rate of chemical change
	Structure 2.3—The metallic model		Reactivity 2.3—How far? The extent of chemical change
	Structure 2.4—From models to materials		
Structure 3. **Classification of matter**	Structure 3.1—The periodic table: Classification of elements	**Reactivity 3.** **What are the mechanisms of chemical change?**	Reactivity 3.1—Proton transfer reactions
	Structure 3.2—Functional groups: Classification of organic compounds		Reactivity 3.2—Electron transfer reactions
			Reactivity 3.3—Electron sharing reactions
			Reactivity 3.4—Electron-pair sharing reactions

Syllabus format



Subtopic name

The **guiding question** frames the subtopic. By studying the subtopic, students will be able to answer the question with increasing depth.

Standard level and higher level: 2 hours

Standard level and higher level must be covered for both SL and HL courses.

Each topic is divided into numbered **Understandings**. The first statement in **bold** is the content statement.

The second statement (and any further such statements) in normal text are the outcomes of learning and teaching.

This box clarifies the requirements and parameters of the skills and understandings students should acquire.

This box outlines **linking questions** from this subtopic to another in chemistry, or to "Skills in the study of chemistry" or "Nature of science". The questions can be asked in either direction. They signpost related concepts and encourage problem-solving beyond the immediate content. Teachers and students are encouraged to create their own linking questions.

Additional higher level content is only for the HL course.

The **recommended hours** should be sufficient to teach this subtopic. They should also be sufficient for assessment of learning, and to cover material from "Skills in the study of chemistry" and "Nature of science".

The time allocated to the experimental programme is in addition to these recommended teaching hours.

Reactivity 3.3—Electron sharing reactions

Guiding question: What happens when a species possesses an unpaired electron?

Standard level and higher level: 2 hours

Reactivity 3.3.1—A radical is a molecular entity that has an unpaired electron. Radicals are highly reactive.

Identify and represent radicals, e.g. •CH$_3$ and Cl•.

	Structure 2.1—How is it possible for a radical to be an atom, a molecule, a cation or an anion? Consider examples of each type.

Reactivity 3.3.2—Radicals are produced by homolytic fission, e.g. of halogens, in the presence of ultraviolet (UV) light or heat.

Explain, including with equations, the homolytic fission of halogens, known as the initiation step in a chain reaction.

The use of a single-barbed arrow (fish hook) to show the movement of a single electron should be covered.	Reactivity 1.2—Why do chlorofluorocarbons (CFCs) in the atmosphere break down to release chlorine radicals but typically not fluorine radicals? Structure 2.2—What is the reverse process of homolytic fission? Structure 2.2—Chlorine radicals released from CFCs are able to break down ozone, O$_3$, but not oxygen, O$_2$, in the stratosphere. What does this suggest about the relative strengths of bonds in the two allotropes?

Reactivity 3.3.3—Radicals take part in substitution reactions with alkanes, producing a mixture of products.

Explain, using equations, the propagation and termination steps in the reactions between alkanes and halogens.

Reference should be made to the stability of alkanes due to the strengths of the C–C and C–H bonds and their essentially non-polar nature.	Reactivity 2.2—Why are alkanes described as kinetically stable but thermodynamically unstable?

Additional higher level: None for Reactivity 3.3

Skills in the study of chemistry

The skills and techniques students must experience through the course are encompassed within the tools. These support the application and development of the inquiry process in the delivery of the chemistry course.

Tools

- **Tool 1:** Experimental techniques
- **Tool 2:** Technology
- **Tool 3:** Mathematics

Inquiry process

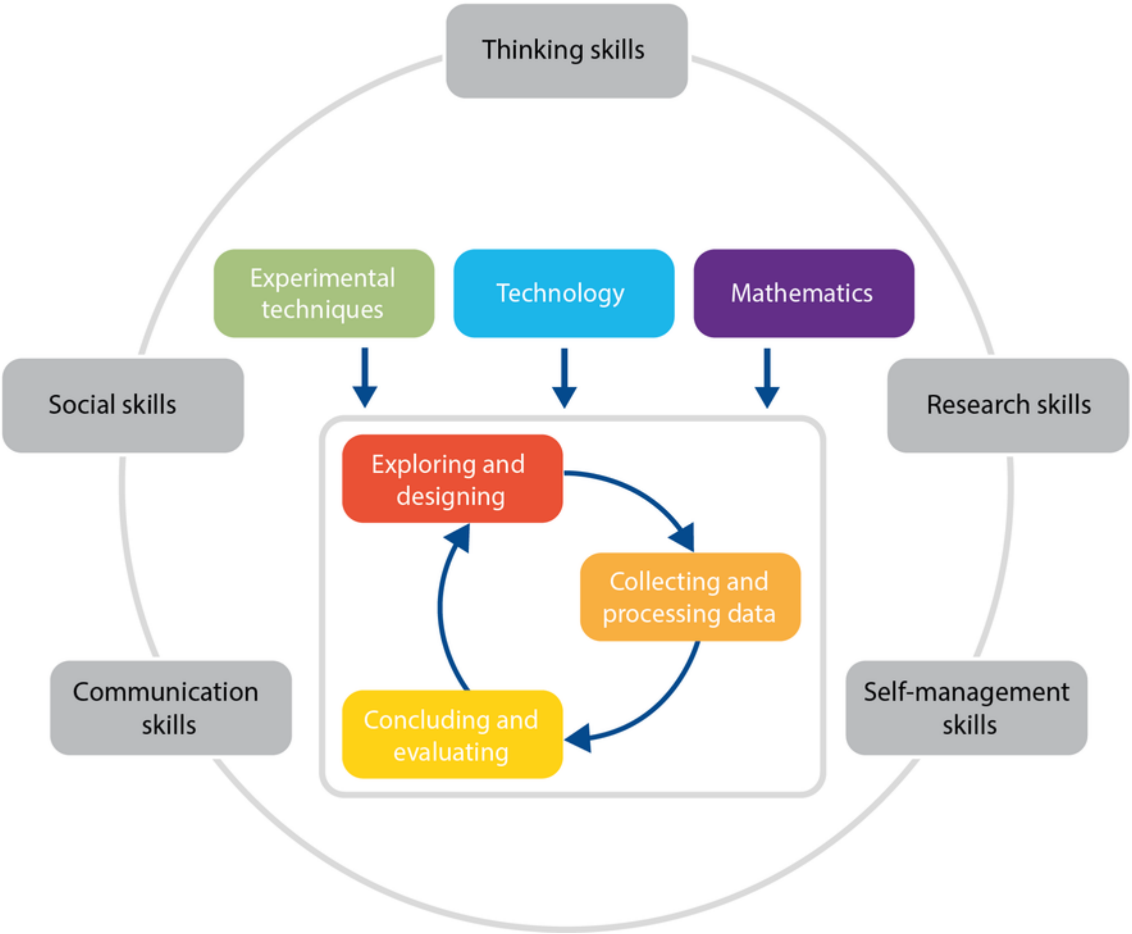
- **Inquiry 1:** Exploring and designing
- **Inquiry 2:** Collecting and processing data
- **Inquiry 3:** Concluding and evaluating

Teachers are encouraged to provide opportunities for students to encounter and practise the skills throughout the programme. Rather than being taught as stand-alone topics, they should be integrated into the teaching of the syllabus when they are relevant to the syllabus topics being covered. The skills in the study of chemistry can be assessed through internal and external assessment.

The approaches to learning provide the framework for the development of these skills.

Figure 2

Skills for chemistry



Tools

Tool 1: Experimental techniques

Skill	Description
Addressing safety of self, others and the environment	Recognize and address relevant safety, ethical or environmental issues in an investigation.
Measuring variables	Understand how to accurately measure the following to an appropriate level of precision. • Mass • Volume • Time • Temperature • Length • pH of a solution • Electric current

Skill	Description
	• Electric potential difference
Applying techniques	Show awareness of the purpose and practice of: • preparing a standard solution • carrying out dilutions • drying to constant mass • distillation and reflux • paper or thin layer chromatography • separation of mixtures • calorimetry • acid–base and redox titration • electrochemical cells • colorimetry or spectrophotometry • physical and digital molecular modelling • recrystallization • melting point determination.

Tool 2: Technology

Skill	Description
Applying technology to collect data	• Use sensors. • Identify and extract data from databases. • Generate data from models and simulations.
Applying technology to process data	• Use spreadsheets to manipulate data. • Represent data in a graphical form. • Use computer modelling.

Tool 3: Mathematics

Skill	Description
Applying general mathematics	• Use basic arithmetic and algebraic calculations to solve problems. • Carry out calculations involving decimals, fractions, percentages, ratios, reciprocals and exponents. • Carry out calculations involving logarithmic functions. • Carry out calculations involving exponential functions (HL). • Determine rates of change from tabulated data. • Calculate mean and range. • Use and interpret scientific notation (e.g. 3.5×10^6). • Use approximation and estimation. • Appreciate when some effects can be ignored and why this is useful. • Compare and quote values to the nearest order of magnitude. • Understand direct and inverse proportionality, as well as positive and negative correlations between variables.

Skill	Description
	• Calculate and interpret percentage change and percentage difference. • Calculate and interpret percentage error and percentage uncertainty. • Distinguish between continuous and discrete variables.
Using units, symbols and numerical values	• Apply and use International System of Units (SI) prefixes and units. • Identify and use symbols stated in the guide and the data booklet. • Express quantities and uncertainties to an appropriate number of significant figures or decimal places.
Processing uncertainties	• Understand the significance of uncertainties in raw and processed data. • Record uncertainties in measurements as a range (±) to an appropriate level of precision. • Propagate uncertainties in processed data, in calculations involving addition, subtraction, multiplication, division and (HL) exponents. • Express measurement and processed uncertainties—absolute, fractional (relative), percentage—to an appropriate number of significant figures or level of precision. • Apply the coefficient of determination (R^2) to evaluate the fit of a trend line or curve.
Graphing	• Sketch graphs, with labelled but unscaled axes, to qualitatively describe trends. • Construct and interpret tables, charts and graphs for raw and processed data including bar charts, histograms, scatter graphs and line and curve graphs. • Plot linear and non-linear graphs showing the relationship between two variables with appropriate scales and axes. • Draw lines or curves of best fit. • Interpret features of graphs including gradient, changes in gradient, intercepts, maxima and minima, and areas. • Draw and interpret uncertainty bars. • Extrapolate and interpolate graphs.

Inquiry process

Inquiry 1: Exploring and designing

Skill	Description
Exploring	• Demonstrate independent thinking, initiative, and insight. • Consult a variety of sources. • Select sufficient and relevant sources of information. • Formulate research questions and hypotheses. • State and explain predictions using scientific understanding.

Skill	Description
Designing	• Demonstrate creativity in the designing, implementation and presentation of the investigation. • Develop investigations that involve hands-on laboratory experiments, databases, simulations, modelling. • Identify and justify the choice of dependent, independent and control variables. • Justify the range and quantity of measurements. • Design and explain a valid methodology. • Pilot methodologies.
Controlling variables	Appreciate when and how to: • calibrate measuring apparatus • maintain constant environmental conditions of systems • insulate against heat loss or gain.

Inquiry 2: Collecting and processing data

Skill	Description
Collecting data	• Identify and record relevant qualitative observations. • Collect and record sufficient relevant quantitative data. • Identify and address issues that arise during data collection.
Processing data	• Carry out relevant and accurate data processing.
Interpreting results	• Interpret qualitative and quantitative data. • Interpret diagrams, graphs and charts. • Identify, describe and explain patterns, trends and relationships. • Identify and justify the removal or inclusion of outliers in data (no mathematical processing is required). • Assess accuracy, precision, reliability and validity.

Inquiry 3: Concluding and evaluating

Skill	Description
Concluding	• Interpret processed data and analysis to draw and justify conclusions. • Compare the outcomes of an investigation to the accepted scientific context. • Relate the outcomes of an investigation to the stated research question or hypothesis. • Discuss the impact of uncertainties on the conclusions.
Evaluating	• Evaluate hypotheses. • Identify and discuss sources and impacts of random and systematic errors. • Evaluate the implications of methodological weaknesses, limitations and assumptions on conclusions.

Skill	Description
	• Explain realistic and relevant improvements to an investigation.

Data booklet

The IB publishes a *Chemistry data booklet* which contains the periodic table, relevant equations, constants, and tabulated data, specific to the course. Students must have access to a copy for the duration of the course, so that they can become familiar with its contents. Direct reference is made to the data booklet in the understandings section of the syllabus. This helps to maintain the emphasis on interpretation and application rather than memorization of data. A clean copy of the *Chemistry data booklet* must also be made available to candidates for all examination papers at both SL and HL.

Syllabus content

Structure

Structure 1. Models of the particulate nature of matter

Structure 1.1—Introduction to the particulate nature of matter

Guiding question: How can we model the particulate nature of matter?

Standard level and higher level: 2 hours

<table>
<tr><td colspan="2">**Structure 1.1.1—Elements are the primary constituents of matter, which cannot be chemically broken down into simpler substances.**
Compounds consist of atoms of different elements chemically bonded together in a fixed ratio.
Mixtures contain more than one element or compound in no fixed ratio, which are not chemically bonded and so can be separated by physical methods.
Distinguish between the properties of elements, compounds and mixtures.</td></tr>
<tr><td>Solvation, filtration, recrystallization, evaporation, distillation and chromatography should be covered.
The differences between homogeneous and heterogeneous mixtures should be understood.</td><td>Tool 1—What factors are considered in choosing a method to separate the components of a mixture?
Tool 1—How can the products of a reaction be purified?
Structure 2.2—How do intermolecular forces influence the type of mixture that forms between two substances?
Structure 2.3—Why are alloys generally considered to be mixtures, even though they often contain metallic bonding?</td></tr>
</table>

<table>
<tr><td colspan="2">**Structure 1.1.2—The kinetic molecular theory is a model to explain physical properties of matter (solids, liquids and gases) and changes of state.**
Distinguish the different states of matter.
Use state symbols (s, l, g and aq) in chemical equations.</td></tr>
<tr><td>Names of the changes of state should be covered: melting, freezing, vaporization (evaporation and boiling), condensation, sublimation and deposition.</td><td>Structure 2.4—Why are some substances solid while others are fluid under standard conditions?
Structure 2 (all), Reactivity 1.2—Why are some changes of state endothermic and some exothermic?</td></tr>
</table>

<table>
<tr><td>**Structure 1.1.3—The temperature, T, in Kelvin (K) is a measure of average kinetic energy (E_k) of particles.**
Interpret observable changes in physical properties and temperature during changes of state.
Convert between values in the Celsius and Kelvin scales.</td></tr>
</table>

The kelvin (K) is the SI unit of temperature and has the same incremental value as the Celsius degree (°C).	Reactivity 2.2—What is the graphical distribution of kinetic energy values of particles in a sample at a fixed temperature? Reactivity 2.2—What must happen to particles for a chemical reaction to occur?

Additional higher level: None for Structure 1.1

Structure 1.2—The nuclear atom

Guiding question: How do the nuclei of atoms differ?

Standard level and higher level: 2 hours

<table>
<tr><td colspan="2">Structure 1.2.1—Atoms contain a positively charged, dense nucleus composed of protons and neutrons (nucleons). Negatively charged electrons occupy the space outside the nucleus.
Use the nuclear symbol $^{A}_{Z}X$ to deduce the number of protons, neutrons and electrons in atoms and ions.</td></tr>
<tr><td>Relative masses and charges of the subatomic particles should be known; actual values are given in the data booklet. The mass of the electron can be considered negligible.</td><td>Structure 1.3—What determines the different chemical properties of atoms?
Structure 3.1—How does the atomic number relate to the position of an element in the periodic table?</td></tr>
</table>

<table>
<tr><td colspan="2">Structure 1.2.2—Isotopes are atoms of the same element with different numbers of neutrons.
Perform calculations involving non-integer relative atomic masses and abundance of isotopes from given data.</td></tr>
<tr><td>Differences in the physical properties of isotopes should be understood.
Specific examples of isotopes need not be learned.</td><td>Nature of science, Reactivity 3.4—How can isotope tracers provide evidence for a reaction mechanism?</td></tr>
</table>

Additional higher level: 1 hour

<table>
<tr><td colspan="2">Structure 1.2.3—Mass spectra are used to determine the relative atomic masses of elements from their isotopic composition.
Interpret mass spectra in terms of identity and relative abundance of isotopes.</td></tr>
<tr><td>The operational details of the mass spectrometer will not be assessed.</td><td>Structure 3.2—How does the fragmentation pattern of a compound in the mass spectrometer help in the determination of its structure?</td></tr>
</table>

Structure 1.3—Electron configurations

Guiding question: How can we model the energy states of electrons in atoms?

Standard level and higher level: 3 hours

<table>
<tr><td colspan="2">Structure 1.3.1—Emission spectra are produced by atoms emitting photons when electrons in excited states return to lower energy levels.
Qualitatively describe the relationship between colour, wavelength, frequency and energy across the electromagnetic spectrum.
Distinguish between a continuous and a line spectrum.</td></tr>
<tr><td>Details of the electromagnetic spectrum are given in the data booklet.</td><td></td></tr>
</table>

Structure 1.3.2—The line emission spectrum of hydrogen provides evidence for the existence of electrons in discrete energy levels, which converge at higher energies.

Describe the emission spectrum of the hydrogen atom, including the relationships between the lines and energy transitions to the first, second and third energy levels.

The names of the different series in the hydrogen emission spectrum will not be assessed.	Inquiry 2—In the study of emission spectra from gaseous elements and of light, what qualitative and quantitative data can be collected from instruments such as gas discharge tubes and prisms? Nature of science, Structure 1.2—How do emission spectra provide evidence for the existence of different elements?

Structure 1.3.3—The main energy level is given an integer number, n, and can hold a maximum of $2n^2$ electrons.

Deduce the maximum number of electrons that can occupy each energy level.

	Structure 3.1—How does an element's highest main energy level relate to its period number in the periodic table?

Structure 1.3.4—A more detailed model of the atom describes the division of the main energy level into s, p, d and f sublevels of successively higher energies.

Recognize the shape and orientation of an s atomic orbital and the three p atomic orbitals.

	Structure 3.1—What is the relationship between energy sublevels and the block nature of the periodic table?

Structure 1.3.5—Each orbital has a defined energy state for a given electron configuration and chemical environment, and can hold two electrons of opposite spin.

Sublevels contain a fixed number of orbitals, regions of space where there is a high probability of finding an electron.

Apply the Aufbau principle, Hund's rule and the Pauli exclusion principle to deduce electron configurations for atoms and ions up to $Z = 36$.

Full electron configurations and condensed electron configurations using the noble gas core should be covered. Orbital diagrams, i.e. arrow-in-box diagrams, should be used to represent the filling and relative energy of orbitals. The electron configurations of Cr and Cu as exceptions should be covered.	

Additional higher level: 3 hours

Structure 1.3.6—In an emission spectrum, the limit of convergence at higher frequency corresponds to ionization.

Explain the trends and discontinuities in first ionization energy (IE) across a period and down a group.

Calculate the value of the first IE from spectral data that gives the wavelength or frequency of the convergence limit.

<table>
<tr><td>The value of the Planck constant (h) and the equations $E = hf$ and $c = \lambda f$ are given in the data booklet.</td><td>Structure 3.1—How does the trend in IE values across a period and down a group explain the trends in properties of metals and non-metals?
Nature of science, Tool 3, Reactivity 3.1—Why are log scales useful when discussing $[H^+]$ and IEs?</td></tr>
</table>

<table>
<tr><td colspan="2">Structure 1.3.7—Successive ionization energy (IE) data for an element give information about its electron configuration.
Deduce the group of an element from its successive ionization data.</td></tr>
<tr><td>Databases are useful for compiling graphs of trends in IEs.</td><td>HL Structure 3.1—How do patterns of successive IEs of transition elements help to explain the variable oxidation states of these elements?</td></tr>
</table>

Structure 1.4—Counting particles by mass: The mole

Guiding question: How do we quantify matter on the atomic scale?

Standard level and higher level: 7 hours

<table>
<tr><td colspan="2">Structure 1.4.1—The mole (mol) is the SI unit of amount of substance. One mole contains exactly the number of elementary entities given by the Avogadro constant.
Convert the amount of substance, n, to the number of specified elementary entities.</td></tr>
<tr><td>An elementary entity may be an atom, a molecule, an ion, an electron, any other particle or a specified group of particles.
The Avogadro constant (N_A) is given in the data booklet. It has the units mol^{-1}.</td><td></td></tr>
</table>

<table>
<tr><td colspan="2">Structure 1.4.2—Masses of atoms are compared on a scale relative to ^{12}C and are expressed as relative atomic mass (A_r) and relative formula mass (M_r).
Determine relative formula masses (M_r) from relative atomic masses (A_r).</td></tr>
<tr><td>Relative atomic mass and relative formula mass have no units.
The values of relative atomic masses given to two decimal places in the data booklet should be used in calculations.</td><td>Structure 3.1—Atoms increase in mass as their position descends in the periodic table. What properties might be related to this trend?</td></tr>
</table>

<table>
<tr><td colspan="2">Structure 1.4.3—Molar mass (M) has the units $g\ mol^{-1}$.
Solve problems involving the relationships between the number of particles, the amount of substance in moles and the mass in grams.</td></tr>
<tr><td>The relationship $n = \frac{m}{M}$ is given in the data booklet.</td><td>Reactivity 2.1—How can molar masses be used with chemical equations to determine the masses of the products of a reaction?</td></tr>
</table>

<table>
<tr><td>Structure 1.4.4—The empirical formula of a compound gives the simplest ratio of atoms of each element present in that compound. The molecular formula gives the actual number of atoms of each element present in a molecule.
Interconvert the percentage composition by mass and the empirical formula.
Determine the molecular formula of a compound from its empirical formula and molar mass.</td></tr>
</table>

	Tool 1—How can experimental data on mass changes in combustion reactions be used to derive empirical formulas? Nature of science, Tool 3, Structure 3.2—What is the importance of approximation in the determination of an empirical formula?

<table>
<tr><td colspan="2">Structure 1.4.5—The molar concentration is determined by the amount of solute and the volume of solution.
Solve problems involving the molar concentration, amount of solute and volume of solution.</td></tr>
<tr><td>The use of square brackets to represent molar concentration is required.
Units of concentration should include g dm^{-3} and mol dm^{-3} and conversion between these.
The relationship $n = CV$ is given in the data booklet.</td><td>Tool 1—What are the considerations in the choice of glassware used in preparing a standard solution and a serial dilution?
Tool 1, Inquiry 2—How can a calibration curve be used to determine the concentration of a solution?</td></tr>
</table>

<table>
<tr><td colspan="2">Structure 1.4.6—Avogadro's law states that equal volumes of all gases measured under the same conditions of temperature and pressure contain equal numbers of molecules.
Solve problems involving the mole ratio of reactants and/or products and the volume of gases.</td></tr>
<tr><td></td><td>Structure 1.5—Avogadro's law applies to ideal gases. Under what conditions might the behaviour of a real gas deviate most from an ideal gas?</td></tr>
</table>

Additional higher level: None for Structure 1.4

Structure 1.5—Ideal gases

Guiding question: How does the model of ideal gas behaviour help us to predict the behaviour of real gases?

Standard level and higher level: 3 hours

Structure 1.5.1—An ideal gas consists of moving particles with negligible volume and no intermolecular forces. All collisions between particles are considered elastic. Recognize the key assumptions in the ideal gas model.

<table>
<tr><td colspan="2">Structure 1.5.2—Real gases deviate from the ideal gas model, particularly at low temperature and high pressure.
Explain the limitations of the ideal gas model.</td></tr>
<tr><td>No mathematical coverage is required.</td><td>Structure 2.2—Under comparable conditions, why do some gases deviate more from ideal behaviour than others?</td></tr>
</table>

<table>
<tr><td colspan="2">Structure 1.5.3—The molar volume of an ideal gas is a constant at a specific temperature and pressure.
Investigate the relationship between temperature, pressure and volume for a fixed mass of an ideal gas and analyse graphs relating these variables.</td></tr>
<tr><td>The names of specific gas laws will not be assessed.</td><td>Nature of science, Tools 2 and 3, Reactivity 2.2—Graphs can be presented as sketches or as</td></tr>
</table>

The value for the molar volume of an ideal gas under standard temperature and pressure (STP) is given in the data booklet.	accurately plotted data points. What are the advantages and limitations of each representation?

<table>
<tr><td colspan="2">Structure 1.5.4—The relationship between the pressure, volume, temperature and amount of an ideal gas is shown in the ideal gas equation $PV = nRT$ and the combined gas law $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$.
Solve problems relating to the ideal gas equation.</td></tr>
<tr><td>Units of volume and pressure should be SI only. The value of the gas constant R, the ideal gas equation, and the combined gas law, are given in the data booklet.</td><td>Tool 1, Inquiry 2—How can the ideal gas law be used to calculate the molar mass of a gas from experimental data?</td></tr>
</table>

Additional higher level: None for Structure 1.5

Structure 2. Models of bonding and structure

Structure 2.1—The ionic model

Guiding question: What determines the ionic nature and properties of a compound?

Standard level and higher level: 4 hours

<table>
<tr><td colspan="2">Structure 2.1.1—When metal atoms lose electrons, they form positive ions called cations.
When non-metal atoms gain electrons, they form negative ions called anions.
Predict the charge of an ion from the electron configuration of the atom.</td></tr>
<tr><td>The formation of ions with different charges from a transition element should be included.</td><td>Structure 3.1—How does the position of an element in the periodic table relate to the charge of its ion(s)?
HL Structure 1.3—How does the trend in successive ionization energies of transition elements explain their variable oxidation states?</td></tr>
</table>

<table>
<tr><td colspan="2">Structure 2.1.2—The ionic bond is formed by electrostatic attractions between oppositely charged ions.
Deduce the formula and name of an ionic compound from its component ions, including polyatomic ions.
Binary ionic compounds are named with the cation first, followed by the anion. The anion adopts the suffix “ide”.
Interconvert names and formulas of binary ionic compounds.</td></tr>
<tr><td>The following polyatomic ions should be known by name and formula: ammonium NH_4^+, hydroxide OH^-, nitrate NO_3^-, hydrogencarbonate HCO_3^-, carbonate CO_3^{2-}, sulfate SO_4^{2-}, phosphate PO_4^{3-}.</td><td>Reactivity 3.2—Why is the formation of an ionic compound from its elements a redox reaction?
HL Structure 2.2—How is formal charge used to predict the preferred structure of sulfate?
HL Reactivity 3.1—Polyatomic anions are conjugate bases of common acids. What is the relationship between their stability and the conjugate acid’s dissociation constant, K_a?</td></tr>
</table>

<table>
<tr><td colspan="2">Structure 2.1.3—Ionic compounds exist as three-dimensional lattice structures, represented by empirical formulas.
Explain the physical properties of ionic compounds to include volatility, electrical conductivity and solubility.</td></tr>
</table>

Include lattice enthalpy as a measure of the strength of the ionic bond in different compounds, influenced by ion radius and charge.	Tool 1, Inquiry 2—What experimental data demonstrate the physical properties of ionic compounds? Structure 3.1—How can lattice enthalpies and the bonding continuum explain the trend in melting points of metal chlorides across period 3?

Additional higher level: None for Structure 2.1

Structure 2.2—The covalent model

Guiding question: What determines the covalent nature and properties of a substance?

Standard level and higher level: 10 hours

<table>
<tr><td colspan="2">Structure 2.2.1—A covalent bond is formed by the electrostatic attraction between a shared pair of electrons and the positively charged nuclei.
The octet rule refers to the tendency of atoms to gain a valence shell with a total of 8 electrons.
Deduce the Lewis formula of molecules and ions for up to four electron pairs on each atom.</td></tr>
<tr><td>Lewis formulas (also known as electron dot or Lewis structures) show all the valence electrons (bonding and non-bonding pairs) in a covalently bonded species.
Electron pairs in a Lewis formula can be shown as dots, crosses or dashes.
Molecules containing atoms with fewer than an octet of electrons should be covered.
Organic and inorganic examples should be used.</td><td>Nature of science—What are some of the limitations of the octet rule?
Structure 1.3—Why do noble gases form covalent bonds less readily than other elements?
Structure 2.1—Why do ionic bonds only form between different elements while covalent bonds can form between atoms of the same element?</td></tr>
</table>

<table>
<tr><td colspan="2">Structure 2.2.2—Single, double and triple bonds involve one, two and three shared pairs of electrons respectively.
Explain the relationship between the number of bonds, bond length and bond strength.</td></tr>
<tr><td></td><td>Reactivity 2.2—How does the presence of double and triple bonds in molecules influence their reactivity?</td></tr>
</table>

<table>
<tr><td colspan="2">Structure 2.2.3—A coordination bond is a covalent bond in which both the electrons of the shared pair originate from the same atom.
Identify coordination bonds in compounds.</td></tr>
<tr><td>HL—Include coverage of transition element complexes.</td><td>HL Reactivity 3.4—Why do Lewis acid–base reactions lead to the formation of coordination bonds?</td></tr>
</table>

<table>
<tr><td colspan="2">Structure 2.2.4—The valence shell electron pair repulsion (VSEPR) model enables the shapes of molecules to be predicted from the repulsion of electron domains around a central atom.
Predict the electron domain geometry and the molecular geometry for species with up to four electron domains.</td></tr>
<tr><td>Include predicting how non-bonding pairs and multiple bonds affect bond angles.</td><td>Nature of science—How useful is the VSEPR model at predicting molecular geometry?</td></tr>
</table>

Structure 2.2.5—Bond polarity results from the difference in electronegativities of the bonded atoms.

Deduce the polar nature of a covalent bond from electronegativity values.

Bond dipoles can be shown either with partial charges or vectors. Electronegativity values are given in the data booklet.	Structure 2.1—What properties of ionic compounds might be expected in compounds with polar covalent bonding?

Structure 2.2.6—Molecular polarity depends on both bond polarity and molecular geometry.

Deduce the net dipole moment of a molecule or ion by considering bond polarity and molecular geometry.

Examples should include species in which bond dipoles do and do not cancel each other.	HL Structure 3.2—What features of a molecule make it “infrared (IR) active”?

Structure 2.2.7—Carbon and silicon form covalent network structures.

Describe the structures and explain the properties of silicon, silicon dioxide and carbon’s allotropes: diamond, graphite, fullerenes and graphene.

Allotropes of the same element have different bonding and structural patterns, and so have different chemical and physical properties.	Structure 3.1—Why are silicon–silicon bonds generally weaker than carbon–carbon bonds?

Structure 2.2.8—The nature of the force that exists between molecules is determined by the size and polarity of the molecules. Intermolecular forces include London (dispersion), dipole-induced dipole, dipole–dipole and hydrogen bonding.

Deduce the types of intermolecular force present from the structural features of covalent molecules.

The term “van der Waals forces” should be used as an inclusive term to include dipole–dipole, dipole-induced dipole, and London (dispersion) forces. Hydrogen bonds occur when hydrogen, being covalently bonded to an electronegative atom, has an attractive interaction on a neighbouring electronegative atom.	Structure 1.5—To what extent can intermolecular forces explain the deviation of real gases from ideal behaviour? Nature of science, Structure 1.1, 2.1, 2.3—How do the terms “bonds” and “forces” compare? Nature of science—How can advances in technology lead to changes in scientific definitions, e.g. the updated International Union of Pure and Applied Chemistry (IUPAC) definition of the hydrogen bond?

Structure 2.2.9—Given comparable molar mass, the relative strengths of intermolecular forces are generally: London (dispersion) forces < dipole–dipole forces < hydrogen bonding.

Explain the physical properties of covalent substances to include volatility, electrical conductivity and solubility in terms of their structure.

	Tool 1, Inquiry 2—What experimental data demonstrate the physical properties of covalent substances? Structure 3.2—To what extent does a functional group determine the nature of the intermolecular forces?

<table>
<tr><td colspan="2">**Structure 2.2.10—Chromatography is a technique used to separate the components of a mixture based on their relative attractions involving intermolecular forces to mobile and stationary phases.**
Explain, calculate and interpret the retardation factor values, R_{F}.</td></tr>
<tr><td>Knowledge of the use of locating agents in chromatography is not required.
The technical and operational details of a gas chromatograph or high-performance liquid chromatograph will not be assessed.</td><td>Tool 1—How can a mixture be separated using paper chromatography or thin layer chromatography (TLC)?</td></tr>
</table>

Additional higher level: 8 hours

<table>
<tr><td colspan="2">**Structure 2.2.11—Resonance structures occur when there is more than one possible position for a double bond in a molecule.**
Deduce resonance structures of molecules and ions.</td></tr>
<tr><td>Include the term “delocalization”.</td><td>Structure 1.3—Why are oxygen and ozone dissociated by different wavelengths of light?</td></tr>
</table>

<table>
<tr><td colspan="2">**Structure 2.2.12—Benzene, C_6H_6, is an important example of a molecule that has resonance.**
Discuss the structure of benzene from physical and chemical evidence.</td></tr>
<tr><td></td><td>Reactivity 2.1, 2.2—How does the resonance energy in benzene explain its relative unreactivity?
Reactivity 3.4—What are the structural features of benzene that favour it undergoing electrophilic substitution reactions?</td></tr>
</table>

<table>
<tr><td colspan="2">**Structure 2.2.13—Some atoms can form molecules in which they have an expanded octet of electrons.**
Visually represent Lewis formulas for species with five and six electron domains around the central atom.
Deduce the electron domain geometry and the molecular geometry for these species using the VSEPR model.</td></tr>
<tr><td></td><td>Structure 3.1—How does the ability of some atoms to expand their octet relate to their position in the periodic table?</td></tr>
</table>

<table>
<tr><td colspan="2">**Structure 2.2.14—Formal charge values can be calculated for each atom in a species and used to determine which of several possible Lewis formulas is preferred.**
Apply formal charge to determine a preferred Lewis formula from different Lewis formulas for a species.</td></tr>
<tr><td></td><td>Structure 3.1, Reactivity 3.2—What are the different assumptions made in the calculation of formal charge and of oxidation states for atoms in a species?</td></tr>
</table>

<table>
<tr><td>**Structure 2.2.15—Sigma bonds (σ) form by the head-on combination of atomic orbitals where the electron density is concentrated along the bond axis.**
Pi bonds (π) form by the lateral combination of p-orbitals where the electron density is concentrated on opposite sides of the bond axis.
Deduce the presence of sigma bonds and pi bonds in molecules and ions.</td></tr>
</table>

Include both organic and inorganic examples.	

<table>
<tr><td colspan="2">Structure 2.2.16—Hybridization is the concept of mixing atomic orbitals to form new hybrid orbitals for bonding.
Analyse the hybridization and bond formation in molecules and ions.
Identify the relationships between Lewis formulas, electron domains, molecular geometry and type of hybridization.
Predict the geometry around an atom from its hybridization, and vice versa.</td></tr>
<tr><td>Include both organic and inorganic examples.
Only sp, sp^2 and sp^3 hybridization need to be covered.</td><td></td></tr>
</table>

Structure 2.3—The metallic model

Guiding question: What determines the metallic nature and properties of an element

Standard level and higher level: 2 hours

<table>
<tr><td colspan="2">Structure 2.3.1—A metallic bond is the electrostatic attraction between a lattice of cations and delocalized electrons.
Explain the electrical conductivity, thermal conductivity and malleability of metals.</td></tr>
<tr><td>Relate characteristic properties of metals to their uses.</td><td>Tool 1, Inquiry 2, Structure 3.1—What experimental data demonstrate the physical properties of metals, and trends in these properties, in the periodic table?
Reactivity 3.2—What trends in reactivity of metals can be predicted from the periodic table?</td></tr>
</table>

<table>
<tr><td colspan="2">Structure 2.3.2—The strength of a metallic bond depends on the charge of the ions and the radius of the metal ion.
Explain trends in melting points of s and p block metals.</td></tr>
<tr><td>A simple treatment in terms of charge of cations and electron density is required.</td><td>Structure 2.4—What are the features of metallic bonding that make it possible for metals to form alloys?</td></tr>
</table>

Additional higher level: 1 hour

<table>
<tr><td colspan="2">Structure 2.3.3—Transition elements have delocalized d-electrons.
Explain the high melting point and electrical conductivity of transition elements.</td></tr>
<tr><td>Chemical properties of transition elements are covered in Reactivity 3.4.</td><td>Structure 3.1—Why is the trend in melting points of metals across a period less evident across the d-block?</td></tr>
</table>

Structure 2.4—From models to materials

Guiding question: What role do bonding and structure have in the design of materials?

Standard level and higher level: 4 hours

<table>
<tr><td>Structure 2.4.1—Bonding is best described as a continuum between the ionic, covalent and metallic models, and can be represented by a bonding triangle.
Use bonding models to explain the properties of a material.</td></tr>
</table>

A triangular bonding diagram is provided in the data booklet.	Structure 3.1—How do the trends in properties of period 3 oxides reflect the trend in their bonding? Nature of science, Structures 2.1, 2.2—What are the limitations of discrete bonding categories?

Structure 2.4.2—The position of a compound in the bonding triangle is determined by the relative contributions of the three bonding types to the overall bond.

Determine the position of a compound in the bonding triangle from electronegativity data.

Predict the properties of a compound based on its position in the bonding triangle.

To illustrate the relationship between bonding type and properties, include example materials of varying percentage bonding character. Only binary compounds need to be considered. Calculations of percentage ionic character are not required. Electronegativity data are given in the data booklet.	Structure 2.1, 2.2, 2.3—Why do composites like reinforced concretes, which are made from ionic and covalently bonded components and steel bars, have unique properties?

Structure 2.4.3—Alloys are mixtures of a metal and other metals or non-metals. They have enhanced properties.

Explain the properties of alloys in terms of non-directional bonding.

Illustrate with common examples such as bronze, brass and stainless steel. Specific examples of alloys do not have to be learned.	Structure 1.1—Why are alloys more correctly described as mixtures rather than as compounds?

Structure 2.4.4—Polymers are large molecules, or macromolecules, made from repeating subunits called monomers.

Describe the common properties of plastics in terms of their structure.

Examples of natural and synthetic polymers should be discussed.	Structure 3.2—What are the structural features of some plastics that make them biodegradable?

Structure 2.4.5—Addition polymers form by the breaking of a double bond in each monomer.

Represent the repeating unit of an addition polymer from given monomer structures.

Examples should include polymerization reactions of alkenes. Structures of monomers do not have to be learned but will be provided or will need to be deduced from the polymer.	Structure 3.2—What functional groups in molecules can enable them to act as monomers for addition reactions? Reactivity 2.1—Why is the atom economy 100% for an addition polymerization reaction?

Additional higher level: 1 hour

Structure 2.4.6—Condensation polymers form by the reaction between functional groups in each monomer with the release of a small molecule.

Represent the repeating unit of polyamides and polyesters from given monomer structures.

All biological macromolecules form by condensation reactions and break down by hydrolysis.	Structure 3.2—What functional groups in molecules can enable them to act as monomers for condensation reactions?

Structure 3. Classification of matter

Structure 3.1—The periodic table: Classification of elements

Guiding question: How does the periodic table help us to predict patterns and trends in the properties of elements?

Standard level and higher level: 7 hours

Structure 3.1.1—The periodic table consists of periods, groups and blocks. Identify the positions of metals, metalloids and non-metals in the periodic table.	
The four blocks associated with the sublevels s, p, d, f should be recognized. A copy of the periodic table is available in the data booklet.	

Structure 3.1.2—The period number shows the outer energy level that is occupied by electrons. **Elements in a group have a common number of valence electrons.** Deduce the electron configuration of an atom up to $Z = 36$ from the element's position in the periodic table and vice versa.	
Groups are numbered from 1 to 18. The classifications "alkali metals", "halogens", "transition elements" and "noble gases" should be known.	Nature of science, Structure 1.2—How has the organization of elements in the periodic table facilitated the discovery of new elements?

Structure 3.1.3—Periodicity refers to trends in properties of elements across a period and down a group. Explain the periodicity of atomic radius, ionic radius, ionization energy, electron affinity and electronegativity.

Structure 3.1.4—Trends in properties of elements down a group include the increasing metallic character of group 1 elements and decreasing non-metallic character of group 17 elements. Describe and explain the reactions of group 1 metals with water, and of group 17 elements with halide ions.	
	Inquiry 2, Tool 2—Why are simulations often used in exploring the trends in chemical reactivity of group 1 and group 17 elements?

Structure 3.1.5—Metallic and non-metallic properties show a continuum. This includes the trend from basic metal oxides through amphoteric to acidic non-metal oxides. Deduce equations for the reactions with water of the oxides of group 1 and group 2 metals, carbon and sulfur.	
Include acid rain caused by gaseous non-metal oxides, and ocean acidification caused by increasing CO_2 levels.	Structure 2.1, 2.2—How do differences in bonding explain the differences in the properties of metal and non-metal oxides?

Structure 3.1.6—The oxidation state is a number assigned to an atom to show the number of electrons transferred in forming a bond. It is the charge that atom would have if the compound were composed of ions. Deduce the oxidation states of an atom in an ion or a compound.

Explain why the oxidation state of an element is zero.	
Oxidation states are shown with a + or – sign followed by the Arabic symbol for the number, e.g. +2, –1. Examples should include hydrogen in metal hydrides (–1) and oxygen in peroxides (–1). The terms “oxidation number” and “oxidation state” are often used interchangeably, and either term is acceptable in assessment. Naming conventions for oxyanions use oxidation numbers shown with Roman numerals, but generic names persist and are acceptable. Examples include NO_3^- nitrate, NO_2^- nitrite, SO_4^{2-} sulfate, SO_3^{2-} sulfite.	Reactivity 3.2—How can oxidation states be used to analyse redox reactions?

Additional higher level: 4 hours

Structure 3.1.7—Discontinuities occur in the trend of increasing first ionization energy across a period. Explain how these discontinuities provide evidence for the existence of energy sublevels.	
Explanations should be based on the energy of the electron removed, rather than on the “special stability” of filled and half-filled sublevels.	

Structure 3.1.8—Transition elements have incomplete d-sublevels that give them characteristic properties. Recognize properties, including: variable oxidation state, high melting points, magnetic properties, catalytic properties, formation of coloured compounds and formation of complex ions with ligands.	
Knowledge of different types of magnetism will not be assessed.	Nature of science, Structure 2.3—What are the arguments for and against including scandium as a transition element?

Structure 3.1.9—The formation of variable oxidation states in transition elements can be explained by the fact that their successive ionization energies are close in value. Deduce the electron configurations of ions of the first-row transition elements.

Structure 3.1.10—Transition element complexes are coloured due to the absorption of light when an electron is promoted between the orbitals in the split d-sublevels. The colour absorbed is complementary to the colour observed. Apply the colour wheel to deduce the wavelengths and frequencies of light absorbed and/or observed.	
Students are not expected to know the different splitting patterns and their relation to the coordination number. The colour wheel and the equation $c = \lambda f$ are given in the data booklet.	Reactivity 3.4—What is the nature of the reaction between transition element ions and ligands in forming complex ions? Tool 1, Inquiry 2—How can colorimetry or spectrophotometry be used to calculate the concentration of a solution of coloured ions?

Structure 3.2—Functional groups: Classification of organic compounds

Guiding question: How does the classification of organic molecules help us to predict their properties?

Standard level and higher level: 9 hours

<table>
<tr><td colspan="2">Structure 3.2.1—Organic compounds can be represented by different types of formulas. These include empirical, molecular, structural (full and condensed), stereochemical and skeletal.
Identify different formulas and interconvert molecular, skeletal and structural formulas.
Construct 3D models (real or virtual) of organic molecules.</td></tr>
<tr><td>Stereochemical formulas are not expected to be drawn, except where specifically indicated.</td><td>Structure 2.2—What is unique about carbon that enables it to form more compounds than the sum of all the other elements’ compounds?
Nature of science, Structure 2.2—What are the advantages and disadvantages of different depictions of an organic compound (e.g. structural formula, stereochemical formula, skeletal formula, 3D models)?</td></tr>
</table>

<table>
<tr><td colspan="2">Structure 3.2.2—Functional groups give characteristic physical and chemical properties to a compound. Organic compounds are divided into classes according to the functional groups present in their molecules.
Identify the following functional groups by name and structure: halogeno, hydroxyl, carbonyl, carboxyl, alkoxy, amino, amido, ester, phenyl.</td></tr>
<tr><td>The terms “saturated” and “unsaturated” should be included.</td><td>HL Structure 2.4—What is the nature of the reaction that occurs when two amino acids form a dipeptide?
Nature of science, Reactivity 3.2, 3.4—How can functional group reactivity be used to determine a reaction pathway between compounds, e.g. converting ethene into ethanoic acid?</td></tr>
</table>

<table>
<tr><td colspan="2">Structure 3.2.3—A homologous series is a family of compounds in which successive members differ by a common structural unit, typically CH_2. Each homologous series can be described by a general formula.
Identify the following homologous series: alkanes, alkenes, alkynes, halogenoalkanes, alcohols, aldehydes, ketones, carboxylic acids, ethers, amines, amides and esters.</td></tr>
<tr><td></td><td>Nature of science, Tool 2—How useful are 3D models (real or virtual) to visualize the invisible?</td></tr>
</table>

<table>
<tr><td colspan="2">Structure 3.2.4—Successive members of a homologous series show a trend in physical properties.
Describe and explain the trend in melting and boiling points of members of a homologous series.</td></tr>
<tr><td></td><td>Structure 2.2—What is the influence of the carbon chain length, branching and the nature of the functional groups on intermolecular forces?</td></tr>
</table>

<table>
<tr><td colspan="2">Structure 3.2.5—“IUPAC nomenclature” refers to a set of rules used by the International Union of Pure and Applied Chemistry to apply systematic names to organic and inorganic compounds.
Apply IUPAC nomenclature to saturated or mono-unsaturated compounds that have up to six carbon atoms in the parent chain and contain one type of the following functional groups: halogeno, hydroxyl, carbonyl, carboxyl.</td></tr>
<tr><td>Include straight-chain and branched-chain isomers.
Include numeric prefixes (mono, di, tri, tetra, penta, hexa).</td><td></td></tr>
</table>

Structure 3.2.6—Structural isomers are molecules that have the same molecular formula but different connectivities. Recognize isomers, including branched, straight-chain, position and functional group isomers.	
Primary, secondary and tertiary alcohols, halogenoalkanes and amines should be included.	HL Structure 2.2—How does the fact that there are only 3 isomers of dibromobenzene support the current model of benzene's structure?

Additional higher level: 11 hours

Structure 3.2.7—Stereoisomers have the same constitution (atom identities, connectivities and bond multiplicities) but different spatial arrangements of atoms. Describe and explain the features that give rise to *cis*-*trans* isomerism; recognize it in non-cyclic alkenes and C3 and C4 cycloalkanes. Draw stereochemical formulas showing the tetrahedral arrangement around a chiral carbon. Describe and explain a chiral carbon atom giving rise to stereoisomers with different optical properties. Recognize a pair of enantiomers as non-superimposable mirror images from 3D modelling (real or virtual).	
Nomenclature using the E-Z system will not be assessed. The terms "chiral", "optical activity", "enantiomer" and "racemic" mixture should be understood. Knowledge of the different chemical properties of enantiomers can be limited to the fact that they behave differently in chiral environments. Wedge-dash type representations involving tapered bonds should be used for the representation of enantiomers.	

Structure 3.2.8—Mass spectrometry (MS) of organic compounds can cause fragmentation of molecules. Deduce information about the structural features of a compound from specific MS fragmentation patterns.	
Include reference to the molecular ion. Data on specific MS fragments are provided in the data booklet.	

Structure 3.2.9—Infrared (IR) spectra can be used to identify the type of bond present in a molecule. Interpret the functional group region of an IR spectrum, using a table of characteristic frequencies (wavenumber/cm^{-1}).	
Include reference to the absorption of IR radiation by greenhouse gases. Data for interpretation of IR spectra are given in the data booklet.	Structure 2.2—What features of a molecule determine whether it is IR active or not? Reactivity 1.3—What properties of a greenhouse gas determine its "global warming potential"?

Structure 3.2.10—Proton nuclear magnetic resonance spectroscopy (^1H NMR) gives information on the different chemical environments of hydrogen atoms in a molecule. Interpret ^1H NMR spectra to deduce the structures of organic molecules from the number of signals, the chemical shifts, and the relative areas under signals (integration traces).

Structure 3.2.11—Individual signals can be split into clusters of peaks. Interpret ^{1}H NMR spectra from splitting patterns showing singlets, doublets, triplets and quartets to deduce greater structural detail.	
Data for interpretation of ^{1}H NMR spectra are given in the data booklet.	

Structure 3.2.12—Data from different techniques are often combined in structural analysis. Interpret a variety of data, including analytical spectra, to determine the structure of a molecule.

Reactivity

Reactivity 1. What drives chemical reactions?

Reactivity 1.1—Measuring enthalpy changes

Guiding question: What can be deduced from the temperature change that accompanies chemical or physical change?

Standard level and higher level: 5 hours

Reactivity 1.1.1—Chemical reactions involve a transfer of energy between the system and the surroundings, while total energy is conserved. Understand the difference between heat and temperature.	
	Structure 1.1—What is the relationship between temperature and kinetic energy of particles?

Reactivity 1.1.2—Reactions are described as endothermic or exothermic, depending on the direction of energy transfer between the system and the surroundings. Understand the temperature change (decrease or increase) that accompanies endothermic and exothermic reactions, respectively.	
	Tool 1, Inquiry 2—What observations would you expect to make during an endothermic and an exothermic reaction?

Reactivity 1.1.3—The relative stability of reactants and products determines whether reactions are endothermic or exothermic. Sketch and interpret energy profiles for endothermic and exothermic reactions.	
Axes for energy profiles should be labelled as reaction coordinate (x), potential energy (y).	Structure 2.2—Most combustion reactions are exothermic; how does the bonding in N_2 explain the fact that its combustion is endothermic?

Reactivity 1.1.4—The standard enthalpy change for a chemical reaction, $\Delta H^\ominus$, refers to the heat transferred at constant pressure under standard conditions and states. It can be determined from the change in temperature of a pure substance. Apply the equations $Q = mc\Delta T$ and $\Delta H = -\frac{Q}{n}$ in the calculation of the enthalpy change of a reaction.	
The units of $\Delta H^\ominus$ are kJ mol^{-1}.	Tool 1, Inquiry 1, 2, 3—How can the enthalpy change for combustion reactions, such as for alcohols or food, be investigated experimentally?

The equation $Q = mc\Delta T$ and the value of c, the specific heat capacity of water, are given in the data booklet.	Tool 1, Inquiry 3—Why do calorimetry experiments typically measure a smaller change in temperature than is expected from theoretical values?

Additional higher level: None for Reactivity 1.1

Reactivity 1.2—Energy cycles in reactions

Guiding question: How does application of the law of conservation of energy help us to predict energy changes during reactions?

Standard level and higher level: 3 hours

<table>
<tr><td colspan="2">Reactivity 1.2.1—Bond-breaking absorbs and bond-forming releases energy.
Calculate the enthalpy change of a reaction from given average bond enthalpy data.</td></tr>
<tr><td>Include explanation of why bond enthalpy data are average values and may differ from those measured experimentally.
Average bond enthalpy values are given in the data booklet.</td><td>Structure 2.2—How would you expect bond enthalpy data to relate to bond length and polarity?
Reactivity 3.4—How does the strength of a carbon–halogen bond affect the rate of a nucleophilic substitution reaction?</td></tr>
</table>

Reactivity 1.2.2—Hess's law states that the enthalpy change for a reaction is independent of the pathway between the initial and final states. Apply Hess's law to calculate enthalpy changes in multistep reactions.

Additional higher level: 5 hours

<table>
<tr><td colspan="2">Reactivity 1.2.3—Standard enthalpy changes of combustion, $\Delta H_c^\ominus$, and formation, $\Delta H_f^\ominus$, data are used in thermodynamic calculations.
Deduce equations and solutions to problems involving these terms.</td></tr>
<tr><td>Enthalpy of combustion and formation data are given in the data booklet.</td><td>Structure 2.2—Would you expect allotropes of an element, such as diamond and graphite, to have different $\Delta H_f^\ominus$ values?</td></tr>
</table>

<table>
<tr><td colspan="2">Reactivity 1.2.4—An application of Hess's law uses enthalpy of formation data or enthalpy of combustion data to calculate the enthalpy change of a reaction.
Calculate enthalpy changes of a reaction using $\Delta H_f^\ominus$ data or $\Delta H_c^\ominus$ data:
$\Delta H^\ominus = \Sigma(\Delta H_f^\ominus \text{products}) - \Sigma(\Delta H_f^\ominus \text{reactants})$
$\Delta H^\ominus = \Sigma(\Delta H_c^\ominus \text{reactants}) - \Sigma(\Delta H_c^\ominus \text{products})$</td></tr>
<tr><td>The equations to determine the enthalpy change of a reaction using $\Delta H_f^\ominus$ data or $\Delta H_c^\ominus$ data are given in the data booklet.</td><td></td></tr>
</table>

<table>
<tr><td colspan="2">Reactivity 1.2.5—A Born–Haber cycle is an application of Hess's law, used to show energy changes in the formation of an ionic compound.
Interpret and determine values from a Born–Haber cycle for compounds composed of univalent and divalent ions.</td></tr>
<tr><td>The cycle includes: ionization energies, enthalpy of atomization (using sublimation and/or bond</td><td>Structure 2.1—What are the factors that influence the strength of lattice enthalpy in an ionic compound?</td></tr>
</table>

enthalpies), electron affinities, lattice enthalpy, enthalpy of formation. The construction of a complete Born–Haber cycle will not be assessed.	

Reactivity 1.3—Energy from fuels

Guiding question: What are the challenges of using chemical energy to address our energy needs?

Standard level and higher level: 4 hours

Reactivity 1.3.1—Reactive metals, non-metals and organic compounds undergo combustion reactions when heated in oxygen. Deduce equations for reactions of combustion, including hydrocarbons and alcohols.	
	Reactivity 2.2—Why is high activation energy often considered to be a useful property of a fuel? Reactivity 3.2—Which species are the oxidizing and reducing agents in a combustion reaction?

Reactivity 1.3.2—Incomplete combustion of organic compounds, especially hydrocarbons, leads to the production of carbon monoxide and carbon. Deduce equations for the incomplete combustion of hydrocarbons and alcohols.	
	Inquiry 2—What might be observed when a fuel such as methane is burned in a limited supply of oxygen? Reactivity 2.1—How does limiting the supply of oxygen in combustion affect the products and increase health risks?

Reactivity 1.3.3—Fossil fuels include coal, crude oil and natural gas, which have different advantages and disadvantages. Evaluate the amount of carbon dioxide added to the atmosphere when different fuels burn. Understand the link between carbon dioxide levels and the greenhouse effect.	
The tendency for incomplete combustion and energy released per unit mass should be covered.	Structure 3.2—Why do larger hydrocarbons have a greater tendency to undergo incomplete combustion? HL Structure 3.2—Why is carbon dioxide described as a greenhouse gas? Nature of science, Reactivity 3.2—What are some of the environmental, economic, ethical and social implications of burning fossil fuels?

Reactivity 1.3.4—Biofuels are produced from the biological fixation of carbon over a short period of time through photosynthesis. Understand the difference between renewable and non-renewable energy sources. Consider the advantages and disadvantages of biofuels.	
The reactants and products of photosynthesis should be known.	

<table>
<tr><td colspan="2">Reactivity 1.3.5—A fuel cell can be used to convert chemical energy from a fuel directly to electrical energy.
Deduce half-equations for the electrode reactions in a fuel cell.</td></tr>
<tr><td>Hydrogen and methanol should be covered as fuels for fuel cells.
The use of proton exchange membranes will not be assessed.</td><td>Reactivity 3.2—What are the main differences between a fuel cell and a primary (voltaic) cell?</td></tr>
</table>

Additional higher level: None for Reactivity 1.3

Reactivity 1.4—Entropy and spontaneity (Additional higher level)

Guiding question: What determines the direction of chemical change?

Additional higher level: 5 hours

<table>
<tr><td colspan="2">Reactivity 1.4.1—Entropy, S, is a measure of the dispersal or distribution of matter and/or energy in a system. The more ways the energy can be distributed, the higher the entropy. Under the same conditions, the entropy of a gas is greater than that of a liquid, which in turn is greater than that of a solid.
Predict whether a physical or chemical change will result in an increase or decrease in entropy of a system.
Calculate standard entropy changes, $\Delta S^{\ominus}$, from standard entropy values, $S^{\ominus}$.</td></tr>
<tr><td>Standard entropy values are given in the data booklet.</td><td>Structure 1.1—Why is the entropy of a perfect crystal at 0 K predicted to be zero?</td></tr>
</table>

<table>
<tr><td colspan="2">Reactivity 1.4.2—Change in Gibbs energy, ΔG, relates the energy that can be obtained from a chemical reaction to the change in enthalpy, ΔH, change in entropy, ΔS, and absolute temperature, T.
Apply the equation $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$ to calculate unknown values of these terms.</td></tr>
<tr><td>Thermodynamic data values are given in the data booklet.
Note the units: ΔH kJ mol^{-1}; ΔS J K^{-1} mol^{-1}; ΔG kJ mol^{-1}.</td><td></td></tr>
</table>

<table>
<tr><td colspan="2">Reactivity 1.4.3—At constant pressure, a change is spontaneous if the change in Gibbs energy, ΔG, is negative.
Interpret the sign of ΔG calculated from thermodynamic data.
Determine the temperature at which a reaction becomes spontaneous.</td></tr>
<tr><td>ΔG takes into account the direct entropy change resulting from the transformation of the chemicals and the indirect entropy change of the surroundings resulting from the transfer of heat energy.</td><td>Reactivity 3.2—How can electrochemical data also be used to predict the spontaneity of a reaction?</td></tr>
</table>

<table>
<tr><td colspan="2">Reactivity 1.4.4—As a reaction approaches equilibrium, ΔG becomes less negative and finally reaches zero.
Perform calculations using the equation $\Delta G = \Delta G^{\ominus} + RT \ln Q$ and its application to a system at equilibrium $\Delta G^{\ominus} = -RT \ln K$.</td></tr>
<tr><td>The equations are given in the data booklet.</td><td>Reactivity 2.3—What is the likely composition of an equilibrium mixture when $\Delta G^{\ominus}$ is positive?</td></tr>
</table>

Reactivity 2. How much, how fast and how far?

Reactivity 2.1—How much? The amount of chemical change

Guiding question: How are chemical equations used to calculate reacting ratios?

Standard level and higher level: 7 hours

<table>
<tr><td colspan="2">Reactivity 2.1.1—Chemical equations show the ratio of reactants and products in a reaction.
Deduce chemical equations when reactants and products are specified.</td></tr>
<tr><td>Include the use of state symbols in chemical equations.</td><td>Reactivity 3.2—When is it useful to use half-equations?</td></tr>
</table>

<table>
<tr><td colspan="2">Reactivity 2.1.2—The mole ratio of an equation can be used to determine:
• the masses and/or volumes of reactants and products
• the concentrations of reactants and products for reactions occurring in solution.
Calculate reacting masses and/or volumes and concentrations of reactants and products.</td></tr>
<tr><td>Avogadro’s law and definitions of molar concentration are covered in Structure 1.4.
The values for A_r given in the data booklet to two decimal places should be used in calculations.</td><td>Structure 1.5—How does the molar volume of a gas vary with changes in temperature and pressure?
Nature of science, Structure 1.4—In what ways does Avogadro’s law help us to describe, but not explain, the behaviour of gases?</td></tr>
</table>

<table>
<tr><td colspan="2">Reactivity 2.1.3—The limiting reactant determines the theoretical yield.
Identify the limiting and excess reactants from given data.</td></tr>
<tr><td>Distinguish between the theoretical yield and the experimental yield.</td><td>Tool 1, Inquiry 1, 2, 3—What errors may cause the experimental yield to be i) higher and ii) lower than the theoretical yield?</td></tr>
</table>

<table>
<tr><td>Reactivity 2.1.4—The percentage yield is calculated from the ratio of experimental yield to theoretical yield.
Solve problems involving reacting quantities, limiting and excess reactants, theoretical, experimental and percentage yields.</td></tr>
</table>

<table>
<tr><td colspan="2">Reactivity 2.1.5—The atom economy is a measure of efficiency in green chemistry.
Calculate the atom economy from the stoichiometry of a reaction.</td></tr>
<tr><td>Include discussion of the inverse relationship between atom economy and wastage in industrial processes.
The equation for calculation of the atom economy is given in the data booklet.</td><td>Structure 2.4, Reactivity 2.2—The atom economy and the percentage yield both give important information about the “efficiency” of a chemical process. What other factors should be considered in this assessment?</td></tr>
</table>

Additional higher level: None for Reactivity 2.1

Reactivity 2.2—How fast? The rate of chemical change

Guiding question: How can the rate of a reaction be controlled?

Standard level and higher level: 9 hours

<table>
<tr><td>Reactivity 2.2.1—The rate of reaction is expressed as the change in concentration of a particular reactant/product per unit time.</td></tr>
</table>

<table>
<tr><td colspan="2">Determine rates of reaction.</td></tr>
<tr><td>Calculation of reaction rates from tangents of graphs of concentration, volume or mass against time should be covered.</td><td>Tool 1, 3, Inquiry 2—Concentration changes in reactions are not usually measured directly. What methods are used to provide data to determine the rate of reactions?
Tool 1—What experiments measuring reaction rates might use time as i) a dependent variable ii) an independent variable?</td></tr>
</table>

<table>
<tr><td colspan="2">Reactivity 2.2.2—Species react as a result of collisions of sufficient energy and proper orientation.
Explain the relationship between the kinetic energy of the particles and the temperature in kelvin, and the role of collision geometry.</td></tr>
<tr><td></td><td>Structure 1.1—What is the relationship between the kinetic molecular theory and collision theory?</td></tr>
</table>

<table>
<tr><td colspan="2">Reactivity 2.2.3—Factors that influence the rate of a reaction include pressure, concentration, surface area, temperature and the presence of a catalyst.
Predict and explain the effects of changing conditions on the rate of a reaction.</td></tr>
<tr><td></td><td>Tool 1—What variables must be controlled in studying the effect of a factor on the rate of a reaction?
Nature of science, Tool 3, Inquiry 3—How can graphs provide evidence of systematic and random error?</td></tr>
</table>

<table>
<tr><td>Reactivity 2.2.4—Activation energy, E_a, is the minimum energy that colliding particles need for a successful collision leading to a reaction.
Construct Maxwell–Boltzmann energy distribution curves to explain the effect of temperature on the probability of successful collisions.</td></tr>
</table>

<table>
<tr><td colspan="2">Reactivity 2.2.5—Catalysts increase the rate of reaction by providing an alternative reaction pathway with lower E_a.
Sketch and explain energy profiles with and without catalysts for endothermic and exothermic reactions.
Construct Maxwell–Boltzmann energy distribution curves to explain the effect of different values for E_a on the probability of successful collisions.</td></tr>
<tr><td>Biological catalysts are called enzymes.
The different mechanisms of homogeneous and heterogeneous catalysts will not be assessed.</td><td>Reactivity 2.3—What is the relative effect of a catalyst on the rate of the forward and backward reactions?
HL Structure 3.1—What are the features of transition elements that make them useful as catalysts?</td></tr>
</table>

Additional higher level: 6 hours

<table>
<tr><td>Reactivity 2.2.6—Many reactions occur in a series of elementary steps. The slowest step determines the rate of the reaction.
Evaluate proposed reaction mechanisms and recognize reaction intermediates.
Distinguish between intermediates and transition states, and recognize both in energy profiles of reactions.</td></tr>
</table>

Include examples where the rate-determining step is not the first step. Proposed reaction mechanisms must be consistent with kinetic and stoichiometric data.	Reactivity 3.4—Which mechanism in the hydrolysis of halogenoalkanes involves an intermediate?

Reactivity 2.2.7—Energy profiles can be used to show the activation energy and transition state of the rate-determining step in a multistep reaction.

Construct and interpret energy profiles from kinetic data.

Reactivity 2.2.8—The molecularity of an elementary step is the number of reacting particles taking part in that step.

Interpret the terms “unimolecular”, “bimolecular” and “termolecular”.

Reactivity 2.2.9—Rate equations depend on the mechanism of the reaction and can only be determined experimentally.

Deduce the rate equation for a reaction from experimental data.

Reactivity 2.2.10—The order of a reaction with respect to a reactant is the exponent to which the concentration of the reactant is raised in the rate equation.

The order with respect to a reactant can describe the number of particles taking part in the rate-determining step.

The overall reaction order is the sum of the orders with respect to each reactant.

Sketch, identify and analyse graphical representations of zero, first and second order reactions.

Concentration–time and rate–concentration graphs should be included. Only integer values for order of reaction will be assessed.	Tool 1, 3, Inquiry 2—What measurements are needed to deduce the order of reaction for a specific reactant? Nature of science—Why are reaction mechanisms only considered as “possible mechanisms”?

Reactivity 2.2.11—The rate constant, k, is temperature dependent and its units are determined from the overall order of the reaction.

Solve problems involving the rate equation, including the units of k.

	Reactivity 3.4—What are the rate equations and units of k for the reactions of primary and tertiary halogenoalkanes with aqueous alkali?

Reactivity 2.2.12—The Arrhenius equation uses the temperature dependence of the rate constant to determine the activation energy.

Describe the qualitative relationship between temperature and the rate constant.

Analyse graphical representations of the Arrhenius equation, including its linear form.

The Arrhenius equation and its linear form are given in the data booklet.	

Reactivity 2.2.13—The Arrhenius factor, A, takes into account the frequency of collisions with proper orientations.

Determine the activation energy and the Arrhenius factor from experimental data.

Reactivity 2.3—How far? The extent of chemical change

Guiding question: How can the extent of a reversible reaction be influenced?

Standard level and higher level: 5 hours

Reactivity 2.3.1—A state of dynamic equilibrium is reached in a closed system when the rates of forward and backward reactions are equal. Describe the characteristics of a physical and chemical system at equilibrium.

Reactivity 2.3.2—The equilibrium law describes how the equilibrium constant, K, can be determined from the stoichiometry of a reaction. Deduce the equilibrium constant expression from an equation for a homogeneous reaction.

Reactivity 2.3.3—The magnitude of the equilibrium constant indicates the extent of a reaction at equilibrium and is temperature dependent. Determine the relationships between K values for reactions that are the reverse of each other at the same temperature.	
Include the extent of reaction for: $K{<}{<}1, K{<}1, K = 1, K{>}1, K{>}{>}1$.	Reactivity 3.1—How does the value of K for the dissociation of an acid convey information about its strength?

Reactivity 2.3.4—Le Châtelier's principle enables the prediction of the qualitative effects of changes in concentration, temperature and pressure to a system at equilibrium. Apply Le Châtelier's principle to predict and explain responses to changes of systems at equilibrium.	
Include the effects on the value of K and on the equilibrium composition. Le Châtelier's principle can be applied to heterogeneous equilibria such as: X(g) $\rightleftharpoons$ X(aq)	Reactivity 2.2—Why do catalysts have no effect on the value of K or on the equilibrium composition?

Additional higher level: 4 hours

Reactivity 2.3.5—The reaction quotient, Q, is calculated using the equilibrium expression with non-equilibrium concentrations of reactants and products. Calculate the reaction quotient Q from the concentrations of reactants and products at a particular time, and determine the direction in which the reaction will proceed to reach equilibrium.

Reactivity 2.3.6—The equilibrium law is the basis for quantifying the composition of an equilibrium mixture. Solve problems involving values of K and initial and equilibrium concentrations of the components of an equilibrium mixture.	
The approximation $[\text{reactant}]_{\text{initial}} \approx [\text{reactant}]_{\text{eqm}}$ when K is very small should be understood. The use of quadratic equations is not expected. Only homogeneous equilibria will be assessed.	Reactivity 3.1—How does the equilibrium law help us to determine the pH of a weak acid, weak base or a buffer solution?

Reactivity 2.3.7—The equilibrium constant and Gibbs energy change, ΔG, can both be used to measure the position of an equilibrium reaction.

Calculations using the equation $\Delta G^{\ominus} = -RT \ln K$. The equation is given in the data booklet.	Reactivity 1.4—How can Gibbs energy be used to explain which of the forward or backward reaction is favoured before reaching equilibrium?

Reactivity 3. What are the mechanisms of chemical change?

Reactivity 3.1—Proton transfer reactions

Guiding question: What happens when protons are transferred?

Standard level and higher level: 8 hours

Reactivity 3.1.1—Brønsted–Lowry acid is a proton donor and a Brønsted–Lowry base is a proton acceptor. Deduce the Brønsted–Lowry acid and base in a reaction.	
A proton in aqueous solution can be represented as both H^+(aq) and H_3O^+(aq). The distinction between the terms “base” and “alkali” should be understood.	Nature of science, Reactivity 3.4—Why has the definition of acid evolved over time?

Reactivity 3.1.2—A pair of species differing by a single proton is called a conjugate acid–base pair. Deduce the formula of the conjugate acid or base of any Brønsted–Lowry base or acid.	
	Structure 2.1—What are the conjugate acids of the polyatomic anions listed in Structure 2.1?

Reactivity 3.1.3—Some species can act as both Brønsted–Lowry acids and bases. Interpret and formulate equations to show acid–base reactions of these species.	
	Structure 3.1—What is the periodic trend in the acid–base properties of metal and non-metal oxides? Structure 3.1—Why does the release of oxides of nitrogen and sulfur into the atmosphere cause acid rain?

Reactivity 3.1.4—The pH scale can be used to describe the [H^+] of a solution: **$\mathrm{pH} = -\log_{10}[H^+]$; $[H^+] = 10^{-\mathrm{pH}}$** Perform calculations involving the logarithmic relationship between pH and [H^+].	
Include the estimation of pH using universal indicator, and the precise measurement of pH using a pH meter/probe. The equations for pH are given in the data booklet.	Tools 1, 2, 3—What is the shape of a sketch graph of pH against [H^+]? Nature of science, Tool 2—When are digital sensors (e.g. pH probes) more suitable than analogue methods (e.g. pH paper/solution)?

Reactivity 3.1.5—The ion product constant of water, K_w, shows an inverse relationship between [H^+] and [OH^-]. $K_w = [H^+][OH^-]$ Recognize solutions as acidic, neutral and basic from the relative values of [H^+] and [OH^-].	
The equation for K_w and its value at 298 K are given in the data booklet.	Reactivity 2.3—Why does the extent of ionization of water increase as temperature increases?

Reactivity 3.1.6—Strong and weak acids and bases differ in the extent of ionization. Recognize that acid–base equilibria lie in the direction of the weaker conjugate.	
HCl, HBr, HI, HNO_3 and H_2SO_4 are strong acids, and group 1 hydroxides are strong bases. The distinction between strong and weak acids or bases and concentrated and dilute reagents should be covered.	Reactivity 2.3—How would you expect the equilibrium constants of strong and weak acids to compare? Reactivity 1.1—Why does the acid strength of the hydrogen halides increase down group 17? Tool 1, Inquiry 2—What physical and chemical properties can be observed to distinguish between weak and strong acids or bases of the same concentration?

Reactivity 3.1.7—Acids react with bases in neutralization reactions. Formulate equations for the reactions between acids and metal oxides, metal hydroxides, hydrogencarbonates and carbonates.	
Identify the parent acid and base of different salts. Bases should include ammonia, amines, soluble carbonates and hydrogencarbonates; acids should include organic acids.	Tool 1, Structure 1.1—How can the salts formed in neutralization reactions be separated? Reactivity 1.1—Neutralization reactions are exothermic. How can this be explained in terms of bond enthalpies? Reactivity 3.2—How could we classify the reaction that occurs when hydrogen gas is released from the reaction between an acid and a metal?

Reactivity 3.1.8—pH curves for neutralization reactions involving strong acids and bases have characteristic shapes and features. Sketch and interpret the general shape of the pH curve.	
Interpretation should include the intercept with the pH axis and equivalence point. Only monoprotic neutralization reactions will be assessed.	Structure 1.4—Why is the equivalence point sometimes referred to as the stoichiometric point? Tools 1 and 3, Structure 1.3—How can titration be used to calculate the concentration of an acid or base in solution?

Additional higher level: 9 hours

Reactivity 3.1.9—The pOH scale describes the $[OH^-]$ of a solution. pOH = $-\log_{10}[OH^-]$; $[OH^-] = 10^{-pOH}$ Interconvert $[H^+]$, $[OH^-]$, pH and pOH values.	
The equations for pOH are given in the data booklet.	

Reactivity 3.1.10—The strengths of weak acids and bases are described by their K_a, K_b, pK_a or pK_b values. Interpret the relative strengths of acids and bases from these data.

Reactivity 3.1.11—For a conjugate acid–base pair, the relationship $K_a \times K_b = K_w$ can be derived from the expressions for K_a and K_b. Solve problems involving these values.

The use of quadratic equations is not expected in calculations.	Reactivity 2.3—How can we simplify calculations when equilibrium constants K_a and K_b are very small?

Reactivity 3.1.12—The pH of a salt solution depends on the relative strengths of the parent acid and base. Construct equations for the hydrolysis of ions in a salt, and predict the effect of each ion on the pH of the salt solution.	
Examples should include the ammonium ion NH_4^+, the carboxylate ion $RCOO^-$, the carbonate ion CO_3^{2-}, and the hydrogencarbonate ion HCO_3^-. The acidity of hydrated transition element ions and Al^{3+} (aq) is not required.	

Reactivity 3.1.13—pH curves of different combinations of strong and weak monoprotic acids and bases have characteristic shapes and features. Interpret the general shapes of pH curves for all four combinations of strong and weak acids and bases.	
Interpretation should include: intercept with the pH axis, equivalence point, buffer region, points where $\text{pH} = \text{p}K_a$ or $\text{pOH} = \text{p}K_b$.	Tool 1—When collecting data to generate a pH curve, when should smaller volumes of titrant be added between each measurement?

Reactivity 3.1.14—Acid–base indicators are weak acids, where the components of the conjugate acid–base pair have different colours. The pH of the end point of an indicator, where it changes colour, approximately corresponds to its $\text{p}K_a$ value. Construct equilibria expressions to show why the colour of an indicator changes with pH.	
The generalized formula HInd(aq) can be used to represent the undissociated form of an indicator. Examples of indicators with their pH range are given in the data booklet. Include universal indicator as a mixture of many indicators with a wide pH range of colour change.	Tool 1, Inquiry 2, Reactivity 3.2—What are some of the similarities and differences between indicators used in acid–base titrations and in redox titrations?

Reactivity 3.1.15—An appropriate indicator for a titration has an end point range that coincides with the pH at the equivalence point. Identify an appropriate indicator for a titration from the identity of the salt and the pH range of the indicator.	
Distinguish between the terms "end point" and "equivalence point".	

Reactivity 3.1.16—A buffer solution is one that resists change in pH on the addition of small amounts of acid or alkali. Describe the composition of acidic and basic buffers and explain their actions.	
	Reactivity 2.3—Why must buffer solutions be composed of weak acid or base conjugate systems, not of strong acids or bases?

Reactivity 3.1.17—The pH of a buffer solution depends on both:

- **the pK_a or pK_b of its acid or base**
- **the ratio of the concentration of acid or base to the concentration of the conjugate base or acid.**

Solve problems involving the composition and pH of a buffer solution, using the equilibrium constant.

Include explanation of the effect of dilution of a buffer.	Reactivity 2.3—How does Le Châtelier's principle enable us to interpret the behaviour of indicators and buffer solutions?

Reactivity 3.2—Electron transfer reactions

Guiding question: What happens when electrons are transferred?

Standard level and higher level: 10 hours

Reactivity 3.2.1—Oxidation and reduction can be described in terms of electron transfer, change in oxidation state, oxygen gain/loss or hydrogen loss/gain.

Deduce oxidation states of an atom in a compound or an ion.

Identify the oxidized and reduced species and the oxidizing and reducing agents in a chemical reaction.

Include examples to illustrate the variable oxidation states of transition element ions and of most main group non-metals. Include the use of oxidation numbers in the naming of compounds.	Structure 3.1—What are the advantages and limitations of using oxidation states to track redox changes? Structure 2.3—The surface oxidation of metals is often known as corrosion. What are some of the consequences of this process?

Reactivity 3.2.2—Half-equations separate the processes of oxidation and reduction, showing the loss or gain of electrons.

Deduce redox half-equations and equations in acidic or neutral solutions.

	Tool 1, Inquiry 2—Why are some redox titrations described as "self-indicating"?

Reactivity 3.2.3—The relative ease of oxidation and reduction of an element in a group can be predicted from its position in the periodic table.

The reactions between metals and aqueous metal ions demonstrate the relative ease of oxidation of different metals.

Predict the relative ease of oxidation of metals.

Predict the relative ease of reduction of halogens.

Interpret data regarding metal and metal ion reactions.

The relative reactivity of metals observed in metal/metal ion displacement reactions does not need to be learned; appropriate data will be supplied in examination questions.	Structure 3.1—Why does metal reactivity increase, and non-metal reactivity decrease, down the main groups of the periodic table? Tool 1, Inquiry 2—What observations can be made when metals are mixed with aqueous metal ions, and solutions of halogens are mixed with aqueous halide ions?

Reactivity 3.2.4—Acids react with reactive metals to release hydrogen.

Deduce equations for reactions of reactive metals with dilute HCl and H_2SO_4.

Reactivity 3.2.5—Oxidation occurs at the anode and reduction occurs at the cathode in electrochemical cells.

Identify electrodes as anode and cathode, and identify their signs/polarities in voltaic cells and electrolytic cells, based on the type of reaction occurring at the electrode.

Reactivity 3.2.6—A primary (voltaic) cell is an electrochemical cell that converts energy from spontaneous redox reactions to electrical energy.

Explain the direction of electron flow from anode to cathode in the external circuit, and ion movement across the salt bridge.

Construction of primary cells should include: half-cells containing metal/metal ion, anode, cathode, electric circuit, salt bridge.	Reactivity 1.3—Electrical energy can be derived from the combustion of fossil fuels or from electrochemical reactions. What are the similarities and differences in these reactions?

Reactivity 3.2.7—Secondary (rechargeable) cells involve redox reactions that can be reversed using electrical energy.

Deduce the reactions of the charging process from given electrode reactions for discharge, and vice versa.

Include discussion of advantages and disadvantages of fuel cells, primary cells and secondary cells.	Reactivity 2.3—Secondary cells rely on electrode reactions that are reversible. What are the common features of these reactions?

Reactivity 3.2.8—An electrolytic cell is an electrochemical cell that converts electrical energy to chemical energy by bringing about non-spontaneous reactions.

Explain how current is conducted in an electrolytic cell.

Deduce the products of the electrolysis of a molten salt.

Construction of electrolytic cells should include: DC power source connected to anode and cathode, electrolyte.	Structure 2.1—Under what conditions can ionic compounds act as electrolytes?

Reactivity 3.2.9—Functional groups in organic compounds may undergo oxidation.

Deduce equations to show changes in the functional groups during oxidation of primary and secondary alcohols, including the two-step reaction in the oxidation of primary alcohols.

Include explanation of the experimental set-up for distillation and reflux. Include the fact that tertiary alcohols are not oxidized under similar conditions. Names and formulas of specific oxidizing agents, and the mechanisms of oxidation, will not be assessed.	Structure 3.2—How does the nature of the functional group in a molecule affect its physical properties, such as boiling point? Reactivity 1.3—What is the difference between combustion and oxidation of an alcohol? HL Structure 3.1—Why is there a colour change when an alcohol is oxidized by a transition element compound?

Reactivity 3.2.10—Functional groups in organic compounds may undergo reduction.

Deduce equations to show reduction of carboxylic acids to primary alcohols via the aldehyde, and reduction of ketones to secondary alcohols.

Include the role of hydride ions in the reduction reaction.	Structure 3.1—How can oxidation states be used to show that the following molecules are given in

Names and formulas of specific reducing agents, and the mechanisms of reduction, will not be assessed.	increasing order of oxidation: CH_4, CH_3OH, HCHO, HCOOH, CO_2?

Reactivity 3.2.11—Reduction of unsaturated compounds by the addition of hydrogen lowers the degree of unsaturation.

Deduce the products of the reactions of hydrogen with alkenes and alkynes.

	Reactivity 3.4—Why are some reactions of alkenes classified as reduction reactions while others are classified as electrophilic addition reactions?

Additional higher level: 5 hours

Reactivity 3.2.12—The hydrogen half-cell $H^+(aq) + e^- \rightleftharpoons \frac{1}{2}H_2(g)$ is assigned a standard electrode potential of zero by convention. It is used in the measurement of standard electrode potential, $E^\ominus$.

Interpret standard electrode potential data in terms of ease of oxidation/reduction.

Standard reduction potentials are given in the data booklet.	

Reactivity 3.2.13—Standard cell potential, $E^\ominus_{cell}$, can be calculated from standard electrode potentials. $E^\ominus_{cell}$ has a positive value for a spontaneous reaction.

Predict whether a reaction is spontaneous in the forward or reverse direction from $E^\ominus$ data.

Reactivity 3.2.14—The equation $\Delta G^\ominus = -nFE^\ominus_{cell}$ shows the relationship between standard change in Gibbs energy and standard cell potential for a reaction.

Determine the value for $\Delta G^\ominus$ from $E^\ominus$ data.

The equation and the value of F in C mol^{-1} are given in the data booklet.	Reactivity 1.4—How can thermodynamic data also be used to predict the spontaneity of a reaction?

Reactivity 3.2.15—During electrolysis of aqueous solutions, competing reactions can occur at the anode and cathode, including the oxidation and reduction of water.

Deduce from standard electrode potentials the products of the electrolysis of aqueous solutions.

Electrolytic processes should include the electrolysis of water and of aqueous solutions. The effects of concentration and the nature of the electrode are limited to the electrolysis of NaCl(aq) and $CuSO_4$(aq).	

Reactivity 3.2.16—Electroplating involves the electrolytic coating of an object with a metallic thin layer.

Deduce equations for the electrode reactions during electroplating.

	Tool 1—How is an electrolytic cell used for electroplating?

Reactivity 3.3—Electron sharing reactions

Guiding question: What happens when a species possesses an unpaired electron?

Standard level and higher level: 2 hours

<table>
<tr><td colspan="2">Reactivity 3.3.1—A radical is a molecular entity that has an unpaired electron. Radicals are highly reactive.
Identify and represent radicals, e.g. $\cdot CH_3$ and $Cl\cdot$.</td></tr>
<tr><td></td><td>Structure 2.1—How is it possible for a radical to be an atom, a molecule, a cation or an anion? Consider examples of each type.</td></tr>
</table>

<table>
<tr><td colspan="2">Reactivity 3.3.2—Radicals are produced by homolytic fission, e.g. of halogens, in the presence of ultraviolet (UV) light or heat.
Explain, including with equations, the homolytic fission of halogens, known as the initiation step in a chain reaction.</td></tr>
<tr><td>The use of a single-barbed arrow (fish hook) to show the movement of a single electron should be covered.</td><td>Reactivity 1.2—Why do chlorofluorocarbons (CFCs) in the atmosphere break down to release chlorine radicals but typically not fluorine radicals?
Structure 2.2—What is the reverse process of homolytic fission?
Structure 2.2—Chlorine radicals released from CFCs are able to break down ozone, O_3, but not oxygen, O_2, in the stratosphere. What does this suggest about the relative strengths of bonds in the two allotropes?</td></tr>
</table>

<table>
<tr><td colspan="2">Reactivity 3.3.3—Radicals take part in substitution reactions with alkanes, producing a mixture of products.
Explain, using equations, the propagation and termination steps in the reactions between alkanes and halogens.</td></tr>
<tr><td>Reference should be made to the stability of alkanes due to the strengths of the C–C and C–H bonds and their essentially non-polar nature.</td><td>Reactivity 2.2—Why are alkanes described as kinetically stable but thermodynamically unstable?</td></tr>
</table>

Additional higher level: None for Reactivity 3.3

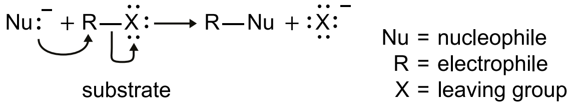
Reactivity 3.4—Electron-pair sharing reactions

Guiding question: What happens when reactants share their electron pairs with others?

Standard level and higher level: 4 hours

<table>
<tr><td colspan="2">Reactivity 3.4.1—A nucleophile is a reactant that forms a bond to its reaction partner (the electrophile) by donating both bonding electrons.
Recognize nucleophiles in chemical reactions.</td></tr>
<tr><td>Both neutral and negatively charged species should be included.</td><td></td></tr>
</table>

<table>
<tr><td colspan="2">Reactivity 3.4.2—In a nucleophilic substitution reaction, a nucleophile donates an electron pair to form a new bond, as another bond breaks producing a leaving group.
Deduce equations with descriptions and explanations of the movement of electron pairs in nucleophilic substitution reactions.</td></tr>
</table>

<table>
<tr><td colspan="2"> </td></tr>
<tr><td>Further details of the mechanisms are not required at SL.</td><td></td></tr>
</table>

<table>
<tr><td colspan="2">**Reactivity 3.4.3—Heterolytic fission is the breakage of a covalent bond when both bonding electrons remain with one of the two fragments formed.**
Explain, with equations, the formation of ions by heterolytic fission.</td></tr>
<tr><td>Curly arrows should be used to show the movement of electron pairs during reactions.</td><td>Reactivity 3.3—What is the difference between the bond-breaking that forms a radical and the bond-breaking that occurs in nucleophilic substitution reactions?</td></tr>
</table>

<table>
<tr><td colspan="2">**Reactivity 3.4.4—An electrophile is a reactant that forms a bond to its reaction partner (the nucleophile) by accepting both bonding electrons from that reaction partner.**
Recognize electrophiles in chemical reactions.</td></tr>
<tr><td>Both neutral and positively-charged species should be included.</td><td></td></tr>
</table>

<table>
<tr><td colspan="2">**Reactivity 3.4.5—Alkenes are susceptible to electrophilic attack because of the high electron density of the carbon–carbon double bond. These reactions lead to electrophilic addition.**
Deduce equations for the reactions of alkenes with water, halogens, and hydrogen halides.</td></tr>
<tr><td>The mechanisms of these reactions will not be assessed at SL.</td><td>Reactivity 3.3—Why is bromine water decolourized in the dark by alkenes but not by alkanes?
Structure 2.4—Why are alkenes sometimes known as “starting molecules” in industry?</td></tr>
</table>

Additional higher level: 7 hours

<table>
<tr><td colspan="2">**Reactivity 3.4.6—A Lewis acid is an electron-pair acceptor and a Lewis base is an electron-pair donor.**
Apply Lewis acid–base theory to inorganic and organic chemistry to identify the role of the reacting species.</td></tr>
<tr><td></td><td>Reactivity 3.1—What is the relationship between Brønsted–Lowry acids and bases and Lewis acids and bases?</td></tr>
</table>

<table>
<tr><td colspan="2">**Reactivity 3.4.7—When a Lewis base reacts with a Lewis acid, a coordination bond is formed. Nucleophiles are Lewis bases and electrophiles are Lewis acids.**
Draw and interpret Lewis formulas of reactants and products to show coordination bond formation in Lewis acid–base reactions.</td></tr>
<tr><td></td><td>Structure 2.2—Do coordination bonds have any different properties from other covalent bonds?</td></tr>
</table>

Reactivity 3.4.8—Coordination bonds are formed when ligands donate an electron pair to transition element cations, forming complex ions.

Deduce the charge on a complex ion, given the formula of the ion and ligands present.

Reactivity 3.4.9—Nucleophilic substitution reactions include the reactions between halogenoalkanes and nucleophiles.

Describe and explain the mechanisms of the reactions of primary and tertiary halogenoalkanes with nucleophiles.

Distinguish between the concerted one-step S_N2 reaction of primary halogenoalkanes and the two-step S_N1 reaction of tertiary halogenoalkanes. Both mechanisms occur for secondary halogenoalkanes. The stereospecific nature of S_N2 reactions should be covered.	Reactivity 2.2—What differences would be expected between the energy profiles for S_N1 and S_N2 reactions? Reactivity 2.2—What are the rate equations for these S_N1 and S_N2 reactions? Nature of science, Reactivity 2.2—How useful are mechanistic models such as S_N1 and S_N2?

Reactivity 3.4.10—The rate of the substitution reactions is influenced by the identity of the leaving group.

Predict and explain the relative rates of the substitution reactions for different halogenoalkanes.

Different halogenoalkanes should include RCl, RBr, RI. The roles of the solvent and the reaction mechanism on the rate will not be assessed.	Structure 3.1—Why is the iodide ion a better leaving group than the chloride ion?

Reactivity 3.4.11—Alkenes readily undergo electrophilic addition reactions.

Describe and explain the mechanisms of the reactions between symmetrical alkenes and halogens, water and hydrogen halides.

Reactivity 3.4.12—The relative stability of carbocations in the addition reactions between hydrogen halides and unsymmetrical alkenes can be used to explain the reaction mechanism.

Predict and explain the major product of a reaction between an unsymmetrical alkene and a hydrogen halide or water.

Reactivity 3.4.13—Electrophilic substitution reactions include the reactions of benzene with electrophiles.

Describe and explain the mechanism of the reaction between benzene and a charged electrophile, E^+.

The formation of the electrophile will not be assessed.	Structure 2.2—What are the features of benzene, C_6H_6, that make it not prone to undergo addition reactions, despite being highly unsaturated? Reactivity 3.1—Nitration of benzene uses a mixture of concentrated nitric and sulfuric acids to generate a strong electrophile, NO_2^+. How can the acid/base behaviour of HNO_3 in this mixture be described?

Assessment in the Diploma Programme

General

Assessment is an integral part of teaching and learning. The most important aims of assessment in the Diploma Programme (DP) are that it should support curricular goals and encourage appropriate student learning. Both external and internal assessments are used in the DP. IB examiners mark work produced for external assessment, while work produced for internal assessment is marked by teachers and externally moderated by the IB.

There are two types of assessment identified by the IB.

- Formative assessment informs both teaching and learning. It is concerned with providing accurate and helpful feedback to students and teachers on the kind of learning taking place and the nature of students' strengths and weaknesses in order to help develop students' understanding and capabilities. Formative assessment can also help to improve teaching quality, as it can provide information to monitor progress towards meeting the course aims and objectives (0404-01).
- Summative assessment gives an overview of previous learning and is concerned with measuring student achievement at, or towards the end, of the course of study (0404-04).

A comprehensive assessment policy is viewed as being integral with teaching, learning and course organization. For further information, see the IB *Programme standards and practices* publication.

The approach to assessment used by the IB is criterion-related, not norm-referenced. This approach to assessment judges students' work by their performance in relation to identified levels of attainment, and not in relation to the work of other students. For further information on assessment within the DP, please refer to the publication *Assessment principles and practices—Quality assessments in a digital age.*

To support teachers in the planning, delivery and assessment of the DP courses, a variety of resources can be found on the Programme Resource Centre or purchased from the IB store (store.ibo.org). Additional publications such as specimen papers and markschemes, teacher support material (TSM), subject reports and grade descriptors can also be found on the Programme Resource Centre. Past examination papers as well as markschemes can be purchased from the IB store.

Methods of assessment

The IB uses several methods to assess work produced by students.

Assessment criteria

Assessment criteria are used when the assessment task is open-ended. Each criterion concentrates on a particular skill that students are expected to demonstrate. An assessment objective describes what students should be able to do, and assessment criteria describe how well they should be able to do it. Using assessment criteria allows discrimination between different answers and encourages a variety of responses. Each criterion comprises a set of hierarchically ordered level descriptors. Each level descriptor is worth one or more marks. Each criterion is applied independently using a best-fit model. The maximum marks for each criterion may differ according to the criterion's importance. The marks awarded for each criterion are added together to give the total mark for the piece of work.

Markbands

Markbands are a comprehensive statement of expected performance against which responses are judged. They represent a single holistic criterion divided into level descriptors. Each level descriptor corresponds to a range of marks to differentiate student performance. A best-fit approach is used to ascertain which particular mark to use from the possible range for each level descriptor.

Analytic markschemes

Analytic markschemes are prepared for those examination questions that expect a particular kind of response and/or a given final answer from students. They give detailed instructions to examiners on how to break down the total mark for each question for different parts of the response.

Marking notes

For some assessment components marked using assessment criteria, marking notes are provided. Marking notes give guidance on how to apply assessment criteria to the particular requirements of a question.

Inclusive access arrangements

Inclusive access arrangements are available for candidates with access requirements. Standard assessment conditions may put candidates with assessment access requirements at a disadvantage by preventing them from demonstrating their attainment level. Inclusive access arrangements enable candidates to demonstrate their ability under assessment conditions that are as fair as possible.

The IB document *Access and inclusion policy* provides details on all the inclusive access arrangements available to candidates. The IB document *Learning diversity and inclusion in IB programmes: Removing barriers to learning* outlines the position of the IB with regard to candidates with diverse learning needs in the IB programmes. For candidates affected by adverse circumstances, the publication *Diploma Programme Assessment procedures* (updated annually), which includes the general regulations, provides details on access consideration.

Responsibilities of the school

The school is required to ensure that equal access arrangements and reasonable adjustments are provided to candidates with learning support requirements that are in line with the IB documents *Access and inclusion policy* and *Learning diversity and inclusion in IB programmes: Removing barriers to learning*.

Assessment outline—SL

First assessment 2025

Assessment component	Weighting
External assessment (3 hours)	**80%**
Paper 1 (1 hour and 30 minutes) Paper 1A—Multiple-choice questions Paper 1B—Data-based questions (Total 55 marks)	**36%**
Paper 2 (1 hour and 30 minutes) Short-answer and extended-response questions (Total 50 marks)	**44%**
Internal assessment (10 hours)	**20%**
The internal assessment consists of one task: the scientific investigation. This component is internally assessed by the teacher and externally moderated by the IB at the end of the course. (Total 24 marks)	

Assessment outline—HL

First assessment 2025

Assessment component	Weighting
External assessment (4 hours and 30 minutes)	**80%**
Paper 1 (2 hours) Paper 1A—Multiple-choice questions Paper 1B—Data-based questions (Total 75 marks)	**36%**
Paper 2 (2 hours and 30 minutes) Short-answer and extended-response questions (Total 90 marks)	**44%**
Internal assessment (10 hours)	**20%**
The internal assessment consists of one task: the scientific investigation. This component is internally assessed by the teacher and externally moderated by the IB at the end of the course. (Total 24 marks)	

External assessment

Detailed markschemes specific to each examination paper (paper 1 and paper 2) are used to assess students.

Examinations may require a general understanding and application of the nature of science (NOS).

External assessment details—SL

Paper 1

Duration: 1 hour and 30 minutes

Weighting: 36%

Marks: 55

Paper 1 is presented as two separate booklets.

Paper 1A—30 marks

- 30 multiple-choice questions on standard level material only

  No marks are deducted for incorrect answers.

Paper 1B—25 marks

- Data-based questions
- Questions on experimental work

Paper 1A and Paper 1B are to be completed together without interruptions.

The questions on paper 1 test assessment objectives 1, 2 and 3.

The use of calculators is permitted. See the *Calculators guidance for examinations booklet* on the Programme Resource Centre.

Each student must have access to a clean copy of the *Chemistry data booklet* during the examination. It is the responsibility of the school to download a copy from IBIS or the Programme Resource Centre and to ensure that there are sufficient copies available for all students.

Paper 2

Duration: 1 hour and 30 minutes

Weighting: 44%

Marks: 50

- Short-answer and extended-response questions on standard level material only

The questions on paper 2 test assessment objectives 1, 2 and 3.

The use of calculators is permitted. See the *Calculators guidance for examinations booklet* on the Programme Resource Centre.

Each student must have access to a clean copy of the *Chemistry data booklet* during the examination. It is the responsibility of the school to download a copy from IBIS or the Programme Resource Centre and to ensure that there are sufficient copies available for all students.

External assessment details—HL

Paper 1

Duration: 2 hours

Weighting: 36%

Marks: 75

Paper 1 is presented as two separate booklets.

Paper 1A—40 marks

- 40 multiple-choice questions on standard level and additional higher level material

  No marks are deducted for incorrect answers.

Paper 1B—35 marks

- Data-based questions
- Questions on experimental work

Paper 1A and Paper 1B are to be completed together without interruptions.

The questions on paper 1 test assessment objectives 1, 2 and 3.

The use of calculators is permitted. See the *Calculators guidance for examinations booklet* on the Programme Resource Centre.

Each student must have access to a clean copy of the *Chemistry data booklet* during the examination. It is the responsibility of the school to download a copy from IBIS or the Programme Resource Centre and to ensure that there are sufficient copies available for all students.

Paper 2

Duration: 2 hours and 30 minutes

Weighting: 44%

Marks: 90

- Short-answer and extended-response questions on standard level and additional higher level material.

The questions on paper 2 test assessment objectives 1, 2 and 3.

The use of calculators is permitted. See the *Calculators guidance for examinations booklet* on the Programme Resource Centre.

Each student must have access to a clean copy of the *Chemistry data booklet* during the examination. It is the responsibility of the school to download a copy from IBIS or the Programme Resource Centre and to ensure that there are sufficient copies available for all students.

Internal assessment

Purpose of internal assessment

Internal assessment is an integral part of the course and is compulsory for both SL and HL students. It enables students to demonstrate the application of their skills and knowledge, and to pursue their personal interests, without the time limitations and other constraints that are associated with written examinations. The internal assessment should, as far as possible, be woven into normal classroom teaching and not be a separate activity conducted after a course has been taught.

The internal assessment requirements at SL and at HL are the same.

Guidance and authenticity

The scientific investigation (SL and HL) submitted for internal assessment must be the student's own work. However, it is not the intention that students should decide upon a title or topic and be left to work on the internal assessment component without any further support from the teacher. The teacher should play an important role during both the planning stage and the period when the student is working on the internally assessed work. It is the responsibility of the teacher to ensure that students are familiar with:

- the requirements of the type of work to be internally assessed
- the *Sciences experimentation guidelines* publication
- the assessment criteria. Students must understand that the work submitted for assessment must address these criteria effectively.

Teachers and students must discuss the internally assessed work. Students should be encouraged to initiate discussions with the teacher to obtain advice and information, and students must not be penalized for seeking guidance. As part of the learning process, teachers should read and give advice to students on one draft of the work. The teacher should provide oral or written advice on how the work could be improved, but not edit the draft. The next version handed to the teacher must be the final version for submission.

It is the responsibility of teachers to ensure that all students understand the basic meaning and significance of concepts that relate to academic integrity, especially authenticity and intellectual property. Teachers must ensure that all student work for assessment is prepared according to the requirements and must explain clearly to students that the internally assessed work must be entirely their own. Where collaboration between students is permitted, it must be clear to all students what the difference is between collaboration and collusion.

All work submitted to the IB for moderation or assessment must be authenticated by a teacher, and must not include any known instances of suspected or confirmed malpractice. Each student must confirm that the work is their authentic work and constitutes the final version of that work. Once a student has officially submitted the final version of the work, it cannot be retracted. The requirement to confirm the authenticity of work applies to the work of all students, not just the sample work that will be submitted to the IB for the purpose of moderation. For further details, refer to the IB publications *Academic integrity policy*, *Diploma Programme: From principles into practice* and the relevant general regulations (in *Diploma Programme Assessment procedures*).

Authenticity may be checked by discussion with the student on the content of the work, and by scrutiny of one or more of the following.

- The student's initial proposal
- The first draft of the written work
- The references cited

- The style of writing compared with work known to be that of the student
- The analysis of the work by a web-based plagiarism detection service such as www.turnitin.com

The same piece of work cannot be submitted to meet the requirements of both the IA and the EE.

Time allocation

Internal assessment is an integral part of the chemistry course, contributing 20% to the final assessment in the SL and the HL courses. This weighting should be reflected in the time that is allocated to teaching the knowledge, skills and understanding required to undertake the work, as well as the total time allocated to carry out the work.

It is recommended that a total of approximately 10 hours (SL and HL) of teaching time should be allocated to the work. This should include:

- time for the teacher to explain to students the requirements of the internal assessment
- class time for students to work on the internal assessment component and ask questions
- time for consultation between the teacher and each student
- time to review and monitor progress, and to check authenticity.

Safety requirements and recommendations

It is the responsibility of everyone involved in science education to make an ongoing commitment to safe and healthy practical work.

The working practices and protocols should be effective in safeguarding students and protecting the environment. Schools are responsible for following national or local guidelines, which differ from country to country. The *Chemistry teacher support material* provides some further guidance.

Using assessment criteria for internal assessment

For internal assessment, a number of assessment criteria have been identified. Each assessment criterion has level descriptors describing specific achievement levels, together with an appropriate range of marks. The level descriptors concentrate on positive achievement, although for the lower levels failure to achieve may be included in the description.

Teachers must judge the internally assessed work at SL and at HL against the criteria using the level descriptors.

- The same assessment criteria are provided for SL and HL.
- The aim is to find, for each criterion, the descriptor that conveys most accurately the level attained by the student, using the best-fit model. A best-fit approach means that compensation should be made when a piece of work matches different aspects of a criterion at different levels. The mark awarded should be one that most fairly reflects the balance of achievement against the criterion. It is not necessary for every single aspect of a level descriptor to be met for that mark to be awarded.
- When assessing a student’s work, teachers should read the level descriptors for each criterion until they reach a descriptor that most appropriately describes the level of the work being assessed. If a piece of work seems to fall between two descriptors, both descriptors should be read again and the one that more appropriately describes the student’s work should be chosen.
- Where there are two marks available within a level, teachers should award the upper marks if the student’s work demonstrates the qualities described to a great extent; the work may be close to achieving marks in the level above. Teachers should award the lower marks if the student’s work demonstrates the qualities described to a lesser extent; the work may be close to achieving marks in the level below.
- Only whole numbers should be recorded; partial marks (fractions and decimals) are not acceptable.

- Teachers should not think in terms of a pass or fail boundary but should concentrate on identifying the appropriate descriptor for each assessment criterion.
- The highest level descriptors do not imply faultless performance but should be achievable by a student. Teachers should not hesitate to use the extremes if they are appropriate descriptions of the work being assessed.
- A student who attains a high achievement level in relation to one criterion will not necessarily attain high achievement levels in relation to the other criteria. Similarly, a student who attains a low achievement level for one criterion will not necessarily attain low achievement levels for the other criteria. Teachers should not assume that the overall assessment of the students will produce any particular distribution of marks.
- It is recommended that the assessment criteria be made available to students.

Internal assessment details—SL and HL

The scientific investigation

Duration: 10 hours

Weighting: 20%

The IA requirement is the same for biology, chemistry and physics. The IA, worth 20% of the final assessment, consists of one task—the scientific investigation.

The scientific investigation is an open-ended task in which the student gathers and analyses data in order to answer their own formulated research question.

The outcome of the scientific investigation will be assessed through the form of a written report. The maximum overall word count for the report is 3,000 words.

The following are not included in the word count.

- Charts and diagrams
- Data tables
- Equations, formulas and calculations
- Citations/references (whether parenthetical, numbered, footnotes or endnotes)
- Bibliography
- Headers

The following details should be stated at the start of the report.

- Title of the investigation
- IB candidate code (alphanumeric, for example, xyz123)
- IB candidate code for all group members (if applicable)
- Number of words

There is no requirement to include a cover page or a contents page.

Facilitating the scientific investigation

The research question should be of interest to the student, but it is not necessary that it encompasses concepts beyond those described by the understandings within the guide.

The scientific investigation undertaken must have sufficient extent and depth to allow for all the descriptors of the assessment criteria to be meaningfully addressed.

The investigation of the research question must involve the collection and analysis of quantitative data that should be supported by qualitative observations where appropriate.

The scientific investigation allows a wide range of techniques for data gathering and analysis to be employed. The approaches that could be used in isolation or in conjunction with each other are as follows.

- Hands-on practical laboratory work

- Fieldwork
- Use of a spreadsheet for analysis and modelling
- Extraction and analysis of data from a database
- Use of a simulation

The *Chemistry teacher support material* contains further guidance on these possible approaches.

Teachers must:

- ensure that students are familiar with the assessment criteria
- ensure that students are able to investigate their individual research question
- counsel the students on whether their proposed methodology is feasible in consideration of available time and resources
- ensure that students have given appropriate consideration to safety, ethical and environmental factors before undertaking the action phase
- remind students of the requirements for academic integrity and the consequences of academic malpractice. The difference between collaboration and collusion must be made clear.

Developing the research question

Each student is expected to formulate, investigate and answer a unique research question, seeking advice from their teacher.

A student must not present the same set of raw data as another student.

Methodology for individual work

Each student develops their own methodology to answer their individual research question. The student investigates by:

- manipulating an independent variable

or

- selecting variables during fieldwork

or

- selecting different data from external databases.

The student might seek support from peers when collecting data.

Methodology for collaborative work

Collaborative work is optional and where it is facilitated the groups formed must be no larger than three students. Students may organize their own groups. The teacher must provide guidance to ensure that all students are fully engaged in the collaborative activity. Students must clearly understand the requirement to conduct an individual investigation.

The methodology developed to answer their individual research question may be in part the outcome of collaborative activity. A student within the group investigates their individual research question by manipulating:

- a different independent variable from those selected by other group members

or

- the same independent variable with a different dependent variable from those selected by other group members

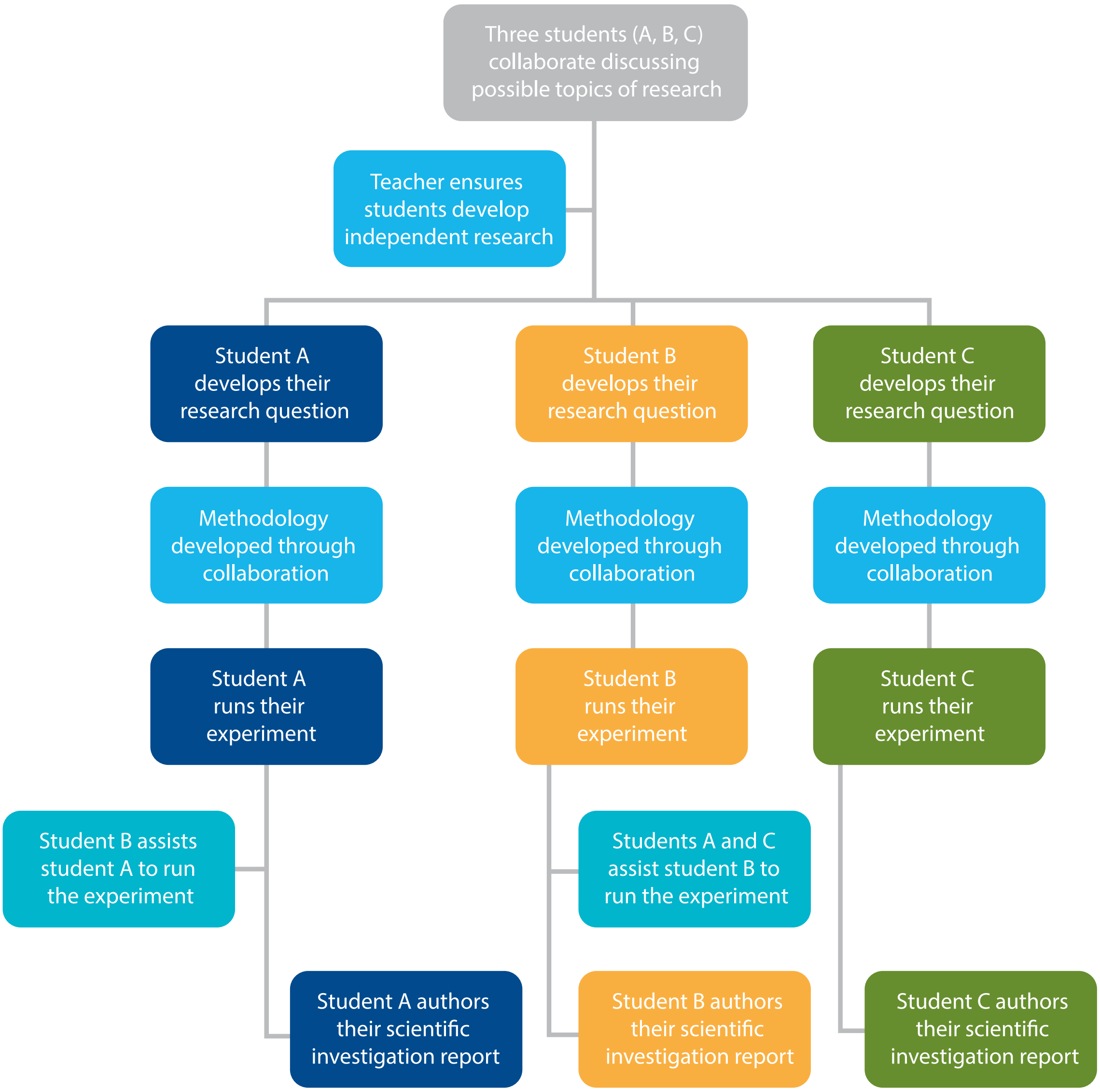
or

- different data from those selected by other group members from within a larger communally acquired data set.

In this context, collaborative work is permitted under the understanding that the final report presented for assessment is that of the individual student. A report by the group is not permitted. All authoring, including the description of the methodology, must be done individually. This diagram illustrates a possible route through the IA process where students collaborate.

Figure 3

A possible route through collaborative work



Class collaboration to set up a database

A school may take part in a large-scale activity collecting data to generate a database using standardized protocols. If a student decides to utilize this database in order to answer their research question, then the investigation must be treated as a database investigation. In such a case the methodology should be focused on the way the data is filtered and sampled from the whole database in the same way as if the data was wholly acquired from an external source.

Assessing the scientific investigation

The performance in IA at both SL and HL is marked against common assessment criteria, with a total mark out of 24. Student work is internally assessed by the teacher and externally moderated by the IB.

The four assessment criteria are as follows.

- Research design
- Data analysis
- Conclusion
- Evaluation

Each assessment criterion has level descriptors describing specific achievement levels, together with an appropriate range of marks. The level descriptors concentrate on positive achievement, although for the lower levels failure to achieve may be included in the description.

Teachers must judge the internally assessed work at SL and at HL against the same criteria using the level descriptors and aided by the clarifications. The criteria must be applied systematically using a best-fit approach—when a piece of work matches different aspects of a criterion at different levels the mark awarded should be one that most fairly reflects the balance of achievement against the criterion. It is not necessary for every single aspect of a level descriptor to be met for that mark to be awarded. The highest level descriptors do not imply faultless performance.

Where there are two or more marks available within a level, teachers should award the upper mark if the student's work largely satisfies the qualities described; the work may be close to achieving marks in the level above. Teachers should award the lower marks if the student's work demonstrates the qualities described to a lesser extent; the work may be close to achieving marks in the level below.

Only whole numbers must be recorded; partial marks (fractions and decimals) are not acceptable.

The criteria should be considered independently. A student who attains a high achievement level in relation to one criterion will not necessarily attain high achievement levels in relation to the other criteria. Similarly, a student who attains a low achievement level for one criterion will not necessarily attain low achievement levels for the other criteria. Teachers should not assume that the overall assessment of the students will produce any particular distribution of marks.

Where command terms are used in the level descriptors, they are to be interpreted as indicated in the "Glossary of command terms" section of this guide. These command terms indicate the depth of treatment required. Command terms used within the descriptors are provided in the following table.

Assessment objective	Command term	Descriptor
AO1	State	Give a specific name, value or other brief answer without explanation or calculation.
AO2	Identify	Provide an answer from a number of possibilities.
AO2	Outline	Give a brief account or summary.
AO2	Describe	Give a detailed account.
AO3	Explain	Give a detailed account including reasons or causes.
AO3	Justify	Give valid reasons or evidence to support an answer or conclusion.

Referencing and academic integrity

Appropriate referencing to sourced information used in the report of the scientific investigation is expected. Omitted or improper referencing will be considered to be academic malpractice.

Students must ensure their assessment work adheres to the IB's academic integrity policy and that all sources are appropriately referenced. A student's failure to appropriately acknowledge a source will be investigated by the IB as a potential breach of regulations that may result in a penalty imposed by the IB Final Award Committee. See the "Academic integrity" section of this guide for full details.

Internal assessment criteria—SL and HL

Download: Internal assessment criteria—SL and HL (PDF)

There are four IA criteria for the scientific investigation. The marks and weightings are as follows.

Criterion	Maximum number of marks available	Weighting (%)
Research design	6	25
Data analysis	6	25
Conclusion	6	25
Evaluation	6	25
Total	**24**	**100**

Research design

This criterion assesses the extent to which the student effectively communicates the methodology (purpose and practice) used to address the research question.

Marks	Level descriptor
0	The report does not reach the standard described by the descriptors below.
1–2	• The research question is stated without context. • Methodological considerations associated with collecting data relevant to the research question are stated. • The description of the methodology for collecting or selecting data lacks the detail to allow for the investigation to be reproduced.
3–4	• The research question is outlined within a broad context. • Methodological considerations associated with collecting relevant and sufficient data to answer the research question are described. • The description of the methodology for collecting or selecting data allows for the investigation to be reproduced with few ambiguities or omissions.
5–6	• The research question is described within a specific and appropriate context. • Methodological considerations associated with collecting relevant and sufficient data to answer the research question are explained. • The description of the methodology for collecting or selecting data allows for the investigation to be reproduced.

Clarifications for research design
A research question with context should contain reference to the dependent and independent variables or two correlated variables, include a concise description of the system in which the research question is embedded, and include background theory of direct relevance. Methodological considerations include: • the selection of the methods for measuring the dependent and independent variables • the selection of the databases or model and the sampling of data • the decisions regarding the scope, quantity and quality of measurements (e.g. the range, interval or frequency of the independent variable, repetition and precision of measurements) • the identification of control variables and the choice of method of their control

Clarifications for research design
• the recognition of any safety, ethical or environmental issues that needed to be taken into account.
The description of the methodology refers to presenting sufficiently detailed information (such as specific materials used and precise procedural steps) while avoiding unnecessary or repetitive information, so that the reader may readily understand how the methodology was implemented and could in principle repeat the investigation.

Data analysis

This criterion assesses the extent to which the student's report provides evidence that the student has recorded, processed and presented the data in ways that are relevant to the research question.

Marks	Level descriptor
0	The report does not reach a standard described by the descriptors below.
1–2	• The recording and processing of the data is communicated but is neither clear nor precise. • The recording and processing of data shows limited evidence of the consideration of uncertainties. • Some processing of data relevant to addressing the research question is carried out but with major omissions, inaccuracies or inconsistencies.
3–4	• The communication of the recording and processing of the data is either clear or precise. • The recording and processing of data shows evidence of a consideration of uncertainties but with some significant omissions or inaccuracies. • The processing of data relevant to addressing the research question is carried out but with some significant omissions, inaccuracies or inconsistencies.
5–6	• The communication of the recording and processing of the data is both clear and precise. • The recording and processing of data shows evidence of an appropriate consideration of uncertainties. • The processing of data relevant to addressing the research question is carried out appropriately and accurately.

Clarifications for data analysis
Data refers to quantitative data or a combination of both quantitative and qualitative data.
Communication
• Clear communication means that the method of processing can be understood easily. • Precise communication refers to following conventions correctly, such as those relating to the annotation of graphs and tables or the use of units, decimal places and significant figures.
Consideration of uncertainties is subject specific and further guidance is given in the *Chemistry teacher support material*.
Major omissions, inaccuracies or inconsistencies impede the possibility of drawing a valid conclusion that addresses the research question.
Significant omissions, inaccuracies or inconsistencies allow the possibility of drawing a conclusion that addresses the research question but with some limit to its validity or detail.

Conclusion

This criterion assesses the extent to which the student successfully answers their research question with regard to their analysis and the accepted scientific context.

Marks	Level descriptor
0	The report does not reach a standard described by the descriptors below.
1–2	• A conclusion is stated that is relevant to the research question but is not supported by the analysis presented. • The conclusion makes superficial comparison to the accepted scientific context.
3–4	• A conclusion is described that is relevant to the research question but is not fully consistent with the analysis presented. • A conclusion is described that makes some relevant comparison to the accepted scientific context.
5–6	• A conclusion is justified that is relevant to the research question and fully consistent with the analysis presented. • A conclusion is justified through relevant comparison to the accepted scientific context.

Clarifications for conclusion
A conclusion that is fully consistent requires the interpretation of processed data including associated uncertainties. Scientific context refers to information that could come from published material (paper or online), published values, course notes, textbooks or other outside sources. The citation of published materials must be sufficiently detailed to allow these sources to be traceable.

Evaluation

This criterion assesses the extent to which the student's report provides evidence of evaluation of the investigation methodology and has suggested improvements.

Marks	Level descriptor
0	The report does not reach a standard described by the descriptors below.
1–2	• The report states generic methodological weaknesses or limitations. • Realistic improvements to the investigation are stated.
3–4	• The report describes specific methodological weaknesses or limitations. • Realistic improvements to the investigation that are relevant to the identified weaknesses or limitations, are described.
5–6	• The report explains the relative impact of specific methodological weaknesses or limitations. • Realistic improvements to the investigation, that are relevant to the identified weaknesses or limitations, are explained.

Clarifications for evaluation
Generic is general to many methodologies and not specifically relevant to the methodology of the investigation being evaluated. Methodological refers to the overall approach to the investigation of the research question as well as procedural steps.

Clarifications for evaluation
Weaknesses could relate to issues regarding the control of variables, the precision of measurement or the variation in the data. Limitations could refer to how the conclusion is limited in scope by the range of the data collected, the confines of the system or the applicability of assumptions made.

Glossary of command terms

Command terms for chemistry

Students must be familiar with the following key terms and phrases used in examination questions, which are to be understood as described in this section. Although these terms will be used frequently in examination questions, other terms may be used to direct students to present an argument in a specific way. These command terms indicate the depth of treatment required.

Assessment objective 1

Command term	Definition
Draw	Represent by means of a labelled, accurate diagram or graph, using a pencil. A ruler (straight edge) should be used for straight lines. Diagrams should be drawn to scale. Graphs should have points correctly plotted (if appropriate) and joined in a straight line or smooth curve.
State	Give a specific name, value or other brief answer without explanation or calculation.

Assessment objective 2

Command term	Definition
Annotate	Add brief notes to a diagram or graph.
Calculate	Obtain a numerical answer showing the relevant stages in the working.
Describe	Give a detailed account.
Estimate	Obtain an approximate value.
Outline	Give a brief account or summary.

Assessment objective 3

Command term	Definition
Comment	Give a judgement based on a given statement or result of a calculation.
Compare	Give an account of the similarities between two (or more) items or situations, referring to both (all) of them throughout.
Contrast	Give an account of the differences between two (or more) items or situations, referring to both (all) of them throughout.
Deduce	Reach a conclusion from the information given.
Determine	Obtain the only possible answer.
Discuss	Offer a considered and balanced review that includes a range of arguments, factors or hypotheses. Opinions or conclusions should be presented clearly and supported by appropriate evidence.

Command term	Definition
Evaluate	Make an appraisal by weighing up the strengths and limitations.
Explain	Give a detailed account including reasons or causes.
Predict	Give an expected result.
Sketch	Represent by means of a diagram or graph (labelled as appropriate). The sketch should give a general idea of the required shape or relationship, and should include relevant features.
Suggest	Propose a solution, hypothesis or other possible answer.

Bibliography

This bibliography lists the principal works used to inform the curriculum review. It is not an exhaustive list and does not include all the literature available: judicious selection was made in order to better advise and guide teachers. This bibliography is not a list of recommended textbooks.

Andain, I., & Murphy, G. (2008). *Creating lifelong learners: Challenges for education in the 21st century*. International Baccalaureate Organization.

Atkins, P. (2010). Chemistry education in New Zealand: Chemistry's core ideas. *Chemistry education in New Zealand*, *120*, 8–12.

Feynman, R., Leighton, R., & Sands, M. (1963). *The Feynman lectures on physics*. California Institute of Technology, Gottlieb, M. A., & Pfeiffer, R. https://www.feynmanlectures.caltech.edu/I_02.html

Gerzon, M. (2010). *Global citizens: How our vision of the world is outdated, and what we can do about it*. Rider Books.

Giddens, J. F., & Brady, D. P. (2007). Rescuing nursing education from content saturation: The case for a concept-based curriculum. *Journal of Nursing Education*, *46*(2), 65–69. https://doi.org/10.3928/01484834-20070201-05

Haydon, G. (2006). *Education, philosophy and the ethical environment*. Routledge.

Headrick, D. (2009). *Technology: A world history*. Oxford University Press.

International Baccalaureate. (2014). "Conceptual understanding". In *MYP: From principles into practice*. International Baccalaureate Organization. https://resources.ibo.org/myp/resource/11162-32896

International Baccalaureate. (2015). "Approaches to teaching". In *Approaches to teaching and learning guide*. International Baccalaureate Organization. https://resources.ibo.org/dp/resource/11162-43504

International Baccalaureate. (2019). *What is an IB education?* International Baccalaureate Organization. https://resources.ibo.org/ib/works/edu_11162-58229

Khine, M. S. (2012). *Advances in nature of science research: Concepts and methodologies*. Springer.

Mills, S. (2016). Conceptual understanding: A concept analysis. *The Qualitative Report*, *21*(3), 546–557. https://doi.org/10.46743/2160-3715/2016.2308

Taber, K. S. (2019). *The nature of the chemical concept: Re-constructing chemical knowledge in teaching and learning*. Royal Society of Chemistry.

Updates to the publication

This section outlines the updates made to this publication over the past two years. The changes are ordered from the most recent to the oldest updates. Minor spelling and typographical corrections are not listed.

Changes for May 2023

Throughout the publication

Alignment of language with other IB documentation. The term “additional higher level (AHL)” has been changed to “HL” throughout.

Syllabus

“Syllabus format”

Correction of error in the previous version. The term “chemical entity” was amended to "molecular entity" to align with the phrasing for subtopic “Reactivity 3.3.1”.

Syllabus > Syllabus content

“Structure 1.1—Introduction to the particulate nature of matter”

Introduction of revised or improved content. In the guidance for “Structure 1.1.1”, the term “paper” in front of chromatography was deleted because different chromatography methods should be covered for this subtopic.

“Structure 3.2— Functional groups: Classification of organic compounds”

Introduction of revised or improved content. In the guidance for “Structure 3.2.5”, the following sentence was introduced to clarify the requirements: “Include numeric prefixes (mono, di, tri, tetra, penta, hexa)”.