Diploma Programme

Chemistry guide

First assessment 2016

International Baccalaureate®
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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.

Contents

Purpose of this document

This publication is intended to guide the planning, teaching and assessment of the subject 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 online curriculum centre (OCC) at http://occ.ibo.org, a password-protected IB website designed to support IB teachers. It can also be purchased from the IB store at http://store.ibo.org.

Additional resources

Additional publications such as teacher support materials, subject reports, internal assessment guidance and grade descriptors can also be found on the OCC. Past examination papers as well as markschemes can be purchased from the IB store.

Teachers are encouraged to check the OCC 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.

Acknowledgment

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

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The Diploma Programme

The Diploma Programme 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, a science, mathematics and one of the creative arts. It is this comprehensive range of subjects that makes the Diploma Programme 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 Diploma Programme 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 his or her own perspectives and how they might differ from others.

Creativity, action, service (CAS) is at the heart of the Diploma Programme. 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 Diploma Programme. The three strands of CAS are Creativity (arts and other experiences that involve creative thinking), Action (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 Diploma Programme, CAS contributes to the IB's mission to create a better and more peaceful world through intercultural understanding and respect.

The extended essay, 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' Diploma Programme 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. As 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 learning across the Diploma Programme refer to deliberate strategies, skills and attitudes which 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 Diploma Programme assessment and beyond. The aims of approaches to teaching and learning in the Diploma Programme 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' Diploma Programme experience
- allow schools to identify the distinctive nature of an IB Diploma Programme education, with its blend of idealism and practicality.

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

Academic honesty

Academic honesty in the Diploma Programme is a set of values and behaviours informed by the attributes of the learner profile. In teaching, learning and assessment, academic honesty 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 honesty in the IB and the Diploma Programme, please consult the IB publications *Academic honesty* (2011), *The Diploma Programme: From principles into practice* (2009) and *General regulations: Diploma Programme* (2011). Specific information regarding academic honesty as it pertains to external and internal assessment components of this Diploma Programme 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.

Diploma Programme candidates submit work for assessment in a variety of media that may include audio-visual 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, three 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 audio-visual 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 *Candidates with assessment access requirements* and *Learning diversity in the International Baccalaureate programmes: Special educational needs within the IB programmes*.

Nature of science

The Nature of science (NOS) is an overarching theme in the biology, chemistry and physics courses. This section, titled Nature of science, is in the biology, chemistry and physics guides to support teachers in their understanding of what is meant by the nature of science. The "Nature of science" section of the guide provides a comprehensive account of the nature of science in the 21st century. It will not be possible to cover in this document all the themes in detail in the three science courses, either for teaching or assessment.

It has a paragraph structure (1.1, 1.2, etc) to link the significant points made to the syllabus (landscape pages) references on the NOS. The NOS parts in the subject-specific sections of the guide are examples of a particular understanding. The NOS statement(s) above every sub-topic outline how one or more of the NOS themes can be exemplified through the understandings, applications and skills in that sub-topic. These are not a repeat of the NOS statements found below but an elaboration of them in a specific context. See the section on "Format of the syllabus".

Technology

Although this section is about the nature of science, the interpretation of the word technology is important, and the role of technology emerging from and contributing to science needs to be clarified. In today's world, the words *science* and *technology* are often used interchangeably, however, historically this is not the case. Technology emerged before science, and materials were used to produce useful and decorative artefacts long before there was an understanding of why materials had different properties that could be used for different purposes. In the modern world the reverse is the case: an understanding of the underlying science is the basis for technological developments. These new technologies in their turn drive developments in science.

Despite their mutual dependence they are based on different values: science on evidence, rationality and the quest for deeper understanding; technology on the practical, the appropriate and the useful with an increasingly important emphasis on sustainability.

1. What is science and what is the scientific endeavour?

1.1. The underlying assumption of science is that the universe has an independent, external reality accessible to human senses and amenable to human reason.

1.2. Pure science aims to come to a common understanding of this external universe; applied science and engineering develop technologies that result in new processes and products. However, the boundaries between these fields are fuzzy.

1.3. Scientists use a wide variety of methodologies which, taken together, make up the process of science. There is no single "scientific method". Scientists have used, and do use, different methods at different times to build up their knowledge and ideas but they have a common understanding about what makes them all scientifically valid.

1.4. This is an exciting and challenging adventure involving much creativity and imagination as well as exacting and detailed thinking and application. Scientists also have to be ready for unplanned, surprising, accidental discoveries. The history of science shows this is a very common occurrence.

1.5. Many scientific discoveries have involved flashes of intuition and many have come from speculation or simple curiosity about particular phenomena.

1.6. Scientists have a common terminology and a common reasoning process, which involves using deductive and inductive logic through analogies and generalizations. They share mathematics, the language of science, as a powerful tool. Indeed, some scientific explanations only exist in mathematical form.

1.7. Scientists must adopt a skeptical attitude to claims. This does not mean that they disbelieve everything, but rather that they suspend judgment until they have a good reason to believe a claim to be true or false. Such reasons are based on evidence and argument.

1.8. The importance of evidence is a fundamental common understanding. Evidence can be obtained by observation or experiment. It can be gathered by human senses, primarily sight, but much modern science is carried out using instrumentation and sensors that can gather information remotely and automatically in areas that are too small, or too far away, or otherwise beyond human sense perception. Improved instrumentation and new technology have often been the drivers for new discoveries. Observations followed by analysis and deduction led to the Big Bang theory of the origin of the universe and to the theory of evolution by natural selection. In these cases, no controlled experiments were possible. Disciplines such as geology and astronomy rely strongly on collecting data in the field, but all disciplines use observation to collect evidence to some extent. Experimentation in a controlled environment, generally in laboratories, is the other way of obtaining evidence in the form of data, and there are many conventions and understandings as to how this is to be achieved.

1.9. This evidence is used to develop theories, generalize from data to form laws and propose hypotheses. These theories and hypotheses are used to make predictions that can be tested. In this way theories can be supported or opposed and can be modified or replaced by new theories.

1.10. Models, some simple, some very complex, based on theoretical understanding, are developed to explain processes that may not be observable. Computer-based mathematical models are used to make testable predictions, which can be especially useful when experimentation is not possible. Models tested against experiments or data from observations may prove inadequate, in which case they may be modified or replaced by new models.

1.11. The outcomes of experiments, the insights provided by modelling and observations of the natural world may be used as further evidence for a claim.

1.12. The growth in computing power has made modelling much more powerful. Models, usually mathematical, are now used to derive new understandings when no experiments are possible (and sometimes when they are). This dynamic modelling of complex situations involving large amounts of data, a large number of variables and complex and lengthy calculations is only possible as a result of increased computing power. Modelling of the Earth's climate, for example, is used to predict or make a range of projections of future climatic conditions. A range of different models have been developed in this field and results from different models have been compared to see which models are most accurate. Models can sometimes be tested by using data from the past and used to see if they can predict the present situation. If a model passes this test, we gain confidence in its accuracy.

1.13. Both the ideas and the processes of science can only occur in a human context. Science is carried out by a community of people from a wide variety of backgrounds and traditions, and this has clearly influenced the way science has proceeded at different times. It is important to understand, however, that to do science is to be involved in a community of inquiry with certain common principles, methodologies, understandings and processes.

2. The understanding of science

2.1. Theories, laws and hypotheses are concepts used by scientists. Though these concepts are connected, there is no progression from one to the other. These words have a special meaning in science and it is important to distinguish these from their everyday use.

2.2. Theories are themselves integrated, comprehensive models of how the universe, or parts of it, work. A theory can incorporate facts and laws and tested hypotheses. Predictions can be made from the theories and these can be tested in experiments or by careful observations. Examples are the germ theory of disease or atomic theory.

2.3. Theories generally accommodate the assumptions and premises of other theories, creating a consistent understanding across a range of phenomena and disciplines. Occasionally, however, a new theory will radically change how essential concepts are understood or framed, impacting other theories and causing what is sometimes called a "paradigm shift" in science. One of the most famous paradigm shifts in science occurred when our idea of time changed from an absolute frame of reference to an observer-dependent frame of reference within Einstein's theory of relativity. Darwin's theory of evolution by natural selection also changed our understanding of life on Earth.

2.4. Laws are descriptive, normative statements derived from observations of regular patterns of behaviour. They are generally mathematical in form and can be used to calculate outcomes and to make predictions. Like theories and hypotheses, laws cannot be proven. Scientific laws may have exceptions and may be modified or rejected based on new evidence. Laws do not necessarily explain a phenomenon. For example, Newton's law of universal gravitation tells us that the force between two masses is inversely proportional to the square of the distance between them, and allows us to calculate the force between masses at any distance apart, but it does not explain why masses attract each other. Also, note that the term law has been used in different ways in science, and whether a particular idea is called a law may be partly a result of the discipline and time period at which it was developed.

2.5. Scientists sometimes form hypotheses—explanatory statements about the world that could be true or false, and which often suggest a causal relationship or a correlation between factors. Hypotheses can be tested by both experiments and observations of the natural world and can be supported or opposed.

2.6. To be scientific, an idea (for example, a theory or hypothesis) must focus on the natural world and natural explanations and must be testable. Scientists strive to develop hypotheses and theories that are compatible with accepted principles and that simplify and unify existing ideas.

2.7. The principle of Occam's razor is used as a guide to developing a theory. The theory should be as simple as possible while maximizing explanatory power.

2.8. The ideas of correlation and cause are very important in science. A correlation is a statistical link or association between one variable and another. A correlation can be positive or negative and a correlation coefficient can be calculated that will have a value between +1, 0 and -1. A strong correlation (positive or negative) between one factor and another suggests some sort of causal relationship between the two factors but more evidence is usually required before scientists accept the idea of a causal relationship. To establish a causal relationship, ie one factor causing another, scientists need to have a plausible scientific mechanism linking the factors. This strengthens the case that one causes the other, eg smoking and lung cancer. This mechanism can be tested in experiments.

2.9. The ideal situation is to investigate the relationship between one factor and another while controlling all other factors in an experimental setting; however, this is often impossible and scientists, especially in biology and medicine, use sampling, cohort studies and case control studies to strengthen their understanding of causation when experiments (such as double blind tests and clinical trials) are not possible. Epidemiology in the field of medicine involves the statistical analysis of data to discover possible correlations when little established scientific knowledge is available or the circumstances are too difficult to control entirely. Here, as in other fields, mathematical analysis of probability also plays a role.

3. The objectivity of science

3.1. Data is the lifeblood of scientists and may be qualitative or quantitative. It can be obtained purely from observations or from specifically designed experiments, remotely using electronic sensors or by direct measurement. The best data for making accurate and precise descriptions and predictions is often quantitative and amenable to mathematical analysis. Scientists analyse data and look for patterns, trends and discrepancies, attempting to discover relationships and establish causal links. This is not always possible, so identifying and classifying observations and artefacts (eg types of galaxies or fossils) is still an important aspect of scientific work.

3.2. Taking repeated measurements and large numbers of readings can improve reliability in data collection. Data can be presented in a variety of formats such as linear and logarithmic graphs that can be analysed for, say, direct or inverse proportion or for power relationships.

3.3. Scientists need to be aware of random errors and systematic errors, and use techniques such as error bars and lines of best fit on graphs to portray the data as realistically and honestly as possible. There is a need to consider whether outlying data points should be discarded or not.

3.4. Scientists need to understand the difference between errors and uncertainties, accuracy and precision, and need to understand and use the mathematical ideas of average, mean, mode, median, etc. Statistical methods such as standard deviation and chi-squared tests are often used. It is important to be able to assess how accurate a result is. A key part of the training and skill of scientists is in being able to decide which technique is appropriate in different circumstances.

3.5. It is also very important for scientists to be aware of the cognitive biases that may impact experimental design and interpretation. The confirmation bias, for example, is a well-documented cognitive bias that urges us to find reasons to reject data that is unexpected or does not conform to our expectations or desires, and to perhaps too readily accept data that agrees with these expectations or desires. The processes and methodologies of science are largely designed to account for these biases. However, care must always be taken to avoid succumbing to them.

3.6. Although scientists cannot ever be certain that a result or finding is correct, we know that some scientific results are very close to certainty. Scientists often speak of "levels of confidence" when discussing outcomes. The discovery of the existence of a Higgs boson is such an example of a "level of confidence". This particle may never be directly observable, but to establish its "existence" particle physicists had to pass the self-imposed definition of what can be regarded as a discovery—the 5-sigma "level of certainty"—or about a 0.00003% chance that the effect is not real based on experimental evidence.

3.7. In recent decades, the growth in computing power, sensor technology and networks has allowed scientists to collect large amounts of data. Streams of data are downloaded continuously from many sources such as remote sensing satellites and space probes and large amounts of data are generated in gene sequencing machines. Experiments in CERN's Large Hadron Collider regularly produce 23 petabytes of data per second, which is equivalent to 13.3 years of high definition TV content per second.

3.8. Research involves analysing large amounts of this data, stored in databases, looking for patterns and unique events. This has to be done using software which is generally written by the scientists involved. The data and the software may not be published with the scientific results but would be made generally available to other researchers.

4. The human face of science

4.1. Science is highly collaborative and the scientific community is composed of people working in science, engineering and technology. It is common to work in teams from many disciplines so that different areas of expertise and specializations can contribute to a common goal that is beyond one scientific field. It is also the case that how a problem is framed in the paradigm of one discipline might limit possible solutions, so framing problems using a variety of perspectives, in which new solutions are possible, can be extremely useful.

4.2. Teamwork of this sort takes place with the common understanding that science should be open-minded and independent of religion, culture, politics, nationality, age and gender. Science involves the free global interchange of information and ideas. Of course, individual scientists are human and may have biases and prejudices, but the institutions, practices and methodologies of science help keep the scientific endeavour as a whole unbiased.

4.3. As well as collaborating on the exchange of results, scientists work on a daily basis in collaborative groups on a small and large scale within and between disciplines, laboratories, organizations and countries, facilitated even more by virtual communication. Examples of large-scale collaboration include:

- The Manhattan project, the aim of which was to build and test an atomic bomb. It eventually employed more than 130,000 people and resulted in the creation of multiple production and research sites that operated in secret, culminating in the dropping of two atomic bombs on Hiroshima and Nagasaki.
- The Human Genome Project (HGP), which was an international scientific research project set up to map the human genome. The $3-billion project beginning in 1990 produced a draft of the genome in 2000. The sequence of the DNA is stored in databases available to anyone on the internet.
- The IPCC (Intergovernmental Panel on Climate Change), organized under the auspices of The United Nations, is officially composed of about 2,500 scientists. They produce reports summarizing the work of many more scientists from all around the world.
- CERN, the European Organization for Nuclear Research, an international organization set up in 1954, is the world's largest particle physics laboratory. The laboratory, situated in Geneva, employs about 2,400 people and shares results with 10,000 scientists and engineers covering over 100 nationalities from 600 or more universities and research facilities.

All the above examples are controversial to some degree and have aroused emotions amongst scientists and the public.

4.4. Scientists spend a considerable amount of time reading the published results of other scientists. They publish their own results in scientific journals after a process called peer review. This is when the work of a scientist or, more usually, a team of scientists is anonymously and independently reviewed by several scientists working in the same field who decide if the research methodologies are sound and if the work represents a new contribution to knowledge in that field. They also attend conferences to make presentations and display posters of their work. Publication of peer-reviewed journals on the internet has increased the efficiency with which the scientific literature can be searched and accessed. There are a large number of national and international organizations for scientists working in specialized areas within subjects.

4.5. Scientists often work in areas, or produce findings, that have significant ethical and political implications. These areas include cloning, genetic engineering of food and organisms, stem cell and reproductive technologies, nuclear power, weapons development (nuclear, chemical and biological), transplantation of tissue and organs and in areas that involve testing on animals (see *IB animal experimentation policy*). There are also questions involving intellectual property rights and the free exchange of information that may impact significantly on a society. Science is undertaken in universities, commercial companies, government organizations, defence agencies and international organizations. Questions of patents and intellectual property rights arise when work is done in a protected environment.

4.6. The integrity and honest representation of data is paramount in science—results should not be fixed or manipulated or doctored. To help ensure academic honesty and guard against plagiarism, all sources are quoted and appropriate acknowledgment made of help or support. Peer review and the scrutiny and skepticism of the scientific community also help achieve these goals.

4.7. All science has to be funded and the source of the funding is crucial in decisions regarding the type of research to be conducted. Funding from governments and charitable foundations is sometimes for pure research with no obvious direct benefit to anyone whereas funding from private companies is often for applied research to produce a particular product or technology. Political and economic factors often determine the nature and extent of the funding. Scientists often have to spend time applying for research grants and have to make a case for what they want to research.

4.8. Science has been used to solve many problems and improve man's lot, but it has also been used in morally questionable ways and in ways that inadvertently caused problems. Advances in sanitation, clean water supplies and hygiene led to significant decreases in death rates but without compensating decreases in birth rates this led to huge population increases with all the problems of resources, energy and food supplies that entails. Ethical discussions, risk-benefit analyses, risk assessment and the precautionary principle are all parts of the scientific way of addressing the common good.

5. Scientific literacy and the public understanding of science

5.1. An understanding of the nature of science is vital when society needs to make decisions involving scientific findings and issues. How does the public judge? It may not be possible to make judgments based on the public's direct understanding of a science, but important questions can be asked about whether scientific processes were followed and scientists have a role in answering such questions.

5.2. As experts in their particular fields, scientists are well placed to explain to the public their issues and findings. Outside their specializations, they may be no more qualified than ordinary citizens to advise others on scientific issues, although their understanding of the processes of science can help them to make personal decisions and to educate the public as to whether claims are scientifically credible.

5.3. As well as comprising knowledge of how scientists work and think scientific literacy involves being aware of faulty reasoning. There are many cognitive biases/fallacies of reasoning to which people are susceptible (including scientists) and these need to be corrected whenever possible. Examples of these are the confirmation bias, hasty generalizations, *post hoc ergo propter hoc* (false cause), the straw man fallacy, redefinition (moving the goal posts), the appeal to tradition, false authority and the accumulation of anecdotes being regarded as evidence.

5.4. When such biases and fallacies are not properly managed or corrected, or when the processes and checks and balances of science are ignored or misapplied, the result is pseudoscience. Pseudoscience is the term applied to those beliefs and practices which claim to be scientific but do not meet or follow the standards of proper scientific methodologies, ie they lack supporting evidence or a theoretical framework, are not always testable and hence falsifiable, are expressed in a non-rigorous or unclear manner and often fail to be supported by scientific testing.

5.5. Another key issue is the use of appropriate terminology. Words that scientists agree on as being scientific terms will often have a different meaning in everyday life and scientific discourse with the public needs to take this into account. For example, a theory in everyday use means a hunch or speculation, but in science an accepted theory is a scientific idea that has produced predictions that have been thoroughly tested in many different ways. An aerosol is just a spray can to the general public, but in science it is a suspension of solid or liquid particles in a gas.

5.6. Whatever the field of science—whether it is in pure research, applied research or in engineering new technology—there is boundless scope for creative and imaginative thinking. Science has achieved a great deal but there are many, many unanswered questions to challenge future scientists.

The flow chart below is part of an interactive flow chart showing the scientific process of inquiry in practice. The interactive version can be found at "How science works: The flowchart". Understanding Science. University of California Museum of Paleontology. 1 February 2013 <http://undsci.berkeley.edu/article/scienceflowchart>.

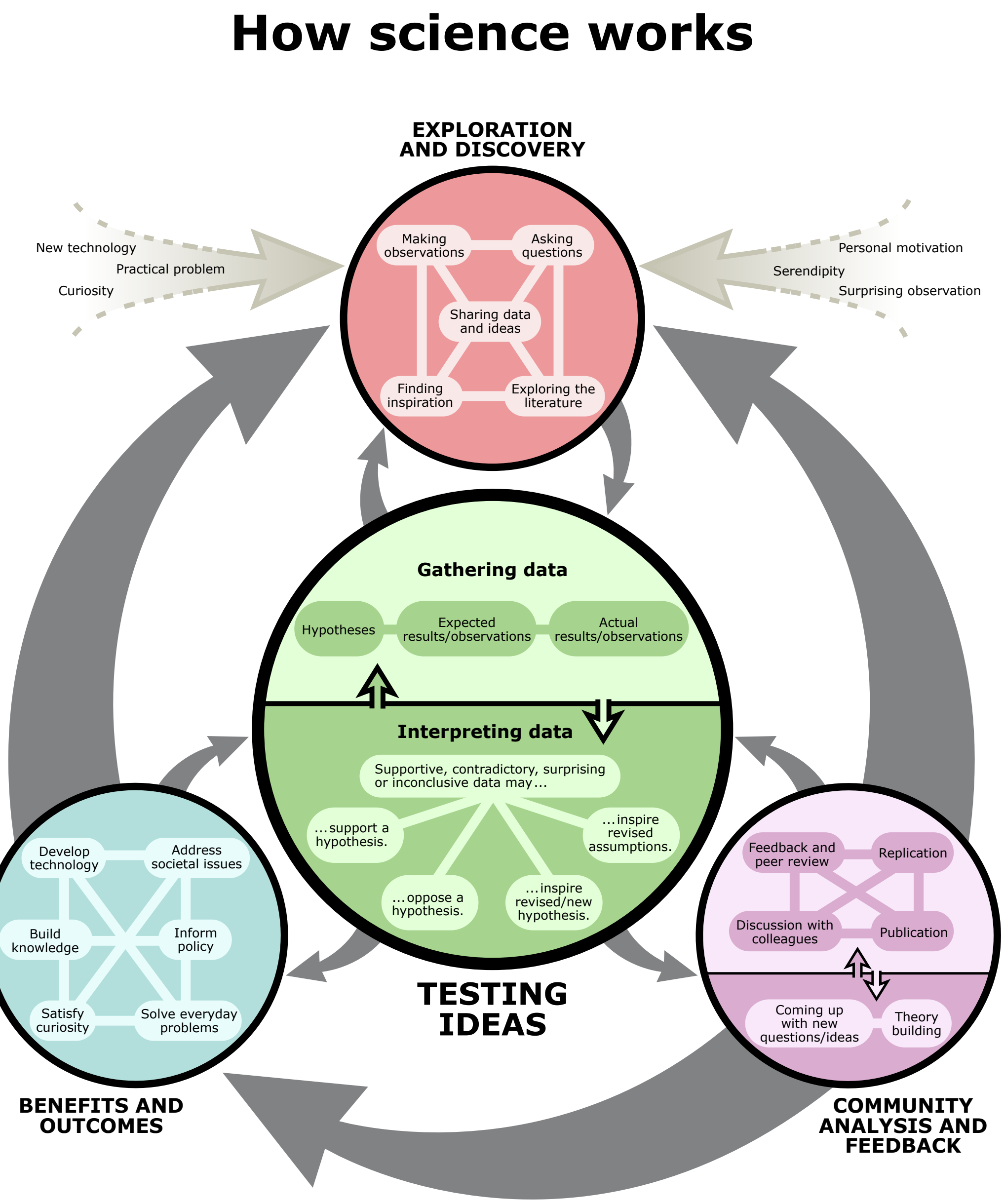


Figure 2

Pathways to scientific discovery

Nature of chemistry

Chemistry is an experimental science that combines academic study with the acquisition of practical and investigational skills. It is often called the central science, as chemical principles underpin both the physical environment in which we live and all biological systems. Apart from being a subject worthy of study in its own right, chemistry is a prerequisite for many other courses in higher education, such as medicine, biological science and environmental science, and serves as useful preparation for employment.

Earth, water, air and fire are often said to be the four classical elements. They have connections with Hinduism and Buddhism. The Greek philosopher Plato was the first to call these entities elements. The study of chemistry has changed dramatically from its origins in the early days of alchemists, who had as their quest the transmutation of common metals into gold. Although today alchemists are not regarded as being true scientists, modern chemistry has the study of alchemy as its roots. Alchemists were among the first to develop strict experimentation processes and laboratory techniques. Robert Boyle, often credited with being the father of modern chemistry, began experimenting as an alchemist.

Despite the exciting and extraordinary development of ideas throughout the history of chemistry, certain things have remained unchanged. Observations remain essential at the very core of chemistry, and this sometimes requires decisions about what to look for. The scientific processes carried out by the most eminent scientists in the past are the same ones followed by working chemists today and, crucially, are also accessible to students in schools. The body of scientific knowledge has grown in size and complexity, and the tools and skills of theoretical and experimental chemistry have become so specialized, that it is difficult (if not impossible) to be highly proficient in both areas. While students should be aware of this, they should also know that the free and rapid interplay of theoretical ideas and experimental results in the public scientific literature maintains the crucial link between these fields.

The Diploma Programme chemistry course includes the essential principles of the subject but also, through selection of an option, allows teachers some flexibility to tailor the course to meet the needs of their students. The course is available at both standard level (SL) and higher level (HL), and therefore accommodates students who wish to study chemistry as their major subject in higher education and those who do not.

At the school level both theory and experiments should be undertaken by all students. They should complement one another naturally, as they do in the wider scientific community. The Diploma Programme chemistry course allows students to develop traditional practical skills and techniques and to increase facility in the use of mathematics, which is the language of science. It also allows students to develop interpersonal skills, and digital technology skills, which are essential in 21st century scientific endeavour and are important life-enhancing, transferable skills in their own right.

Teaching approach

There are a variety of approaches to the teaching of chemistry. By its very nature, chemistry lends itself to an experimental approach, and it is expected that this will be reflected throughout the course.

The order in which the syllabus is arranged is **not** the order in which it should be taught, and it is up to individual teachers to decide on an arrangement that suits their circumstances. Sections of the option material may be taught within the core or the additional higher level (AHL) material if desired, or the option material can be taught as a separate unit.

Science and the international dimension

Science itself is an international endeavour—the exchange of information and ideas across national boundaries has been essential to the progress of science. This exchange is not a new phenomenon but it has accelerated in recent times with the development of information and communication technologies. Indeed, the idea that science is a Western invention is a myth—many of the foundations of modern-day science were laid many centuries before by Arabic, Indian and Chinese civilizations, among others. Teachers are encouraged to emphasize this contribution in their teaching of various topics, perhaps through the use of timeline websites. The scientific method in its widest sense, with its emphasis on peer review, open-mindedness and freedom of thought, transcends politics, religion, gender and nationality. Where appropriate within certain topics, the syllabus details sections in the group 4 guides contain links illustrating the international aspects of science.

On an organizational level, many international bodies now exist to promote science. United Nations bodies such as UNESCO, UNEP and WMO, where science plays a prominent part, are well known, but in addition there are hundreds of international bodies representing every branch of science. The facilities for large-scale research in, for example, particle physics and the Human Genome Project are expensive, and only joint ventures involving funding from many countries allow this to take place. The data from such research is shared by scientists worldwide. Group 4 teachers and students are encouraged to access the extensive websites and databases of these international scientific organizations to enhance their appreciation of the international dimension.

Increasingly there is a recognition that many scientific problems are international in nature and this has led to a global approach to research in many areas. The reports of the Intergovernmental Panel on Climate Change are a prime example of this. On a practical level, the group 4 project (which all science students must undertake) mirrors the work of real scientists by encouraging collaboration between schools across the regions.

The power of scientific knowledge to transform societies is unparalleled. It has the potential to produce great universal benefits, or to reinforce inequalities and cause harm to people and the environment. In line with the IB mission statement, group 4 students need to be aware of the moral responsibility of scientists to ensure that scientific knowledge and data are available to all countries on an equitable basis and that they have the scientific capacity to use this for developing sustainable societies.

Students' attention should be drawn to sections of the syllabus with links to international-mindedness. Examples of issues relating to international-mindedness are given within sub-topics in the syllabus content. Teachers could also use resources found on the Global Engage website (http://globalengage.ibo.org).

Distinction between SL and HL

Group 4 students at standard level (SL) and higher level (HL) undertake a common core syllabus, a common internal assessment (IA) scheme and have some overlapping elements in the option studied. They are presented with a syllabus that encourages the development of certain skills, attributes and attitudes, as described in the "Assessment objectives" section of this guide.

While the skills and activities of group 4 science subjects are common to students at both SL and HL, students at HL are required to study some topics in greater depth, in the additional higher level (AHL) material and in the common options. The distinction between SL and HL is one of breadth and depth.

Prior learning

Past experience shows that students will be able to study a group 4 science subject 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 a group 4 subject at HL, while there is no intention to restrict access to group 4 subjects, 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

Students who have undertaken the MYP science, design and mathematics courses will be well prepared for group 4 subjects. The alignment between MYP science and Diploma Programme group 4 courses allows for a smooth transition for students between programmes. The concurrent planning of the new group 4 courses and MYP: Next chapter (both launched in 2014) has helped develop a closer alignment.

Scientific inquiry is central to teaching and learning science in the MYP. It enables students to develop a way of thinking and a set of skills and processes that, while allowing them to acquire and use knowledge, equip them with the capabilities to tackle, with confidence, the internal assessment component of group 4 subjects. The vision of MYP sciences is to contribute to the development of students as 21st century learners. A holistic sciences programme allows students to develop and utilize a mixture of cognitive abilities, social skills, personal motivation, conceptual knowledge and problem-solving competencies within an inquiry-based learning environment (Rhoton 2010). Inquiry aims to support students' understanding by providing them with opportunities to independently and collaboratively investigate relevant issues through both research and experimentation. This forms a firm base of scientific understanding with deep conceptual roots for students entering group 4 courses.

In the MYP, teachers make decisions about student achievement using their professional judgment, guided by criteria that are public, precise and known in advance, ensuring that assessment is transparent. The IB describes this approach as "criterion-related"—a philosophy of assessment that is neither "norm-referenced" (where students must be compared to each other and to an expected distribution of achievement) nor "criterion-referenced" (where students must master all strands of specific criteria at lower achievement levels before they can be considered to have achieved the next level). It is important to emphasize that the single most important aim of MYP assessment (consistent with the PYP and DP) is to support curricular goals and encourage appropriate student learning. Assessments are based upon evaluating course aims and objectives and, therefore, effective teaching to the course requirements also ensures effective teaching for formal assessment requirements. Students need to understand what the assessment expectations, standards and practices are and these should all be introduced early and naturally in teaching, as well as in class and homework activities. Experience with criterion-related assessment greatly assists students entering group 4 courses with understanding internal assessment requirements.

MYP science is a concept-driven curriculum, aimed at helping the learner construct meaning through improved critical thinking and the transfer of knowledge. At the top level are *key concepts* which are broad, organizing, powerful ideas that have relevance within the science course but also transcend it, having relevance in other subject groups. These key concepts facilitate both disciplinary and interdisciplinary learning as well as making connections with other subjects. While the key concepts provide breadth, the *related concepts* in MYP science add depth to the programme. The related concept can be considered to be the big idea of the unit which brings focus and depth and leads students towards the conceptual understanding.

Across the MYP, there are 16 key concepts, with the three highlighted below as the focus for MYP science.

The key concepts across the MYP curriculum			
Aesthetics	**Change**	Communication	Communities
Connections	Creativity	Culture	Development
Form	Global interactions	Identity	Logic
Perspective	**Relationships**	**Systems**	Time, place and space

MYP students may in addition undertake an optional onscreen concept-based assessment as further preparation for Diploma Programme science courses.

Science and theory of knowledge

The theory of knowledge (TOK) course (first assessment 2015) engages students in reflection on the nature of knowledge and on how we know what we claim to know. The course identifies eight ways of knowing: reason, emotion, language, sense perception, intuition, imagination, faith and memory. Students explore these means of producing knowledge within the context of various areas of knowledge: the natural sciences, the social sciences, the arts, ethics, history, mathematics, religious knowledge systems and indigenous knowledge systems. The course also requires students to make comparisons between the different areas of knowledge, reflecting on how knowledge is arrived at in the various disciplines, what the disciplines have in common, and the differences between them.

TOK lessons can support students in their study of science, just as the study of science can support students in their TOK course. TOK provides a space for students to engage in stimulating wider discussions about questions such as what it means for a discipline to be a science, or whether there should be ethical constraints on the pursuit of scientific knowledge. It also provides an opportunity for students to reflect on the methodologies of science, and how these compare to the methodologies of other areas of knowledge. It is now widely accepted that there is no one scientific method, in the strict Popperian sense. Instead, the sciences utilize a variety of approaches in order to produce explanations for the behaviour of the natural world. The different scientific disciplines share a common focus on utilizing inductive and deductive reasoning, on the importance of evidence, and so on. Students are encouraged to compare and contrast these methods with the methods found in, for example, the arts or in history.

In this way there are rich opportunities for students to make links between their science and TOK courses. One way in which science teachers can help students to make these links to TOK is by drawing students' attention to knowledge questions which arise from their subject content. Knowledge questions are open-ended questions about knowledge, and include questions such as:

- How do we distinguish science from pseudoscience?
- When performing experiments, what is the relationship between a scientist's expectation and their perception?
- How does scientific knowledge progress?
- What is the role of imagination and intuition in the sciences?
- What are the similarities and differences in methods in the natural sciences and the human sciences?

Examples of relevant knowledge questions are provided throughout this guide within the sub-topics in the syllabus content. Teachers can also find suggestions of interesting knowledge questions for discussion in the “Areas of knowledge” and “Knowledge frameworks” sections of the TOK guide. Students should be encouraged to raise and discuss such knowledge questions in both their science and TOK classes.

Aims

Group 4 aims

Through studying biology, chemistry or physics, students should become aware of how scientists work and communicate with each other. While the scientific method may take on a wide variety of forms, it is the emphasis on a practical approach through experimental work that characterizes these subjects.

The aims enable students, through the overarching theme of the Nature of science, to:

1. appreciate scientific study and creativity within a global context through stimulating and challenging opportunities
2. acquire a body of knowledge, methods and techniques that characterize science and technology
3. apply and use a body of knowledge, methods and techniques that characterize science and technology
4. develop an ability to analyse, evaluate and synthesize scientific information
5. develop a critical awareness of the need for, and the value of, effective collaboration and communication during scientific activities
6. develop experimental and investigative scientific skills including the use of current technologies
7. develop and apply 21st century communication skills in the study of science
8. become critically aware, as global citizens, of the ethical implications of using science and technology
9. develop an appreciation of the possibilities and limitations of science and technology
10. develop an understanding of the relationships between scientific disciplines and their influence on other areas of knowledge.

Assessment objectives

The assessment objectives for biology, chemistry and physics reflect those parts of the aims that will be formally assessed either internally or externally. These assessments will centre upon the nature of science. It is the intention of these courses that students are able to fulfill the following assessment objectives:

1. Demonstrate knowledge and understanding of:
   a. facts, concepts, and terminology
   b. methodologies and techniques
   c. communicating scientific information.
2. Apply:
   a. facts, concepts, and terminology
   b. methodologies and techniques
   c. methods of communicating scientific information.
3. Formulate, analyse and evaluate:
   a. hypotheses, research questions and predictions
   b. methodologies and techniques
   c. primary and secondary data
   d. scientific explanations.
4. Demonstrate the appropriate research, experimental, and personal skills necessary to carry out insightful and ethical investigations.

Syllabus outline

Syllabus component	Recommended teaching hours SL	Recommended teaching hours HL
Core	**95**	
1. Stoichiometric relationships	13.5	
2. Atomic structure	6	
3. Periodicity	6	
4. Chemical bonding and structure	13.5	
5. Energetics/thermochemistry	9	
6. Chemical kinetics	7	
7. Equilibrium	4.5	
8. Acids and bases	6.5	
9. Redox processes	8	
10. Organic chemistry	11	
11. Measurement and data processing	10	
Additional higher level (AHL)		**60**
12. Atomic structure		2
13. The periodic table—the transition metals		4
14. Chemical bonding and structure		7
15. Energetics/thermochemistry		7
16. Chemical kinetics		6
17. Equilibrium		4
18. Acids and bases		10
19. Redox processes		6
20. Organic chemistry		12
21. Measurement and analysis		2
Option	**15**	**25**
A. Materials	15	25
B. Biochemistry	15	25
C. Energy	15	25
D. Medicinal chemistry	15	25

Syllabus component	Recommended teaching hours	
	SL	HL
Practical scheme of work	**40**	**60**
Practical activities	20	40
Individual investigation (internal assessment—IA)	10	10
Group 4 project	10	10
Total teaching hours	**150**	**240**

The recommended teaching time is 240 hours to complete HL courses and 150 hours to complete SL courses as stated in the document *General regulations: Diploma Programme* (2011) (page 4, Article 8.2).

Approaches to the teaching of chemistry

Format of the syllabus

The format of the syllabus section of the group 4 guides is the same for each subject physics, chemistry and biology. This new structure gives prominence and focus to the teaching and learning aspects.

Topics or options

Topics are numbered and options are indicated by a letter. For example, "Topic 6: Chemical kinetics", or "Option D: Medicinal chemistry".

Sub-topics

Sub-topics are numbered as follows, "6.1 Collision theory and rates of reaction". Further information and guidance about possible teaching times are contained in the teacher support materials.

Each sub-topic begins with an essential idea. The essential idea is an enduring interpretation that is considered part of the public understanding of science. This is followed by a section on the "Nature of science". This gives specific examples in context illustrating some aspects of the nature of science. These are linked directly to specific references in the "Nature of Science" section of the guide to support teachers in their understanding of the general theme to be addressed.

Under the overarching Nature of Science theme there are two columns. The first column lists "Understandings", which are the main general ideas to be taught. There follows an "Applications and skills" section that outlines the specific applications and skills to be developed from the understandings. A "Guidance" section gives information about the limits and constraints and the depth of treatment required for teachers and examiners. The contents of the "Nature of Science" section above the two columns and contents of the first column are all legitimate items for assessment. In addition, some assessment of international-mindedness in science, from the content of the second column, will take place as in the previous course.

The second column gives suggestions to teachers about relevant references to international-mindedness. It also gives examples of TOK knowledge questions (see *Theory of knowledge* guide published 2013) that can be used to focus students' thoughts on the preparation of the TOK prescribed essay. The "Links" section may link the sub-topic to other parts of the subject syllabus, to other Diploma Programme subject guides or to real-world applications. Finally, the "Aims" section refers to how specific group 4 aims are being addressed in the sub-topic.

Format of the guide

Topic 1: <Title>

Essential idea: This lists the essential idea for each sub-topic.

<table>
<tr><th colspan="2">1.1 Sub-topic</th></tr>
<tr><td colspan="2">Nature of Science: Relates the sub-topic to the overarching theme of Nature of Science.</td></tr>
<tr><td>Understandings:
• This section will provide specifics of the content requirements for each sub-topic.
Applications and skills:
• The content of this section gives details of how students are to apply the understandings. For example, these applications could involve demonstrating mathematical calculations or practical skills.
Guidance:
• This section will provide specifics and give constraints to the requirements for the understandings and applications and skills.
• This section will also include links to specific sections in the data booklet.</td><td>International-mindedness:
• Ideas that teachers can easily integrate into the delivery of their lessons.
Theory of knowledge:
• Examples of TOK knowledge questions.
Utilization: (including syllabus and cross-curricular links)
• Links to other topics within the Chemistry guide, to a variety of real-world applications and to other Diploma Programme courses.
Aims:
• Links to the group 4 subject aims.</td></tr>
</table>

Group 4 experimental skills

> I hear and I forget. I see and I remember. I do and I understand.
>
> (Confucius)

Integral to the experience of students in any of the group 4 courses is their experience in the classroom, laboratory, or in the field. Practical activities allow students to interact directly with natural phenomena and secondary data sources. These experiences provide the students with the opportunity to design investigations, collect data, develop manipulative skills, analyse results, collaborate with peers and evaluate and communicate their findings. Experiments can be used to introduce a topic, investigate a phenomenon or allow students to consider and examine questions and curiosities.

By providing students with the opportunity for hands-on experimentation, they are carrying out some of the same processes that scientists undertake. Experimentation allows students to experience the nature of scientific thought and investigation. All scientific theories and laws begin with observations.

It is important that students are involved in an inquiry-based practical programme that allows for the development of scientific inquiry. It is not enough for students just to be able to follow directions and to simply replicate a given experimental procedure; they must be provided with the opportunities for genuine inquiry. Developing scientific inquiry skills will give students the ability to construct an explanation based on reliable evidence and logical reasoning. Once developed, these higher order thinking skills will enable students to be lifelong learners and scientifically literate.

A school's practical scheme of work should allow students to experience the full breadth and depth of the course including the option. This practical scheme of work must also prepare students to undertake the individual investigation that is required for the internal assessment. The development of students' manipulative skills should involve them being able to follow instructions accurately and demonstrate the safe, competent and methodical use of a range of techniques and equipment.

The "Applications and skills" section of the syllabus lists specific lab skills, techniques and experiments that students must experience at some point during their study of their group 4 course. Other recommended lab skills, techniques and experiments are listed in the "Aims" section of the subject-specific syllabus pages. Aim 6 of the group 4 subjects directly relates to the development of experimental and investigative skills.

Mathematical requirements

All Diploma Programme chemistry students should be able to:

- perform the basic arithmetic functions: addition, subtraction, multiplication and division
- carry out calculations involving means, decimals, fractions, percentages, ratios, approximations and reciprocals
- use standard notation (for example, 3.6×10^6)
- use direct and inverse proportion
- solve simple algebraic equations
- plot graphs (with suitable scales and axes) including two variables that show linear and non-linear relationships
- interpret graphs, including the significance of gradients, changes in gradients, intercepts and areas
- interpret data presented in various forms (for example, bar charts, histograms and pie charts).

Data booklet

The data booklet must be viewed as an integral part of the chemistry programme. It should be used throughout the delivery of the course and not just reserved for use during the external assessments. The data booklet contains useful equations, constants, data, structural formulas and tables of information. In the "Syllabus content" section of the subject guide, explicit links provide direct references to information in the data booklet which will allow students to become familiar with its use and contents. It is suggested that the data booklet be used for all in-class study and school-based assessments.

For both SL and HL external assessments, the data booklet cannot be used for paper 1, but candidates are provided with a copy of the periodic table given in section 6 of that booklet. Clean copies of the data booklet must be made available to both SL and HL candidates for papers 2 and 3.

Use of information communication technology

The use of information communication technology (ICT) is encouraged throughout all aspects of the course in relation to both the practical programme and day-to-day classroom activities. Teachers should make use of the ICT pages of the teacher support materials.

Planning your course

The syllabus as provided in the subject guide is not intended to be a teaching order. Instead it provides detail of what must be covered by the end of the course. A school should develop a scheme of work that best works for its students. For example, the scheme of work could be developed to match available resources, to take into account student prior learning and experience, or in conjunction with other local requirements.

HL teachers may choose to teach the core and AHL topics at the same time or teach them in a spiral fashion, by teaching the core topics in year one of the course and revisiting the core topics through the delivery of the AHL topics in year two of the course. The option topic could be taught as a stand-alone topic or could be integrated into the teaching of the core and/or AHL topics.

However the course is planned, adequate time must be provided for examination revision. Time must also be given for students to reflect on their learning experience and their growth as learners.

The IB learner profile

The chemistry course contributes to the development of attributes of the IB learner profile. By following the course, students will have engaged with the attributes of the IB learner profile. For example, the requirements of the internal assessment provide opportunities for students to develop every aspect of the profile. For each attribute of the learner profile, a number of references from the Group 4 courses are given below.

Learner profile attribute	Biology, chemistry and physics
Inquirers	Aims 2 and 6 Practical work and internal assessment
Knowledgeable	Aims 1 and 10, international-mindedness links Practical work and internal assessment
Thinkers	Aims 3 and 4, Theory of knowledge links Practical work and internal assessment
Communicators	Aims 5 and 7, external assessment Practical work and internal assessment
Principled	Aims 8 and 9 Practical work and internal assessment. Ethical behaviour/practice (*Ethical practice* poster, *IB animal experimentation policy*), academic honesty
Open-minded	Aims 8 and 9, International-mindedness links Practical work and internal assessment, the group 4 project
Caring	Aims 8 and 9 Practical work and internal assessment, the group 4 project, ethical behaviour/practice (*Ethical practice* poster, *IB animal experimentation policy*)

Learner profile attribute	Biology, chemistry and physics
Risk-takers	Aims 1 and 6 Practical work and internal assessment, the group 4 project
Balanced	Aims 8 and 10 Practical work and internal assessment, the group 4 project and fieldwork
Reflective	Aims 5 and 9 Practical work and internal assessment, the group 4 project

Syllabus content

	Recommended teaching hours
Core	**95 hours**
Topic 1: Stoichiometric relationships	**13.5**
1.1 Introduction to the particulate nature of matter and chemical change	
1.2 The mole concept	
1.3 Reacting masses and volumes	
Topic 2: Atomic structure	**6**
2.1 The nuclear atom	
2.2 Electron configuration	
Topic 3: Periodicity	**6**
3.1 Periodic table	
3.2 Periodic trends	
Topic 4: Chemical bonding and structure	**13.5**
4.1 Ionic bonding and structure	
4.2 Covalent bonding	
4.3 Covalent structures	
4.4 Intermolecular forces	
4.5 Metallic bonding	
Topic 5: Energetics/thermochemistry	**9**
5.1 Measuring energy changes	
5.2 Hess's Law	
5.3 Bond enthalpies	
Topic 6: Chemical kinetics	**7**
6.1 Collision theory and rates of reaction	
Topic 7: Equilibrium	**4.5**
7.1 Equilibrium	

	Recommended teaching hours
Topic 8: Acids and bases	**6.5**
8.1 Theories of acids and bases	
8.2 Properties of acids and bases	
8.3 The pH scale	
8.4 Strong and weak acids and bases	
8.5 Acid deposition	
Topic 9: Redox processes	**8**
9.1 Oxidation and reduction	
9.2 Electrochemical cells	
Topic 10: Organic chemistry	**11**
10.1 Fundamentals of organic chemistry	
10.2 Functional group chemistry	
Topic 11: Measurement and data processing	**10**
11.1 Uncertainties and errors in measurement and results	
11.2 Graphical techniques	
11.3 Spectroscopic identification of organic compounds	
Additional higher level (AHL)	**60 hours**
Topic 12: Atomic structure	**2**
12.1 Electrons in atoms	
Topic 13: The periodic table—the transition metals	**4**
13.1 First-row d-block elements	
13.2 Coloured complexes	
Topic 14: Chemical bonding and structure	**7**
14.1 Covalent bonding and electron domain and molecular geometries	
14.2 Hybridization	
Topic 15: Energetics/thermochemistry	**7**
15.1 Energy cycles	
15.2 Entropy and spontaneity	

	Recommended teaching hours
Topic 16: Chemical kinetics	**6**
16.1 Rate expression and reaction mechanism	
16.2 Activation energy	
Topic 17: Equilibrium	**4**
17.1 The equilibrium law	
Topic 18: Acids and bases	**10**
18.1 Lewis acids and bases	
18.2 Calculations involving acids and bases	
18.3 pH curves	
Topic 19: Redox processes	**6**
19.1 Electrochemical cells	
Topic 20: Organic chemistry	**12**
20.1 Types of organic reactions	
20.2 Synthetic routes	
20.3 Stereoisomerism	
Topic 21: Measurement and analysis	**2**
21.1 Spectroscopic identification of organic compounds	

Options — 15 hours (SL)/25 hours (HL)

A: Materials

Core topics

A.1 Materials science introduction

A.2 Metals and inductively coupled plasma (ICP) spectroscopy

A.3 Catalysts

A.4 Liquid crystals

A.5 Polymers

A.6 Nanotechnology

A.7 Environmental impact—plastics

Additional higher level topics

A.8 Superconducting metals and X-ray crystallography (HL only)

A.9 Condensation polymers (HL only)

A.10 Environmental impact—heavy metals (HL only)

B: Biochemistry

Core topics

B.1 Introduction to biochemistry

B.2 Proteins and enzymes

B.3 Lipids

B.4 Carbohydrates

B.5 Vitamins

B.6 Biochemistry and the environment

Additional higher level topics

B.7 Proteins and enzymes (HL only)

B.8 Nucleic acids (HL only)

B.9 Biological pigments (HL only)

B.10 Stereochemistry in biomolecules (HL only)

C: Energy

Core topics

C.1 Energy sources

C.2 Fossil fuels

C.3 Nuclear fusion and fission

C.4 Solar energy

C.5 Environmental impact—global warming

Additional higher level topics

C.6 Electrochemistry, rechargeable batteries and fuel cells (HL only)

C.7 Nuclear fusion and nuclear fission (HL only)

C.8 Photovoltaic and dye-sensitized solar cells (HL only)

D: Medicinal chemistry

Core topics

D.1 Pharmaceutical products and drug action

D.2 Aspirin and penicillin

D.3 Opiates

D.4 pH regulation of the stomach

D.5 Anti-viral medications

D.6 Environmental impact of some medications

Additional higher level topics
D.7 Taxol—a chiral auxiliary case study (HL only)

D.8 Nuclear medicine (HL only)

D.9 Drug detection and analysis (HL only)

Core

Topic 1: Stoichiometric relationships

13.5 hours

Essential idea: Physical and chemical properties depend on the ways in which different atoms combine.

1.1 Introduction to the particulate nature of matter and chemical change

Nature of science:

Making quantitative measurements with replicates to ensure reliability—definite and multiple proportions. (3.1)

Understandings:

- Atoms of different elements combine in fixed ratios to form compounds, which have different properties from their component elements.
- Mixtures contain more than one element and/or compound that are not chemically bonded together and so retain their individual properties.
- Mixtures are either homogeneous or heterogeneous.

Applications and skills:

- Deduction of chemical equations when reactants and products are specified.
- Application of the state symbols (s), (l), (g) and (aq) in equations.
- Explanation of observable changes in physical properties and temperature during changes of state.

Guidance:

- Balancing of equations should include a variety of types of reactions.
- Names of the changes of state—melting, freezing, vaporization (evaporation and boiling), condensation, sublimation and deposition—should be covered.

International-mindedness:

- Chemical symbols and equations are international, enabling effective communication amongst scientists without need for translation.
- IUPAC (International Union of Pure and Applied Chemistry) is the world authority in developing standardized nomenclature for both organic and inorganic compounds.

Theory of knowledge:

- Chemical equations are the “language” of chemistry. How does the use of universal languages help and hinder the pursuit of knowledge?
- The discovery of oxygen, which overturned the phlogiston theory of combustion, is an example of a paradigm shift. How does scientific knowledge progress?

Utilization:

- Refrigeration and how it is related to the changes of state.
- Atom economy.
- Freeze-drying of foods.

1.1 Introduction to the particulate nature of matter and chemical change	
• The term "latent heat" is not required. • Names and symbols of elements are in the data booklet in section 5.	Syllabus and cross-curricular links: Topic 4.1—deduction of formulae of ionic compounds Topic 5.1—enthalpy cycle reaction; standard state of an element or compound Topic 6.1—kinetic theory Topic 8.2—neutralization reactions Topic 10.2—combustion reactions Option A.4—liquid crystals **Aims:** • **Aim 8**: The negative environmental impacts of refrigeration and air conditioning systems are significant. The use of CFCs as refrigerants has been a major contributor to ozone depletion.

Essential idea: The mole makes it possible to correlate the number of particles with the mass that can be measured.

1.2 The mole concept

Nature of science:

Concepts—the concept of the mole developed from the related concept of “equivalent weight” in the early 19th century. (2.3)

Understandings:

- The mole is a fixed number of particles and refers to the amount, *n*, of substance.
- Masses of atoms are compared on a scale relative to ^{12}C and are expressed as relative atomic mass (A_r) and relative formula/molecular mass (M_r).
- Molar mass (M) has the units g mol^{-1}.
- The empirical formula and molecular formula of a compound give the simplest ratio and the actual number of atoms present in a molecule respectively.

Applications and skills:

- Calculation of the molar masses of atoms, ions, molecules and formula units.
- Solution of problems involving the relationships between the number of particles, the amount of substance in moles and the mass in grams.
- Interconversion of the percentage composition by mass and the empirical formula.
- Determination of the molecular formula of a compound from its empirical formula and molar mass.
- Obtaining and using experimental data for deriving empirical formulas from reactions involving mass changes.

International-mindedness:

- The SI system (Système International d’Unités) refers to the metric system of measurement, based on seven base units.
- The International Bureau of Weights and Measures (BIPM according to its French initials) is an international standards organization, which aims to ensure uniformity in the application of SI units around the world.

Theory of knowledge:

- The magnitude of Avogadro’s constant is beyond the scale of our everyday experience. How does our everyday experience limit our intuition?

Utilization:

- Stoichiometric calculations are fundamental to chemical processes in research and industry, for example in the food, medical, pharmaceutical and manufacturing industries.
- The molar volume for crystalline solids is determined by the technique of X-ray crystallography.

Syllabus and cross-curricular links:
Topic 2.1—the scale of atoms and their component particles
Topics 4.1, 4.3 and 4.5—lattice structure of ionic compounds, molecular structure of covalent compounds and metallic lattice
Topics 5.1 and 15.2—standard enthalpy and entropy changes defined per mole
Topic 19.1—mole ratios of products in electrolysis

1.2 The mole concept	
Guidance: • The value of the Avogadro's constant (*L* or N_A) is given in the data booklet in section 2 and will be given for paper 1 questions. • The generally used unit of molar mass (g mol^{-1}) is a derived SI unit.	**Aims:** • **Aim 6**: Experiments could include percent mass of hydrates, burning of magnesium or calculating Avogadro's number. • **Aim 7**: Data loggers can be used to measure mass changes during reactions.

Essential idea: Mole ratios in chemical equations can be used to calculate reacting ratios by mass and gas volume.

1.3 Reacting masses and volumes	
Nature of science: Making careful observations and obtaining evidence for scientific theories—Avogadro's initial hypothesis. (1.8)	
Understandings: • Reactants can be either limiting or excess. • The experimental yield can be different from the theoretical yield. • Avogadro's law enables the mole ratio of reacting gases to be determined from volumes of the gases. • The molar volume of an ideal gas is a constant at specified temperature and pressure. • The molar concentration of a solution is determined by the amount of solute and the volume of solution. • A standard solution is one of known concentration. **Applications and skills:** • Solution of problems relating to reacting quantities, limiting and excess reactants, theoretical, experimental and percentage yields. • Calculation of reacting volumes of gases using Avogadro's law. • Solution of problems and analysis of graphs involving the relationship between temperature, pressure and volume for a fixed mass of an ideal gas. • Solution of problems relating to the ideal gas equation. • Explanation of the deviation of real gases from ideal behaviour at low	**International-mindedness:** • The SI unit of pressure is the Pascal (Pa), N m^{-2}, but many other units remain in common usage in different countries. These include atmosphere (atm), millimetres of mercury (mm Hg), Torr, bar and pounds per square inch (psi). The bar (10^5 Pa) is now widely used as a convenient unit, as it is very close to 1 atm. The SI unit for volume is m^3, although litre is a commonly used unit. **Theory of knowledge:** • Assigning numbers to the masses of the chemical elements has allowed chemistry to develop into a physical science. Why is mathematics so effective in describing the natural world? • The ideal gas equation can be deduced from a small number of assumptions of ideal behaviour. What is the role of reason, perception, intuition and imagination in the development of scientific models? **Utilization:** • Gas volume changes during chemical reactions are responsible for the inflation of air bags in vehicles and are the basis of many other explosive reactions, such as the decomposition of TNT (trinitrotoluene). • The concept of percentage yield is vital in monitoring the efficiency of industrial processes. Syllabus and cross-curricular links: Topic 4.4—intermolecular forces Topic 5.1—calculations of molar enthalpy changes

1.3 Reacting masses and volumes	
temperature and high pressure. • Obtaining and using experimental values to calculate the molar mass of a gas from the ideal gas equation. • Solution of problems involving molar concentration, amount of solute and volume of solution. • Use of the experimental method of titration to calculate the concentration of a solution by reference to a standard solution. **Guidance:** • Values for the molar volume of an ideal gas are given in the data booklet in section 2. • The ideal gas equation, $PV = nRT$, and the value of the gas constant (*R*) are given in the data booklet in sections 1 and 2. • Units of concentration to include: g dm^{-3}, mol dm^{-3} and parts per million (ppm). • The use of square brackets to denote molar concentration is required.	Topic 9.1—redox titrations Topic 17.1—equilibrium calculations Topic 18.2—acid-base titrations Topic 21.1 and A.8—X-ray crystallography Physics topic 3.2—Ideal gas law **Aims:** • **Aim 6**: Experimental design could include excess and limiting reactants. Experiments could include gravimetric determination by precipitation of an insoluble salt. • **Aim 7**: Data loggers can be used to measure temperature, pressure and volume changes in reactions or to determine the value of the gas constant, *R*. • **Aim 8**: The unit parts per million, ppm, is commonly used in measuring small levels of pollutants in fluids. This unit is convenient for communicating very low concentrations, but is not a formal SI unit.

Core

Topic 2: Atomic structure

6 hours

Essential idea: The mass of an atom is concentrated in its minute, positively charged nucleus.

2.1 The nuclear atom

Nature of science:

Evidence and improvements in instrumentation—alpha particles were used in the development of the nuclear model of the atom that was first proposed by Rutherford. (1.8)

Paradigm shifts—the subatomic particle theory of matter represents a paradigm shift in science that occurred in the late 1800s. (2.3)

Understandings:

- Atoms contain a positively charged dense nucleus composed of protons and neutrons (nucleons).
- Negatively charged electrons occupy the space outside the nucleus.
- The mass spectrometer is used to determine the relative atomic mass of an element from its isotopic composition.

Applications and skills:

- Use of the nuclear symbol notation $^{A}_{Z}X$ to deduce the number of protons, neutrons and electrons in atoms and ions.
- Calculations involving non-integer relative atomic masses and abundance of isotopes from given data, including mass spectra.

Guidance:

- Relative masses and charges of the subatomic particles should be known, actual values are given in section 4 of the data booklet. The mass of the electron can be considered negligible.
- Specific examples of isotopes need not be learned.
- The operation of the mass spectrometer is not required.

International-mindedness:

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

Theory of knowledge:

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

Utilization:

- Radioisotopes are used in nuclear medicine for diagnostics, treatment and research, as tracers in biochemical and pharmaceutical research, and as “chemical clocks” in geological and archaeological dating.
- PET (positron emission tomography) scanners give three-dimensional images of tracer concentration in the body, and can be used to detect cancers.

2.1 The nuclear atom	
	Syllabus and cross-curricular links: Topics 11.3, 21.1 and options D.8 and D.9—NMR Options C.3 and C.7—nuclear fission Option D.8—nuclear medicine **Aims:** • **Aim 7**: Simulations of Rutherford’s gold foil experiment can be undertaken. • **Aim 8**: Radionuclides carry dangers to health due to their ionizing effects on cells.

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

2.2 Electron configuration

Nature of science:

Developments in scientific research follow improvements in apparatus—the use of electricity and magnetism in Thomson's cathode rays.(1.8)

Theories being superseded—quantum mechanics is among the most current models of the atom. (1.9)

Use theories to explain natural phenomena—line spectra explained by the Bohr model of the atom. (2.2)

Understandings:

- Emission spectra are produced when photons are emitted from atoms as excited electrons return to a lower energy level.
- The line emission spectrum of hydrogen provides evidence for the existence of electrons in discrete energy levels, which converge at higher energies.
- The main energy level or shell is given an integer number, *n*, and can hold a maximum number of electrons, $2n^2$.
- A more detailed model of the atom describes the division of the main energy level into s, p, d and f sub-levels of successively higher energies.
- Sub-levels contain a fixed number of orbitals, regions of space where there is a high probability of finding an electron.
- Each orbital has a defined energy state for a given electronic configuration and chemical environment and can hold two electrons of opposite spin.

Applications and skills:

- Description of the relationship between colour, wavelength, frequency and energy across the electromagnetic spectrum.
- Distinction between a continuous spectrum and a line spectrum.

International-mindedness:

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

Theory of knowledge:

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

Utilization:

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

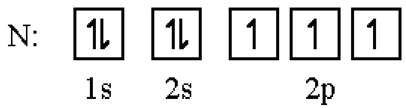
2.2 Electron configuration

- Description of the emission spectrum of the hydrogen atom, including the relationships between the lines and energy transitions to the first, second and third energy levels.
- Recognition of the shape of an s atomic orbital and the p_x, p_y and p_z atomic orbitals.
- Application of the Aufbau principle, Hund's rule and the Pauli exclusion principle to write electron configurations for atoms and ions up to Z = 36.

Guidance:

- Details of the electromagnetic spectrum are given in the data booklet in section 3.
- The names of the different series in the hydrogen line emission spectrum are not required.
- Full electron configurations (eg $1s^2 2s^2 2p^6 3s^2 3p^4$) and condensed electron configurations (eg [Ne] $3s^2 3p^4$) should be covered.

Orbital diagrams should be used to represent the character and relative energy of orbitals. Orbital diagrams refer to arrow-in-box diagrams, such as the one given below.



- The electron configurations of Cr and Cu as exceptions should be covered.

- Fireworks—emission spectra.

Syllabus and cross-curricular links:
Topics 3.1 and 3.2—periodicity
Topic 4.1—deduction of formulae of ionic compounds
Topic 6.1—Maxwell–Boltzmann distribution as a probability density function
Physics topic 7.1 and option D.2—stellar characteristics

Aims:

- **Aim 6**: Emission spectra could be observed using discharge tubes of different gases and a spectroscope. Flame tests could be used to study spectra.

Topic 3: Periodicity

6 hours

Essential idea: The arrangement of elements in the periodic table helps to predict their electron configuration.

3.1 Periodic table

Nature of science:

Obtain evidence for scientific theories by making and testing predictions based on them—scientists organize subjects based on structure and function; the periodic table is a key example of this. Early models of the periodic table from Mendeleev, and later Moseley, allowed for the prediction of properties of elements that had not yet been discovered. (1.9)

Understandings:

- The periodic table is arranged into four blocks associated with the four sub-levels—s, p, d, and f.
- The periodic table consists of groups (vertical columns) and periods (horizontal rows).
- The period number (*n*) is the outer energy level that is occupied by electrons.
- The number of the principal energy level and the number of the valence electrons in an atom can be deduced from its position on the periodic table.
- The periodic table shows the positions of metals, non-metals and metalloids.

Applications and skills:

- Deduction of the electron configuration of an atom from the element's position on the periodic table, and vice versa.

Guidance:

- The terms alkali metals, halogens, noble gases, transition metals, lanthanoids and actinoids should be known.
- The group numbering scheme from group 1 to group 18, as recommended by IUPAC, should be used.

International-mindedness:

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

Theory of knowledge:

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

Utilization:

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

Syllabus and cross-curricular links:
Topic 2.2—electron configuration

Aims:

- **Aim 3**: Apply the organization of the periodic table to understand general trends in properties.
- **Aim 4**: Be able to analyse data to explain the organization of the elements.
- **Aim 6**: Be able to recognize physical samples or images of common elements.

Essential idea: Elements show trends in their physical and chemical properties across periods and down groups.

3.2 Periodic trends	
Nature of science: Looking for patterns—the position of an element in the periodic table allows scientists to make accurate predictions of its physical and chemical properties. This gives scientists the ability to synthesize new substances based on the expected reactivity of elements. (3.1)	
Understandings: • Vertical and horizontal trends in the periodic table exist for atomic radius, ionic radius, ionization energy, electron affinity and electronegativity. • Trends in metallic and non-metallic behaviour are due to the trends above. • Oxides change from basic through amphoteric to acidic across a period. **Applications and skills:** • Prediction and explanation of the metallic and non-metallic behaviour of an element based on its position in the periodic table. • Discussion of the similarities and differences in the properties of elements in the same group, with reference to alkali metals (group 1) and halogens (group 17). • Construction of equations to explain the pH changes for reactions of Na_2O, MgO, P_4O_{10}, and the oxides of nitrogen and sulfur with water. **Guidance:** • Only examples of general trends across periods and down groups are required. For ionization energy the discontinuities in the increase across a period should be covered. • Group trends should include the treatment of the reactions of alkali metals with water, alkali metals with halogens and halogens with halide ions.	**International-mindedness:** • Industrialization has led to the production of many products that cause global problems when released into the environment. **Theory of knowledge:** • The predictive power of Mendeleev's Periodic Table illustrates the "risk-taking" nature of science. What is the demarcation between scientific and pseudoscientific claims? • The Periodic Table is an excellent example of classification in science. How does classification and categorization help and hinder the pursuit of knowledge? **Utilization:** Syllabus and cross-curricular links: Topic 2.2—anomalies in first ionization energy values can be connected to stability in electron configuration Topic 8.5—production of acid rain **Aims:** • **Aims 1** and **8**: What is the global impact of acid deposition? • **Aim 6**: Experiment with chemical trends directly in the laboratory or through the use of teacher demonstrations. • **Aim 6**: The use of transition metal ions as catalysts could be investigated. • **Aim 7**: Periodic trends can be studied with the use of computer databases.

Topic 4: Chemical bonding and structure

13.5 hours

Essential idea: Ionic compounds consist of ions held together in lattice structures by ionic bonds.

4.1 Ionic bonding and structure

Nature of science:

Use theories to explain natural phenomena—molten ionic compounds conduct electricity but solid ionic compounds do not. The solubility and melting points of ionic compounds can be used to explain observations. (2.2)

Understandings:

- Positive ions (cations) form by metals losing valence electrons.
- Negative ions (anions) form by non-metals gaining electrons.
- The number of electrons lost or gained is determined by the electron configuration of the atom.
- The ionic bond is due to electrostatic attraction between oppositely charged ions.
- Under normal conditions, ionic compounds are usually solids with lattice structures.

Applications and skills:

- Deduction of the formula and name of an ionic compound from its component ions, including polyatomic ions.
- Explanation of the physical properties of ionic compounds (volatility, electrical conductivity and solubility) in terms of their structure.

Guidance:

- Students should be familiar with the names of these polyatomic ions: NH_4^+, OH^-, NO_3^-, HCO_3^-, CO_3^{2-}, SO_4^{2-} and PO_4^{3-}.

Theory of knowledge:

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

Utilization:

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

Syllabus and cross-curricular links:
Topic 3.2—periodic trends
Topic 21.1 and Option A.8—use of X-ray crystallography in structural determinations
Physics topic 5.1—electrostatics

Aims:

- **Aim 3**: Use naming conventions to name ionic compounds.
- **Aim 6**: Students could investigate compounds based on their bond type and properties or obtain sodium chloride by solar evaporation.
- **Aim 7**: Computer simulation could be used to observe crystal lattice structures.

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

<table>
<tr><td colspan="2">4.2. Covalent bonding</td></tr>
<tr><td colspan="2">Nature of science:
Looking for trends and discrepancies—compounds containing non-metals have different properties than compounds that contain non-metals and metals. (2.5)
Use theories to explain natural phenomena—Lewis introduced a class of compounds which share electrons. Pauling used the idea of electronegativity to explain unequal sharing of electrons. (2.2)</td></tr>
<tr><td>Understandings:
• A covalent bond is formed by the electrostatic attraction between a shared pair of electrons and the positively charged nuclei.
• Single, double and triple covalent bonds involve one, two and three shared pairs of electrons respectively.
• Bond length decreases and bond strength increases as the number of shared electrons increases.
• Bond polarity results from the difference in electronegativities of the bonded atoms.
Applications and skills:
• Deduction of the polar nature of a covalent bond from electronegativity values.
Guidance:
• Bond polarity can be shown either with partial charges, dipoles or vectors.
• Electronegativity values are given in the data booklet in section 8.</td><td>Utilization:
• Microwaves—cooking with polar molecules.
Syllabus and cross-curricular links:
Topic 10.1—organic molecules
Aims:
• Aim 3: Use naming conventions to name covalently bonded compounds.</td></tr>
</table>

Essential idea: Lewis (electron dot) structures show the electron domains in the valence shell and are used to predict molecular shape.

4.3 Covalent structures

Nature of science:

Scientists use models as representations of the real world—the development of the model of molecular shape (VSEPR) to explain observable properties. (1.10)

Understandings:

- Lewis (electron dot) structures show all the valence electrons in a covalently bonded species.
- The “octet rule” refers to the tendency of atoms to gain a valence shell with a total of 8 electrons.
- Some atoms, like Be and B, might form stable compounds with incomplete octets of electrons.
- Resonance structures occur when there is more than one possible position for a double bond in a molecule.
- Shapes of species are determined by the repulsion of electron pairs according to VSEPR theory.
- Carbon and silicon form giant covalent/network covalent structures.

Applications and skills:

- Deduction of Lewis (electron dot) structure of molecules and ions showing all valence electrons for up to four electron pairs on each atom.
- The use of VSEPR theory to predict the electron domain geometry and the molecular geometry for species with two, three and four electron domains.
- Prediction of bond angles from molecular geometry and presence of non-bonding pairs of electrons.
- Prediction of molecular polarity from bond polarity and molecular geometry.
- Deduction of resonance structures, examples include but are not limited to C_6H_6, CO_3^{2-} and O_3.

Theory of knowledge:

- Does the need for resonance structures decrease the value or validity of Lewis (electron dot) theory? What criteria do we use in assessing the validity of a scientific theory?

Utilization:

Syllabus and cross-curricular links:
Option A.7—biodegradability of plastics
Biology topic 2.3—3-D structure of molecules and relating structure to function

Aims:

- **Aim 7**: Computer simulations could be used to model VSEPR structures.

4.3 Covalent structures	
• Explanation of the properties of giant covalent compounds in terms of their structures. **Guidance:** • The term “electron domain” should be used in place of “negative charge centre”. • Electron pairs in a Lewis (electron dot) structure can be shown as dots, crosses, a dash or any combination. • Allotropes of carbon (diamond, graphite, graphene, C_{60} buckminsterfullerene) and SiO_2 should be covered. • Coordinate covalent bonds should be covered.	

Essential idea: The physical properties of molecular substances result from different types of forces between their molecules.

4.4 Intermolecular forces

Nature of science:

Obtain evidence for scientific theories by making and testing predictions based on them—London (dispersion) forces and hydrogen bonding can be used to explain special interactions. For example, molecular covalent compounds can exist in the liquid and solid states. To explain this, there must be attractive forces between their particles which are significantly greater than those that could be attributed to gravity. (2.2)

Understandings:

- Intermolecular forces include London (dispersion) forces, dipole-dipole forces and hydrogen bonding.
- The relative strengths of these interactions are London (dispersion) forces < dipole-dipole forces < hydrogen bonds.

Applications and skills

- Deduction of the types of intermolecular force present in substances, based on their structure and chemical formula.
- Explanation of the physical properties of covalent compounds (volatility, electrical conductivity and solubility) in terms of their structure and intermolecular forces.

Guidance:

- The term “London (dispersion) forces” refers to instantaneous induced dipole-induced dipole forces that exist between any atoms or groups of atoms and should be used for non-polar entities. The term “van der Waals” is an inclusive term, which includes dipole–dipole, dipole-induced dipole and London (dispersion) forces.

Theory of knowledge:

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

Utilization:

Syllabus and cross-curricular links:
Option A.5—using plasticizers
Option A.7—controlling biodegradability
Option B.3—melting points of *cis-/trans-* fats
Biology topics 2.2, 2.3, 2.4 and 2.6—understanding of intermolecular forces to work with molecules in the body

Aims:

- **Aim 7**: Computer simulations could be used to show intermolecular forces interactions.

Essential idea: Metallic bonds involve a lattice of cations with delocalized electrons.

<table>
<tr><td colspan="2">4.5 Metallic bonding</td></tr>
<tr><td colspan="2">Nature of science:
Use theories to explain natural phenomena—the properties of metals are different from covalent and ionic substances and this is due to the formation of non-directional bonds with a “sea” of delocalized electrons. (2.2)</td></tr>
<tr><td>Understandings:
• A metallic bond is the electrostatic attraction between a lattice of positive ions and delocalized electrons.
• The strength of a metallic bond depends on the charge of the ions and the radius of the metal ion.
• Alloys usually contain more than one metal and have enhanced properties.
Applications and skills:
• Explanation of electrical conductivity and malleability in metals.
• Explanation of trends in melting points of metals.
• Explanation of the properties of alloys in terms of non-directional bonding.
Guidance:
• Trends should be limited to s- and p-block elements.
• Examples of various alloys should be covered.</td><td>International-mindedness:
• The availability of metal resources, and the means to extract them, varies greatly in different countries, and is a factor in determining national wealth. As technologies develop, the demands for different metals change and careful strategies are needed to manage the supply of these finite resources.
Utilization:
Syllabus and cross-curricular links:
Option A.6—use of metals in nanotechnology
Biology topic 2.2—water
Aims:
• Aim 1: Global impact of value of precious metals and their extraction processes and locations.
• Aim 7: Computer simulations could be used to view examples of metallic bonding.</td></tr>
</table>

Topic 5: Energetics/thermochemistry

9 hours

Essential idea: The enthalpy changes from chemical reactions can be calculated from their effect on the temperature of their surroundings.

5.1 Measuring energy changes

Nature of science:

Fundamental principle—conservation of energy is a fundamental principle of science. (2.6)

Making careful observations—measurable energy transfers between systems and surroundings. (3.1)

Understandings:

- Heat is a form of energy.
- Temperature is a measure of the average kinetic energy of the particles.
- Total energy is conserved in chemical reactions.
- Chemical reactions that involve transfer of heat between the system and the surroundings are described as endothermic or exothermic.
- The enthalpy change (ΔH) for chemical reactions is indicated in kJ mol^{-1}.
- ΔH values are usually expressed under standard conditions, given by $\Delta H°$, including standard states.

Applications and skills:

- Calculation of the heat change when the temperature of a pure substance is changed using $q = mc\Delta T$.
- A calorimetry experiment for an enthalpy of reaction should be covered and the results evaluated.

Guidance:

- Enthalpy changes of combustion (ΔH_c°) and formation (ΔH_f°)should be covered.
- Consider reactions in aqueous solution and combustion reactions.

International-mindedness:

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

Theory of knowledge:

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

Utilization:

- Determining energy content of important substances in food and fuels.

Syllabus and cross-curricular links:
Topic 1.1—conservation of mass, changes of state
Topic 1.2—the mole concept

Aims:

- **Aim 6**: Experiments could include calculating enthalpy changes from given experimental data (energy content of food, enthalpy of melting of ice or the enthalpy change of simple reactions in aqueous solution).
- **Aim 7**: Use of databases to analyse the energy content of food.
- **Aim 7**: Use of data loggers to record temperature changes.

5.1 Measuring energy changes	
• Standard state refers to the normal, most pure stable state of a substance measured at 100 kPa. Temperature is not a part of the definition of standard state, but 298 K is commonly given as the temperature of interest. • The specific heat capacity of water is provided in the data booklet in section 2. • Students can assume the density and specific heat capacities of aqueous solutions are equal to those of water, but should be aware of this limitation. • Heat losses to the environment and the heat capacity of the calorimeter in experiments should be considered, but the use of a bomb calorimeter is not required.	

Essential idea: In chemical transformations energy can neither be created nor destroyed (the first law of thermodynamics).

5.2 Hess's Law

Nature of science:

Hypotheses—based on the conservation of energy and atomic theory, scientists can test the hypothesis that if the same products are formed from the same initial reactants then the energy change should be the same regardless of the number of steps. (2.4)

Understandings:

- The enthalpy change for a reaction that is carried out in a series of steps is equal to the sum of the enthalpy changes for the individual steps.

Applications and skills:

- Application of Hess's Law to calculate enthalpy changes.
- Calculation of ΔH reactions using ΔH_f° data.
- Determination of the enthalpy change of a reaction that is the sum of multiple reactions with known enthalpy changes.

Guidance:

- Enthalpy of formation data can be found in the data booklet in section 12.
- An application of Hess's Law is $\Delta H \text{ reaction} = \Sigma(\Delta H_f^\circ \text{products}) - \Sigma(\Delta H_f^\circ \text{reactants})$.

International-mindedness:

- Recycling of materials is often an effective means of reducing the environmental impact of production, but varies in its efficiency in energy terms in different countries.

Theory of knowledge:

- Hess's Law is an example of the application of the Conservation of Energy. What are the challenges and limitations of applying general principles to specific instances?

Utilization:

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

Syllabus and cross-curricular links:
Physics topic 2.3—conservation of mass-energy

Aims:

- **Aim 4**: Discuss the source of accepted values and use this idea to critique experiments.
- **Aim 6**: Experiments could include Hess's Law labs.
- **Aim 7**: Use of data loggers to record temperature changes.

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

5.3 Bond enthalpies	
Nature of science: Models and theories—measured energy changes can be explained based on the model of bonds broken and bonds formed. Since these explanations are based on a model, agreement with empirical data depends on the sophistication of the model and data obtained can be used to modify theories where appropriate. (2.2)	
Understandings: • Bond-forming releases energy and bond-breaking requires energy. • Average bond enthalpy is the energy needed to break one mol of a bond in a gaseous molecule averaged over similar compounds. **Applications and skills:** • Calculation of the enthalpy changes from known bond enthalpy values and comparison of these to experimentally measured values. • Sketching and evaluation of potential energy profiles in determining whether reactants or products are more stable and if the reaction is exothermic or endothermic. • Discussion of the bond strength in ozone relative to oxygen in its importance to the atmosphere. **Guidance:** • Bond enthalpy values are given in the data booklet in section 11. • Average bond enthalpies are only valid for gases and calculations involving bond enthalpies may be inaccurate because they do not take into account intermolecular forces.	**International-mindedness:** • Stratospheric ozone depletion is a particular concern in the polar regions of the planet, although the pollution that causes it comes from a variety of regions and sources. International action and cooperation have helped to ameliorate the ozone depletion problem. **Utilization:** • Energy sources, such as combustion of fossil fuels, require high ΔH values. Syllabus and cross-curricular links: Topic 4.3—covalent structures **Aims:** • **Aim 6**: Experiments could be enthalpy of combustion of propane or butane. • **Aim 7**: Data loggers can be used to record temperature changes. • **Aim 8**: Moral, ethical, social, economic and environmental consequences of ozone depletion and its causes.

Topic 6: Chemical kinetics

7 hours

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

6.1 Collision theory and rates of reaction	
Nature of science: The principle of Occam's razor is used as a guide to developing a theory—although we cannot directly see reactions taking place at the molecular level, we can theorize based on the current atomic models. Collision theory is a good example of this principle. (2.7)	
Understandings: • Species react as a result of collisions of sufficient energy and proper orientation. • The rate of reaction is expressed as the change in concentration of a particular reactant/product per unit time. • Concentration changes in a reaction can be followed indirectly by monitoring changes in mass, volume and colour. • Activation energy (E_a) is the minimum energy that colliding molecules need in order to have successful collisions leading to a reaction. • By decreasing E_a, a catalyst increases the rate of a chemical reaction, without itself being permanently chemically changed. **Applications and skills:** • Description of the kinetic theory in terms of the movement of particles whose average kinetic energy is proportional to temperature in Kelvin. • Analysis of graphical and numerical data from rate experiments.	**International-mindedness:** • Depletion of stratospheric ozone has been caused largely by the catalytic action of CFCs and is a particular concern in the polar regions. These chemicals are released from a variety of regions and sources, so international action and cooperation have been needed to ameliorate the ozone depletion problem. **Theory of knowledge:** • The Kelvin scale of temperature gives a natural measure of the kinetic energy of gas whereas the artificial Celsius scale is based on the properties of water. Are physical properties such as temperature invented or discovered? **Utilization:** Syllabus and cross-curricular links: Topic 5.3—what might be meant by thermodynamically stable vs kinetically stable? Topic 13.1—fireworks and ions Option A.3—everyday uses of catalysts Option B.2—enzymes Biology topic 8.1—metabolism

6.1 Collision theory and rates of reaction	
• Explanation of the effects of temperature, pressure/concentration and particle size on rate of reaction. • Construction of Maxwell–Boltzmann energy distribution curves to account for the probability of successful collisions and factors affecting these, including the effect of a catalyst. • Investigation of rates of reaction experimentally and evaluation of the results. • Sketching and explanation of energy profiles with and without catalysts. **Guidance:** • Calculation of reaction rates from tangents of graphs of concentration, volume or mass against time should be covered. • Students should be familiar with the interpretation of graphs of changes in concentration, volume or mass against time.	**Aims:** • **Aims 1** and **8**: What are some of the controversies over rate of climate change? Why do these exist? • **Aim 6**: Investigate the rate of a reaction with and without a catalyst. • **Aim 6**: Experiments could include investigating rates by changing concentration of a reactant or temperature. • **Aim 7**: Use simulations to show how molecular collisions are affected by change of macroscopic properties such as temperature, pressure and concentration. • **Aim 8**: The role that catalysts play in the field of green chemistry.

Topic 7: Equilibrium

4.5 hours

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

7.1 Equilibrium

Nature of science:

Obtaining evidence for scientific theories—isotopic labelling and its use in defining equilibrium. (1.8)

Common language across different disciplines—the term dynamic equilibrium is used in other contexts, but not necessarily with the chemistry definition in mind. (5.5)

Understandings:

- A state of equilibrium is reached in a closed system when the rates of the forward and reverse reactions are equal.
- The equilibrium law describes how the equilibrium constant (K_c) can be determined for a particular chemical reaction.
- The magnitude of the equilibrium constant indicates the extent of a reaction at equilibrium and is temperature dependent.
- The reaction quotient (*Q*) measures the relative amount of products and reactants present during a reaction at a particular point in time. *Q* is the equilibrium expression with non-equilibrium concentrations. The position of the equilibrium changes with changes in concentration, pressure, and temperature.
- A catalyst has no effect on the position of equilibrium or the equilibrium constant.

Applications and skills:

- The characteristics of chemical and physical systems in a state of equilibrium.
- Deduction of the equilibrium constant expression (K_c) from an equation for a homogeneous reaction.
- Determination of the relationship between different equilibrium constants (K_c) for the same reaction (at the same temperature) when represented by equations written in different ways.

International-mindedness:

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

Theory of knowledge:

- Scientists investigate the world at different scales; the macroscopic and microscopic. Which ways of knowing allow us to move from the macroscopic to the microscopic?
- Chemistry uses a specialized vocabulary: a closed system is one in which no matter is exchanged with the surroundings. Does our vocabulary simply communicate our knowledge; or does it shape what we can know?
- The career of Fritz Haber coincided with the political upheavals of two world wars. He supervised the release of chlorine on the battlefield in World War I and worked on the production of explosives. How does the social context of scientific work affect the methods and findings of science? Should scientists be held morally responsible for the applications of their discoveries?

Utilization:

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

7.1 Equilibrium	
• Application of Le Châtelier's principle to predict the qualitative effects of changes of temperature, pressure and concentration on the position of equilibrium and on the value of the equilibrium constant. **Guidance:** • Physical and chemical systems should be covered. • Relationship between K_c values for reactions that are multiples or inverses of one another should be covered. • Specific details of any industrial process are not required.	Syllabus and cross-curricular links: Topic 8.4—the behaviour of weak acids and bases **Aims:** • **Aim 6**: Le Châtelier's principle can be investigated qualitatively by looking at pressure, concentration and temperature changes on different equilibrium systems. • **Aim 7**: Animations and simulations can be used to illustrate the concept of dynamic equilibrium. • **Aim 8**: Raise awareness of the moral, ethical, and economic implications of using science and technology. A case study of Fritz Haber can be used to debate the role of scientists in society.

Topic 8: Acids and bases

6.5 hours

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

8.1 Theories of acids and bases	
Nature of science: Falsification of theories—HCN altering the theory that oxygen was the element which gave a compound its acidic properties allowed for other acid–base theories to develop. (2.5) Theories being superseded—one early theory of acidity derived from the sensation of a sour taste, but this had been proven false. (1.9) Public understanding of science—outside of the arena of chemistry, decisions are sometimes referred to as "acid test" or "litmus test". (5.5)	
Understandings: • A Brønsted–Lowry acid is a proton/H^+ donor and a Brønsted–Lowry base is a proton/H^+ acceptor. • Amphiprotic species can act as both Brønsted–Lowry acids and bases. • A pair of species differing by a single proton is called a conjugate acid-base pair. **Applications and skills:** • Deduction of the Brønsted–Lowry acid and base in a chemical reaction. • Deduction of the conjugate acid or conjugate base in a chemical reaction. **Guidance:** • Lewis theory is not required here. • The location of the proton transferred should be clearly indicated. For example, CH_3COOH/CH_3COO^- rather than $C_2H_4O_2/C_2H_3O_2^-$. • Students should know the representation of a proton in aqueous solution as both H^+ (aq) and H_3O^+ (aq). • The difference between the terms amphoteric and amphiprotic should be covered.	**International-mindedness:** • *Acidus* means sour in Latin, while *alkali* is derived from the Arabic word for calcined ashes. *Oxygene* means acid-forming in Greek, and reflects the mistaken belief that the element oxygen was responsible for a compound's acidic properties. Acid–base theory has been developed by scientists from around the world, and its vocabulary has been influenced by their languages. **Theory of knowledge:** • Acid and base behaviour can be explained using different theories. How are the explanations in chemistry different from explanations in other subjects such as history? **Utilization:** Syllabus and cross-curricular links: Topic 3.2—the acid/base character of oxides Topic 8.5—non-metal oxides are responsible for acid precipitation Option B.2—amino acids acting as amphiprotic species Option D.4—antacids are bases which neutralize excess hydrochloric acid in the stomach **Aims:** • **Aim 9**: Each theory has its strengths and limitations. Lavoisier has been called the father of modern chemistry but he was mistaken about oxygen in this context.

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

8.2 Properties of acids and bases

Nature of science:

Obtaining evidence for theories—observable properties of acids and bases have led to the modification of acid–base theories. (1.9)

Understandings:

- Most acids have observable characteristic chemical reactions with reactive metals, metal oxides, metal hydroxides, hydrogen carbonates and carbonates.
- Salt and water are produced in exothermic neutralization reactions.

Applications and skills:

- Balancing chemical equations for the reaction of acids.
- Identification of the acid and base needed to make different salts.
- Candidates should have experience of acid-base titrations with different indicators.

Guidance:

- Bases which are not hydroxides, such as ammonia, soluble carbonates and hydrogen carbonates should be covered.
- The colour changes of different indicators are given in the data booklet in section 22.

Utilization:

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

Syllabus and cross-curricular links:
Topic 1.3—acid–base titrations
Topic 3.2—the acid/base character of oxides
Topic 5.1—enthalpy change of neutralization reactions

Aims:

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

Essential idea: The pH scale is an artificial scale used to distinguish between acid, neutral and basic/alkaline solutions.

8.3 The pH scale	
Nature of science: Occam's razor—the pH scale is an attempt to scale the relative acidity over a wide range of H^+ concentrations into a very simple number. (2.7)	
Understandings: • $\mathrm{pH} = -\log[\mathrm{H^+(aq)}]$ and $[\mathrm{H^+}] = 10^{-\mathrm{pH}}$. • A change of one pH unit represents a 10-fold change in the hydrogen ion concentration $[\mathrm{H^+}]$. • pH values distinguish between acidic, neutral and alkaline solutions. • The ionic product constant, $K_w = [\mathrm{H^+}][\mathrm{OH^-}] = 10^{-14}$ at 298 K. **Applications and skills:** • Solving problems involving pH, $[\mathrm{H^+}]$ and $[\mathrm{OH^-}]$. • Students should be familiar with the use of a pH meter and universal indicator. **Guidance:** • Students will not be assessed on pOH values. • Students should be concerned only with strong acids and bases in this sub-topic. • Knowing the temperature dependence of K_w is not required. • Equations involving H_3O^+ instead of H^+ may be applied.	**Theory of knowledge:** • Chemistry makes use of the universal language of mathematics as a means of communication. Why is it important to have just one "scientific" language? **Utilization:** Syllabus and cross-curricular links: Mathematics SL (topic 1.2) and Mathematics HL (topic 1.2)—study of logs **Aims:** • **Aim 3**: Students should be able to use and apply the pH concept in a range of experimental and theoretical contexts. • **Aim 6**: An acid–base titration could be monitored with an indicator or a pH probe.

Essential idea: The pH depends on the concentration of the solution. The strength of acids or bases depends on the extent to which they dissociate in aqueous solution.

8.4 Strong and weak acids and bases

Nature of science:

Improved instrumentation—the use of advanced analytical techniques has allowed the relative strength of different acids and bases to be quantified. (1.8)

Looking for trends and discrepancies—patterns and anomalies in relative strengths of acids and bases can be explained at the molecular level. (3.1)

The outcomes of experiments or models may be used as further evidence for a claim—data for a particular type of reaction supports the idea that weak acids exist in equilibrium. (1.9)

Understandings:

- Strong and weak acids and bases differ in the extent of ionization.
- Strong acids and bases of equal concentrations have higher conductivities than weak acids and bases.
- A strong acid is a good proton donor and has a weak conjugate base.
- A strong base is a good proton acceptor and has a weak conjugate acid.

Applications and skills:

- Distinction between strong and weak acids in terms of the rates of their reactions with metals, metal oxides, metal hydroxides, metal hydrogen carbonates and metal carbonates. Strong and weak acids and bases also differ in their electrical conductivities for solutions of equal concentrations.

Guidance:

- The terms ionization and dissociation can be used interchangeably.
- See section 21 in the data booklet for a list of weak acids and bases.

Theory of knowledge:

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

Utilization:

Syllabus and cross-curricular links:
Topic 1.3—solution chemistry
Topic 7.1—weak acids and bases involve reversible reactions

Aims:

- **Aim 6**: Students should have experimental experience of working qualitatively with both strong and weak acids and bases. Examples to include: H_2SO_4 (aq), HCl (aq), HNO_3 (aq), NaOH (aq), NH_3 (aq).
- **Aim 7**: Students could use data loggers to investigate the strength of acid and bases.

Essential idea: Increased industrialization has led to greater production of nitrogen and sulfur oxides leading to acid rain, which is damaging our environment. These problems can be reduced through collaboration with national and intergovernmental organizations.

8.5 Acid deposition

Nature of science:

Risks and problems—oxides of metals and non-metals can be characterized by their acid–base properties. Acid deposition is a topic that can be discussed from different perspectives. Chemistry allows us to understand and to reduce the environmental impact of human activities. (4.8)

Understandings:

- Rain is naturally acidic because of dissolved CO_2 and has a pH of 5.6. Acid deposition has a lower pH, usually below 5.0.
- Acid deposition is formed when nitrogen or sulfur oxides dissolve in water to form HNO_3, HNO_2, H_2SO_4 and H_2SO_3.
- Sources of the oxides of sulfur and nitrogen and the effects of acid deposition should be covered.

Applications and skills:

- Balancing the equations that describe the combustion of sulfur and nitrogen to their oxides and the subsequent formation of H_2SO_3, H_2SO_4, HNO_2 and HNO_3.
- Distinction between the pre-combustion and post-combustion methods of reducing sulfur oxides emissions.
- Deduction of acid deposition equations for acid deposition with reactive metals and carbonates.

International-mindedness:

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

Theory of knowledge:

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

Utilization:

Syllabus and cross-curricular links:
Topic 3.2—the acid/base character of the oxides
Option B.2—pH change and enzyme activity
Option C.2—sulfur dioxide is produced by the combustion of fossil fuels with high levels of sulfur impurities
Environmental systems and societies topic 5.8—acid deposition
Geography Option G: Urban Environments—urban stress and the sustainable city; HL—Global interactions—environmental change

Aims:

- **Aim 6**: The effects of acid rain on different construction materials could be quantitatively investigated.
- **Aim 8**: A discussion of the impact of acid rain in different countries will help raise awareness of the environmental impact of this secondary pollutant and the political implications.
- **Aim 8**: Other means of reducing oxide production—bus use, car pooling, etc. could be discussed.

Topic 9: Redox processes

8 hours

Essential idea: Redox (reduction–oxidation) reactions play a key role in many chemical and biochemical processes.

9.1 Oxidation and reduction

Nature of science:

How evidence is used—changes in the definition of oxidation and reduction from one involving specific elements (oxygen and hydrogen), to one involving electron transfer, to one invoking oxidation numbers is a good example of the way that scientists broaden similarities to general principles. (1.9)

Understandings:

- Oxidation and reduction can be considered in terms of oxygen gain/hydrogen loss, electron transfer or change in oxidation number.
- An oxidizing agent is reduced and a reducing agent is oxidized.
- Variable oxidation numbers exist for transition metals and for most main-group non-metals.
- The activity series ranks metals according to the ease with which they undergo oxidation.
- The Winkler Method can be used to measure biochemical oxygen demand (BOD), used as a measure of the degree of pollution in a water sample.

Applications and skills:

- Deduction of the oxidation states of an atom in an ion or a compound.
- Deduction of the name of a transition metal compound from a given formula, applying oxidation numbers represented by Roman numerals.
- Identification of the species oxidized and reduced and the oxidizing and reducing agents, in redox reactions.
- Deduction of redox reactions using half-equations in acidic or neutral solutions.
- Deduction of the feasibility of a redox reaction from the activity series or reaction data.

International-mindedness:

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

Theory of knowledge:

- Chemistry has developed a systematic language that has resulted in older names becoming obsolete. What has been lost and gained in this process?
- Oxidation states are useful when explaining redox reactions. Are artificial conversions a useful or valid way of clarifying knowledge?

Utilization:

- Aerobic respiration, batteries, solar cells, fuel cells, bleaching by hydrogen peroxide of melanin in hair, household bleach, the browning of food exposed to air, etc.
- Driving under the influence of alcohol is a global problem which results in serious road accidents. A redox reaction is the basis of the breathalyser test.
- Natural and synthetic antioxidants in food chemistry.
- Photochromic lenses.
- Corrosion and galvanization.

9.1 Oxidation and reduction	
• Solution of a range of redox titration problems. • Application of the Winkler Method to calculate BOD. **Guidance:** • Oxidation number and oxidation state are often used interchangeably, though IUPAC does formally distinguish between the two terms. Oxidation numbers are represented by Roman numerals according to IUPAC. • Oxidation states should be represented with the sign given before the number, eg +2 not 2+. • The oxidation state of hydrogen in metal hydrides (-1) and oxygen in peroxides (-1) should be covered. • A simple activity series is given in the data booklet in section 25.	Syllabus and cross-curricular links: Topic 1.3—experimental determination of amounts, masses, volumes and concentrations of solutions Topic 3.2—halogen reactivity Topics 4.1 and 4.2—difference between ionic and covalent bonding Topic 10.2—oxidation of alcohols Biology topics 8.2 and 8.3—redox reactions in physiology **Aims:** • **Aim 6**: Experiments could include demonstrating the activity series, redox titrations and using the Winkler Method to measure BOD. • **Aim 8**: Oxidizing agents such as chlorine can be used as disinfectants. Use of chlorine as a disinfectant is of concern due to its ability to oxidize other species forming harmful by-products (eg trichloromethane).

Essential idea: Voltaic cells convert chemical energy to electrical energy and electrolytic cells convert electrical energy to chemical energy.

9.2 Electrochemical cells	
Nature of science: Ethical implications of research—the desire to produce energy can be driven by social needs or profit. (4.5)	
Understandings: Voltaic (*Galvanic*) cells: • Voltaic cells convert energy from spontaneous, exothermic chemical processes to electrical energy. • Oxidation occurs at the anode (negative electrode) and reduction occurs at the cathode (positive electrode) in a voltaic cell. Electrolytic cells: • Electrolytic cells convert electrical energy to chemical energy, by bringing about non-spontaneous processes. • Oxidation occurs at the anode (positive electrode) and reduction occurs at the cathode (negative electrode) in an electrolytic cell. **Applications and skills:** • Construction and annotation of both types of electrochemical cells. • Explanation of how a redox reaction is used to produce electricity in a voltaic cell and how current is conducted in an electrolytic cell. • Distinction between electron and ion flow in both electrochemical cells. • Performance of laboratory experiments involving a typical voltaic cell using two metal/metal-ion half-cells. • Deduction of the products of the electrolysis of a molten salt.	**International-mindedness:** • Research in space exploration often centres on energy factors. The basic hydrogen–oxygen fuel cell can be used as an energy source in spacecraft, such as those first engineered by NASA in the USA. The International Space Station is a good example of a multinational project involving the international scientific community. **Theory of knowledge:** • Is energy just an abstract concept used to justify why certain types of changes are always associated with each other? Are concepts such as energy **real**? **Utilization:** • Fuel cells. • Heart pacemakers. Syllabus and cross-curricular links: Option C.6—fuel cells Physics topic 5.3—electrochemical cells **Aims:** • **Aim 6**: Construction of a typical voltaic cell using two metal/metal-ion half-cells. • **Aim 6**: Electrolysis experiments could include that of a molten salt. A video could also be used to show some of these electrolytic processes.

9.2 Electrochemical cells	
Guidance: • For voltaic cells, a cell diagram convention should be covered.	• **Aim 8**: Although the hydrogen fuel cell is considered an environmentally friendly, efficient alternative to the internal combustion engine, storage of hydrogen fuel is a major problem. The use of liquid methanol, which can be produced from plants as a carbon neutral fuel (one which does not contribute to the greenhouse effect), in fuel cells has enormous potential. What are the current barriers to the development of fuel cells?

Core

Topic 10: Organic chemistry

11 hours

Essential idea: Organic chemistry focuses on the chemistry of compounds containing carbon.

10.1 Fundamentals of organic chemistry

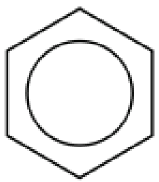
Nature of science:

Serendipity and scientific discoveries—PTFE and superglue. (1.4)

Ethical implications—drugs, additives and pesticides can have harmful effects on both people and the environment. (4.5)

Understandings:

- A homologous series is a series of compounds of the same family, with the same general formula, which differ from each other by a common structural unit.
- Structural formulas can be represented in full and condensed format.
- Structural isomers are compounds with the same molecular formula but different arrangements of atoms.
- Functional groups are the reactive parts of molecules.
- Saturated compounds contain single bonds only and unsaturated compounds contain double or triple bonds.



- Benzene is an aromatic, unsaturated hydrocarbon.

Applications and skills:

- Explanation of the trends in boiling points of members of a homologous series.
- Distinction between empirical, molecular and structural formulas.

International-mindedness:

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

Theory of knowledge:

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

Utilization:

- Fractional distillation makes great use of many petrochemicals.
- Dyes, pesticides, herbicides, explosives, soap, cosmetics, synthetic scents and flavourings.

10.1 Fundamentals of organic chemistry

- Identification of different classes: alkanes, alkenes, alkynes, halogenoalkanes, alcohols, ethers, aldehydes, ketones, esters, carboxylic acids, amines, amides, nitriles and arenes.
- Identification of typical functional groups in molecules eg phenyl, hydroxyl, carbonyl, carboxyl, carboxamide, aldehyde, ester, ether, amine, nitrile, alkyl, alkenyl and alkynyl.
- Construction of 3-D models (real or virtual) of organic molecules.
- Application of IUPAC rules in the nomenclature of straight-chain and branched-chain isomers.
- Identification of primary, secondary and tertiary carbon atoms in halogenoalkanes and alcohols and primary, secondary and tertiary nitrogen atoms in amines.
- Discussion of the structure of benzene using physical and chemical evidence.

Guidance:

- Skeletal formulas should be discussed in the course.
- The general formulas (eg C_nH_{2n+2}) of alkanes, alkenes, alkynes, ketones, alcohols, aldehydes and carboxylic acids should be known.
- The distinction between class names and functional group names needs to be made. Eg for OH, hydroxyl is the functional group whereas alcohol is the class name.
- The following nomenclature should be covered:
  - non-cyclic alkanes and halogenoalkanes up to halohexanes.
  - alkenes up to hexene and alkynes up to hexyne.
  - compounds up to six carbon atoms (in the basic chain for nomenclature purposes) containing only one functional group: such as hydroxyl, carbonyl, carboxyl, alkenyl etc.

Syllabus and cross-curricular links:
Topic 1.2—empirical and molecular formulas
Topics 4.2 and 4.3—Lewis (electron dot) structures, multiple bonds, VSEPR theory, resonance and bond and molecular polarity
Topic 4.4—intermolecular forces
Topic 5.3—exothermic reactions and bond enthalpies
Topic 8.4—weak acids
Option A.5—materials and polymers
Options B.2 and B.7—proteins
Option D.9—organic structure in medicines

Aims:

- **Aim 6**: Either use model kits or suitable computer-generated molecular graphics programmes to construct three-dimensional models of a wide range of organic molecules.
- **Aim 6**: Experiments could include distillation to separate liquids or the use of a rotary evaporator to remove a solvent from a mixture.
- **Aim 8**: There are consequences in using fossil fuels as our main source of energy. Many products can be obtained from fossil fuels due to the inherently rich chemistry of carbon. This raises some fundamental questions—are fossil fuels too valuable to burn and how do they affect the environment? Who should be responsible for making decisions in this regard?
- **Aim 8**: Discuss the use of alcohols and biofuels as fuel alternatives to petrol (gasoline) and diesel.

Essential idea: Structure, bonding and chemical reactions involving functional group interconversions are key strands in organic chemistry.

<table>
<tr><td colspan="2">10.2 Functional group chemistry</td></tr>
<tr><td colspan="2">Nature of science:
Use of data—much of the progress that has been made to date in the developments and applications of scientific research can be mapped back to key organic chemical reactions involving functional group interconversions. (3.1)</td></tr>
<tr><td>Understandings:
Alkanes:
• Alkanes have low reactivity and undergo free-radical substitution reactions.
Alkenes:
• Alkenes are more reactive than alkanes and undergo addition reactions. Bromine water can be used to distinguish between alkenes and alkanes.
Alcohols:
• Alcohols undergo esterification (or condensation) reactions with acids and some undergo oxidation reactions.
Halogenoalkanes:
• Halogenoalkanes are more reactive than alkanes. They can undergo (nucleophilic) substitution reactions. A nucleophile is an electron-rich species containing a lone pair that it donates to an electron-deficient carbon.
Polymers:
• Addition polymers consist of a wide range of monomers and form the basis of the plastics industry.
Benzene:
• Benzene does not readily undergo addition reactions but does undergo electrophilic substitution reactions.</td><td>International-mindedness:
• Methane is a greenhouse gas, and its release from ruminants in countries such as Brazil, Uruguay, Argentina and New Zealand contributes significantly to total greenhouse gas emissions. Landfills are also a source of methane, and technologies are developing in some countries to capture the gas as a source of energy for electricity and heat generation.
• Alcohol misuse is a growing problem in many countries and can have an impact on their economies and social structures.
Utilization:
• Alkane usage as fuels.
• The role of ethene in fruit ripening.
• Alcohols, usage as fuel additives.
• Alcohols, role in the breathalyser.
• Esters, varied uses—perfumes, food flavourings, solvents, nitroglycerin, biofuels and painkillers.
Syllabus and cross-curricular links:
Topic 9.1—redox processes
Option A.5—polymers
Option B.3—lipids</td></tr>
</table>

10.2 Functional group chemistry	
Applications and skills: *Alkanes:* • Writing equations for the complete and incomplete combustion of hydrocarbons. • Explanation of the reaction of methane and ethane with halogens in terms of a free-radical substitution mechanism involving photochemical homolytic fission. *Alkenes:* • Writing equations for the reactions of alkenes with hydrogen and halogens and of symmetrical alkenes with hydrogen halides and water. • Outline of the addition polymerization of alkenes. • Relationship between the structure of the monomer to the polymer and repeating unit. *Alcohols:* • Writing equations for the complete combustion of alcohols. • Writing equations for the oxidation reactions of primary and secondary alcohols (using acidified potassium dichromate(VI) or potassium manganate(VII) as oxidizing agents). Explanation of distillation and reflux in the isolation of the aldehyde and carboxylic acid products. • Writing the equation for the condensation reaction of an alcohol with a carboxylic acid, in the presence of a catalyst (eg concentrated sulfuric acid) to form an ester. *Halogenoalkanes:* • Writing the equation for the substitution reactions of halogenoalkanes with aqueous sodium hydroxide.	**Aims:** • **Aim 6**: Experiments could include distinguishing between alkanes and alkenes, preparing soap and the use of gravity filtration, filtration under vacuum (using a Buchner flask), purification including recrystallization, reflux and distillation, melting point determination and extraction. • **Aim 8**: Discuss the significance of the hydrogenation of alkenes in the food production including *trans*-fats as by-products.

10.2 Functional group chemistry	
Guidance: • Reference should be made to initiation, propagation and termination steps in free-radical substitution reactions. Free radicals should be represented by a single dot. • The mechanisms of S_N1 and S_N2 and electrophilic substitution reactions are not required.	

Core

Topic 11: Measurement and data processing

10 hours

Essential idea: All measurement has a limit of precision and accuracy, and this must be taken into account when evaluating experimental results.

11.1 Uncertainties and errors in measurement and results

Nature of science:

Making quantitative measurements with replicates to ensure reliability—precision, accuracy, systematic, and random errors must be interpreted through replication. (3.2, 3.4)

Understandings:

- Qualitative data includes all non-numerical information obtained from observations not from measurement.
- Quantitative data are obtained from measurements, and are always associated with random errors/uncertainties, determined by the apparatus, and by human limitations such as reaction times.
- Propagation of random errors in data processing shows the impact of the uncertainties on the final result.
- Experimental design and procedure usually lead to systematic errors in measurement, which cause a deviation in a particular direction.
- Repeat trials and measurements will reduce random errors but not systematic errors.

Applications and skills:

- Distinction between random errors and systematic errors.
- Record uncertainties in all measurements as a range (±) to an appropriate precision.
- Discussion of ways to reduce uncertainties in an experiment.
- Propagation of uncertainties in processed data, including the use of percentage uncertainties.
- Discussion of systematic errors in all experimental work, their impact on the results and how they can be reduced.
- Estimation of whether a particular source of error is likely to have a major or

International-mindedness:

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

Theory of knowledge:

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

Utilization:

- Crash of the Mars Climate Orbiter spacecraft.
- Original results from CERN regarding the speed of neutrinos were flawed.

Syllabus and cross-curricular links:
Option D.1—drug trials

Aims:

- **Aim 6**: The distinction and different roles of Class A and Class B glassware could be explored.
- **Aim 8**: Consider the moral obligations of scientists to communicate the full extent of their data, including experimental uncertainties. The “cold fusion” case of Fleischmann and Pons in the 1990s is an example of when this was not fulfilled.

11.1 Uncertainties and errors in measurement and results	
minor effect on the final result. • Calculation of percentage error when the experimental result can be compared with a theoretical or accepted result. • Distinction between accuracy and precision in evaluating results. **Guidance:** • The number of significant figures in a result is based on the figures given in the data. When adding or subtracting, the final answer should be given to the least number of decimal places. When multiplying or dividing the final answer is given to the least number of significant figures. • Note that the data value must be recorded to the same precision as the random error. • SI units should be used throughout the programme.	

Essential idea: Graphs are a visual representation of trends in data.

11.2 Graphical techniques

Nature of science:

The idea of correlation—can be tested in experiments whose results can be displayed graphically. (2.8)

Understandings:	International-mindedness:
• Graphical techniques are an effective means of communicating the effect of an independent variable on a dependent variable, and can lead to determination of physical quantities. • Sketched graphs have labelled but unscaled axes, and are used to show qualitative trends, such as variables that are proportional or inversely proportional. • Drawn graphs have labelled and scaled axes, and are used in quantitative measurements. **Applications and skills:** • Drawing graphs of experimental results including the correct choice of axes and scale. • Interpretation of graphs in terms of the relationships of dependent and independent variables. • Production and interpretation of best-fit lines or curves through data points, including an assessment of when it can and cannot be considered as a linear function. • Calculation of quantities from graphs by measuring slope (gradient) and intercept, including appropriate units.	• Charts and graphs, which largely transcend language barriers, can facilitate communication between scientists worldwide. **Theory of knowledge:** • Graphs are a visual representation of data, and so use sense perception as a way of knowing. To what extent does their interpretation also rely on the other ways of knowing, such as language and reason? **Utilization:** • Graphical representations of data are widely used in diverse areas such as population, finance and climate modelling. Interpretation of these statistical trends can often lead to predictions, and so underpins the setting of government policies in many areas such as health and education. Syllabus and cross-curricular links: Topic 1.3—gas volume, temperature, pressure graphs Topic 6.1—Maxwell–Boltzmann frequency distribution; concentration–time and rate–concentration graphs Topic 16.2—Arrhenius plot to determine activation energy Topic 18.3—titration curves Option B.7—enzyme kinetics Option C.5—greenhouse effect; carbon dioxide concentration and global temperatures Option C.7—first order/decay graph **Aims:** • **Aim 7**: Graph-plotting software may be used, including the use of spreadsheets and the derivation of best-fit lines and gradients.

Essential idea: Analytical techniques can be used to determine the structure of a compound, analyse the composition of a substance or determine the purity of a compound. Spectroscopic techniques are used in the structural identification of organic and inorganic compounds.

11.3 Spectroscopic identification of organic compounds	
Nature of science: Improvements in instrumentation—mass spectrometry, proton nuclear magnetic resonance and infrared spectroscopy have made identification and structural determination of compounds routine. (1.8) Models are developed to explain certain phenomena that may not be observable—for example, spectra are based on the bond vibration model. (1.10)	
Understandings: • The degree of unsaturation or index of hydrogen deficiency (IHD) can be used to determine from a molecular formula the number of rings or multiple bonds in a molecule. • Mass spectrometry (MS), proton nuclear magnetic resonance spectroscopy (^{1}H NMR) and infrared spectroscopy (IR) are techniques that can be used to help identify compounds and to determine their structure. **Applications and skills:** • Determination of the IHD from a molecular formula. • Deduction of information about the structural features of a compound from percentage composition data, MS, ^{1}H NMR or IR. **Guidance:** • The electromagnetic spectrum (EMS) is given in the data booklet in section 3. The regions employed for each technique should be understood. • The operating principles are not required for any of these methods.	**International-mindedness:** • Monitoring and analysis of toxins and xenobiotics in the environment is a continuous endeavour that involves collaboration between scientists in different countries. **Theory of knowledge:** • Electromagnetic waves can transmit information beyond that of our sense perceptions. What are the limitations of sense perception as a way of knowing? **Utilization:** • IR spectroscopy is used in heat sensors and remote sensing in physics. • Protons in water molecules within human cells can be detected by magnetic resonance imaging (MRI), giving a three-dimensional view of organs in the human body. Syllabus and cross-curricular links: Topic 1.2—determination of the empirical formula from percentage composition data or from other experimental data and determination of the molecular formula from both the empirical formula and experimental data.

11.3 Spectroscopic identification of organic compounds	
• The data booklet contains characteristic ranges for IR absorptions (section 26), ^{1}H NMR data (section 27) and specific MS fragments (section 28). For ^{1}H NMR, only the ability to deduce the number of different hydrogen (proton) environments and the relative numbers of hydrogen atoms in each environment is required. Integration traces should be covered but splitting patterns are not required.	Topic 2.1—the nuclear atom Topic 5.3—bond enthalpies **Aims:** • **Aim 7**: Spectral databases could be used here. • **Aim 8**: The effects of the various greenhouse gases depend on their abundance and their ability to absorb heat radiation.

Topic 12: Atomic structure

2 hours

Essential idea: The quantized nature of energy transitions is related to the energy states of electrons in atoms and molecules.

12.1 Electrons in atoms

Nature of science:

Experimental evidence to support theories—emission spectra provide evidence for the existence of energy levels. (1.8)

Understandings:

- In an emission spectrum, the limit of convergence at higher frequency corresponds to the first ionization energy.
- Trends in first ionization energy across periods account for the existence of main energy levels and sub-levels in atoms.
- Successive ionization energy data for an element give information that shows relations to electron configurations.

Applications and skills:

- Solving problems using $E = h\nu$.
- Calculation of the value of the first ionization energy from spectral data which gives the wavelength or frequency of the convergence limit.
- Deduction of the group of an element from its successive ionization energy data.
- Explanation of the trends and discontinuities in first ionization energy across a period.

Guidance:

- The value of Planck's constant (*h*) and $E = h\nu$ are given in the data booklet in sections 1 and 2.
- Use of the Rydberg formula is not expected in calculations of ionization energy.

International-mindedness:

- In 2012 two separate international teams working at the Large Hadron Collider at CERN independently announced that they had discovered a particle with behaviour consistent with the previously predicted "Higgs boson".

Theory of knowledge:

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

Utilization:

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

Syllabus and cross-curricular links:
Topic 3.2—periodic trends
Topic 4.1—ionic bonding
Topic 15.1—lattice enthalpy

Aims:

- **Aim 7**: Databases could be used for compiling graphs of trends in ionization energies and simulations are available for the Davisson-Germer electron diffraction experiment.

Topic 13: The periodic table—the transition metals

4 hours

Essential idea: The transition elements have characteristic properties; these properties are related to their all having incomplete d sublevels.

13.1 First-row d-block elements

Nature of science:

Looking for trends and discrepancies—transition elements follow certain patterns of behaviour. The elements Zn, Cr and Cu do not follow these patterns and are therefore considered anomalous in the first-row d-block. (3.1)

Understandings:

- Transition elements have variable oxidation states, form complex ions with ligands, have coloured compounds, and display catalytic and magnetic properties.
- Zn is not considered to be a transition element as it does not form ions with incomplete d-orbitals.
- Transition elements show an oxidation state of +2 when the s-electrons are removed.

Applications and skills:

- Explanation of the ability of transition metals to form variable oxidation states from successive ionization energies.
- Explanation of the nature of the coordinate bond within a complex ion.
- Deduction of the total charge given the formula of the ion and ligands present.
- Explanation of the magnetic properties in transition metals in terms of unpaired electrons.

Guidance:

- Common oxidation charges on transition metal ions are given in section 9 of the data booklet, and common oxidation states are given in section 14.

International-mindedness:

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

Theory of knowledge:

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

Utilization:

Syllabus and cross-curricular links:
Topic 9.1—redox reactions
Topic 10.2—oxidation of alcohols, hydrogenation of alkenes
Option A.3—homogeneous and heterogeneous catalysis

Aims:

- **Aim 6**: The oxidation states of vanadium and manganese, for example, could be investigated experimentally. Transition metals could be analysed using redox titrations.
- **Aim 8**: Economic impact of the corrosion of iron.

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

13.2 Coloured complexes	
Nature of science: Models and theories—the colour of transition metal complexes can be explained through the use of models and theories based on how electrons are distributed in d-orbitals. (1.10) Transdisciplinary—colour linked to symmetry can be explored in the sciences, architecture, and the arts. (4.1)	
Understandings: • The d sub-level splits into two sets of orbitals of different energy in a complex ion. • Complexes of d-block elements are coloured, as light is absorbed when an electron is excited between the d-orbitals. • The colour absorbed is complementary to the colour observed. **Applications and skills:** • Explanation of the effect of the identity of the metal ion, the oxidation number of the metal and the identity of the ligand on the colour of transition metal ion complexes. • Explanation of the effect of different ligands on the splitting of the d-orbitals in transition metal complexes and colour observed using the spectrochemical series. **Guidance:** • The spectrochemical series is given in the data booklet in section 15. A list of polydentate ligands is given in the data booklet in section 16. • Students are not expected to recall the colour of specific complex ions.	**Utilization:** Syllabus and cross-curricular links: Topic 2.2—electron configuration of atoms and ions **Aims:** • **Aim 6**: The colours of a range of complex ions, of elements such as Cr, Fe, Co, Ni and Cu could be investigated. • **Aim 7**: Complex ions could be investigated using a spectrometer data logger. • **Aim 8**: The concentration of toxic transition metal ions needs to be carefully monitored in environmental systems.

13.2 Coloured complexes	
• The relation between the colour observed and absorbed is illustrated by the colour wheel in the data booklet in section 17. • Students are not expected to know the different splitting patterns and their relation to the coordination number. Only the splitting of the 3d orbitals in an octahedral crystal field is required.	

Topic 14: Chemical bonding and structure

7 hours

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

14.1 Further aspects of covalent bonding and structure

Nature of science:

Principle of Occam's razor—bonding theories have been modified over time. Newer theories need to remain as simple as possible while maximizing explanatory power, for example the idea of formal charge. (2.7)

Understandings:

- Covalent bonds result from the overlap of atomic orbitals. A sigma bond (σ) is formed by the direct head-on/end-to-end overlap of atomic orbitals, resulting in electron density concentrated between the nuclei of the bonding atoms. A pi bond (π) is formed by the sideways overlap of atomic orbitals, resulting in electron density above and below the plane of the nuclei of the bonding atoms.
- Formal charge (FC) can be used to decide which Lewis (electron dot) structure is preferred from several. The FC is the charge an atom would have if all atoms in the molecule had the same electronegativity. FC = (Number of valence electrons)-½(Number of bonding electrons)-(Number of non-bonding electrons). The Lewis (electron dot) structure with the atoms having FC values closest to zero is preferred.
- Exceptions to the octet rule include some species having incomplete octets and expanded octets.
- Delocalization involves electrons that are shared by/between more than one pair in a molecule or ion as opposed to being localized between a pair of atoms.
- Resonance involves using two or more Lewis (electron dot) structures to represent a particular molecule or ion. A resonance structure is one of two or more alternative Lewis (electron dot) structures for a molecule or ion that cannot be described fully with one Lewis (electron dot) structure alone.

International-mindedness:

- How has ozone depletion changed over time? What have we done as a global community to reduce ozone depletion?
- To what extent is ozone depletion an example of both a success and a failure for solving an international environmental concern?

Theory of knowledge:

- Covalent bonding can be described using valence bond or molecular orbital theory. To what extent is having alternative ways of describing the same phenomena a strength or a weakness?

Utilization:

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

Syllabus and cross-curricular links:
Topics 4.2 and 4.3—Lewis (electron dot) structures, VSEPR theory, resonance and bond and molecular polarity
Topic 10.1—shapes of organic molecules
Topic 13.1—transition metal chemistry

14.1 Further aspects of covalent bonding and structure

Applications and skills:

- Prediction whether sigma (σ) or pi (π) bonds are formed from the linear combination of atomic orbitals.
- Deduction of the Lewis (electron dot) structures of molecules and ions showing all valence electrons for up to six electron pairs on each atom.
- Application of FC to ascertain which Lewis (electron dot) structure is preferred from different Lewis (electron dot) structures.
- Deduction using VSEPR theory of the electron domain geometry and molecular geometry with five and six electron domains and associated bond angles.
- Explanation of the wavelength of light required to dissociate oxygen and ozone.
- Description of the mechanism of the catalysis of ozone depletion when catalysed by CFCs and NO_x.

Guidance:

- The linear combination of atomic orbitals to form molecular orbitals should be covered in the context of the formation of sigma (σ) and pi (π) bonds.
- Molecular polarities of geometries corresponding to five and six electron domains should also be covered.

Aims:

- **Aim 1**: Global impact of ozone depletion.
- **Aim 7**: Computer simulations can be used to model structures predicted by VSEPR theory.
- **Aim 8**: Moral, ethical, social, economic and environmental implications of ozone depletion and its solution.

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

14.2 Hybridization	
Nature of science: The need to regard theories as uncertain—hybridization in valence bond theory can help explain molecular geometries, but is limited. Quantum mechanics involves several theories explaining the same phenomena, depending on specific requirements. (2.2)	
Understandings: • A hybrid orbital results from the mixing of different types of atomic orbitals on the same atom. **Applications:** • Explanation of the formation of sp^3, sp^2 and sp hybrid orbitals in methane, ethene and ethyne. • Identification and explanation of the relationships between Lewis (electron dot) structures, electron domains, molecular geometries and types of hybridization. **Guidance:** • Students need only consider species with sp^3, sp^2 and sp hybridization.	**Theory of knowledge:** • Hybridization is a mathematical device which allows us to relate the bonding in a molecule to its symmetry. What is the relationship between the natural sciences, mathematics and the natural world? Which role does symmetry play in the different areas of knowledge? **Utilization:** Syllabus and cross-curricular links: Topic 4.3—Lewis (electron dot) structures, VSEPR theory, resonance and bond and molecular polarity Topic 10.1—shapes of organic molecules Topic 13.1—transition metal chemistry **Aims:** • **Aim 7**: Computer simulations could be used to model hybrid orbitals.

Topic 15: Energetics/thermochemistry

7 hours

Essential idea: The concept of the energy change in a single step reaction being equivalent to the summation of smaller steps can be applied to changes involving ionic compounds.

15.1 Energy cycles

Nature of science:

Making quantitative measurements with replicates to ensure reliability—energy cycles allow for the calculation of values that cannot be determined directly. (3.2)

Understandings	International-mindedness
Understandings: • Representative equations (eg $M^+(g) \rightarrow M^+(aq)$) can be used for enthalpy/energy of hydration, ionization, atomization, electron affinity, lattice, covalent bond and solution. • Enthalpy of solution, hydration enthalpy and lattice enthalpy are related in an energy cycle. **Applications and skills:** • Construction of Born-Haber cycles for group 1 and 2 oxides and chlorides. • Construction of energy cycles from hydration, lattice and solution enthalpy. For example dissolution of solid NaOH or NH_4Cl in water. • Calculation of enthalpy changes from Born-Haber or dissolution energy cycles. • Relate size and charge of ions to lattice and hydration enthalpies. • Perform lab experiments which could include single replacement reactions in aqueous solutions. **Guidance:** • Polarizing effect of some ions producing covalent character in some largely ionic substances will not be assessed. • The following enthalpy/energy terms should be covered: ionization, atomization, electron affinity, lattice, covalent bond, hydration and solution. • Value for lattice enthalpies (section 18), enthalpies of aqueous solutions (section 19) and enthalpies of hydration (section 20) are given in the data booklet.	**International-mindedness:** • The importance of being able to obtain measurements of something which cannot be measured directly is significant everywhere. Borehole temperatures, snow cover depth, glacier recession, rates of evaporation and precipitation cycles are among some indirect indicators of global warming. Why is it important for countries to collaborate to combat global problems like global warming? **Utilization:** • Other energy cycles—carbon cycle, the Krebs cycle and electron transfer in biology. Syllabus and cross-curricular links: Topics 1.2 and 1.3—stoichiometric relationships Topic 3.2—ionization energy, atomic and ionic radii Topic 5.3—bond enthalpy **Aims:** • **Aim 4**: Discuss the source of accepted values and use this idea to critique experiments. • **Aim 6**: A possible experiment is to calculate either the enthalpy of crystallization of water or the heat capacity of water when a cube of ice is added to hot water. • **Aim 7**: Use of data loggers to record temperature changes. Use of databases to source accepted values.

Essential idea: A reaction is spontaneous if the overall transformation leads to an increase in total entropy (system plus surroundings). The direction of spontaneous change always increases the total entropy of the universe at the expense of energy available to do useful work. This is known as the second law of thermodynamics.

15.2 Entropy and spontaneity

Nature of science:

Theories can be superseded—the idea of entropy has evolved through the years as a result of developments in statistics and probability. (2.2)

Understandings:

- Entropy (*S*) refers to the distribution of available energy among the particles. The more ways the energy can be distributed the higher the entropy.
- Gibbs free energy (*G*) relates the energy that can be obtained from a chemical reaction to the change in enthalpy (*ΔH*), change in entropy (*ΔS*), and absolute temperature (*T*).
- Entropy of gas>liquid>solid under same conditions.

Applications and skills:

- Prediction of whether a change will result in an increase or decrease in entropy by considering the states of the reactants and products.
- Calculation of entropy changes (*ΔS*) from given standard entropy values (S°).
- Application of $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ in predicting spontaneity and calculation of various conditions of enthalpy and temperature that will affect this.
- Relation of *ΔG* to position of equilibrium.

Guidance:

- Examine various reaction conditions that affect *ΔG*.
- *ΔG* is a convenient way to take into account both the direct entropy change resulting from the transformation of the chemicals, and the indirect entropy change of the surroundings as a result of the gain/loss of heat energy.
- Thermodynamic data is given in section 12 of the data booklet.

International-mindedness:

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

Theory of knowledge:

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

Utilization:

Syllabus and cross-curricular links:
Topic 5.2—Hess's Law
Topic 5.3—bond enthalpy
Topic 7.1—equilibrium
Option C.1—quality of energy
Physics option B.2—thermodynamics

Aims:

- **Aims 1**, **4** and **7**: Use of databases to research hypothetical reactions capable of generating free energy.
- **Aim 6**: Experiments investigating endothermic and exothermic processes could be run numerous times to compare reliability of repetitive data and compare to theoretical values.

Topic 16: Chemical kinetics

6 hours

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

16.1 Rate expression and reaction mechanism	
Nature of science: Principle of Occam's razor—newer theories need to remain as simple as possible while maximizing explanatory power. The low probability of three molecule collisions means stepwise reaction mechanisms are more likely. (2.7)	
Understandings: • Reactions may occur by more than one step and the slowest step determines the rate of reaction (rate determining step/RDS). • The molecularity of an elementary step is the number of reactant particles taking part in that step. • The order of a reaction can be either integer or fractional in nature. The order of a reaction can describe, with respect to a reactant, the number of particles taking part in the rate-determining step. • Rate equations can only be determined experimentally. • The value of the rate constant (*k*) is affected by temperature and its units are determined from the overall order of the reaction. • Catalysts alter a reaction mechanism, introducing a step with lower activation energy. **Applications and skills:** • Deduction of the rate expression for an equation from experimental data and solving problems involving the rate expression. • Sketching, identifying, and analysing graphical representations for zero, first and second order reactions. • Evaluation of proposed reaction mechanisms to be consistent with kinetic and stoichiometric data.	**International-mindedness:** • The first catalyst used in industry was for the production of sulfuric acid. Sulfuric acid production closely mirrored a country's economic health for a long time. What are some current indicators of a country's economic health? **Theory of knowledge:** • Reaction mechanism can be supported by indirect evidence. What is the role of empirical evidence in scientific theories? Can we ever be certain in science? **Utilization:** • Cancer research is all about identifying mechanisms; for carcinogens as well as cancer-killing agents and inhibitors. Syllabus and cross-curricular links: Topic 20.1—organic mechanisms especially S_N1 and S_N2 Option A.3—catalysts Biology topic 8.1—enzymes acting as catalysts **Aims:** • **Aim 7**: Databases, data loggers and other ICT applications can be used to research proposed mechanisms for lab work performed and to carry out virtual experiments to investigate factors which influence rate equations.

16.1 Rate expression and reaction mechanism	
Guidance: • Calculations will be limited to orders with whole number values. • Consider concentration against time and rate against concentration graphs. • Use potential energy level profiles to illustrate multi-step reactions; showing the higher E_a in the rate-determining step in the profile. • Catalysts are involved in the rate-determining step. • Reactions where the rate-determining step is not the first step should be considered. • Any experiment which allows students to vary concentrations to see the effect upon the rate and hence determine a rate equation is appropriate.	

Essential idea: The activation energy of a reaction can be determined from the effect of temperature on reaction rate.

16.2 Activation energy

Nature of science:

Theories can be supported or falsified and replaced by new theories—changing the temperature of a reaction has a much greater effect on the rate of reaction than can be explained by its effect on collision rates. This resulted in the development of the Arrhenius equation which proposes a quantitative model to explain the effect of temperature change on reaction rate. (2.5)

Understandings:

- The Arrhenius equation uses the temperature dependence of the rate constant to determine the activation energy.
- A graph of *1/T* against ln *k* is a linear plot with gradient – E_a / R and intercept, ln*A*.
- The frequency factor (or pre-exponential factor) (*A*) takes into account the frequency of collisions with proper orientations.

Applications and skills:

- Analysing graphical representation of the Arrhenius equation in its linear form $\ln k = \frac{-E_a}{RT} + \ln A$.
- Using the Arrhenius equation $k = A e^{\frac{-E_a}{RT}}$.
- Describing the relationships between temperature and rate constant; frequency factor and complexity of molecules colliding.
- Determining and evaluating values of activation energy and frequency factors from data.

Guidance:

- Use energy level diagrams to illustrate multi-step reactions showing the RDS in the diagram.
- Consider various data sources in using the linear expression $\ln k = \frac{-E_a}{RT} + \ln A$. The expression $\ln\frac{k_1}{k_2} = \frac{E_a}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$ is given in the data booklet.

Utilization:

- The flashing light of fireflies is produced by a chemical process involving enzymes.
- The relationship between the “lock and key” hypothesis of enzymes and the Arrhenius equation.

Syllabus and cross-curricular links:
Topic 6.1—collision theory

Aims:

- **Aims 4** and **7**: Use of simulations and virtual experiments to study effect of temperature and steric factors on rates of reaction.
- **Aim 6**: Experiments could include those involving the collection of temperature readings to obtain sufficient data for a graph.
- **Aim 7**: Graphing calculators can be employed to easily input and analyse data for E_a and frequency factor values.

Additional higher level

Topic 17: Equilibrium

4 hours

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

17.1 The equilibrium law	
Nature of science: Employing quantitative reasoning—experimentally determined rate expressions for forward and backward reactions can be deduced directly from the stoichiometric equations and allow Le Châtelier's principle to be applied. (1.8, 1.9)	
Understandings: • Le Châtelier's principle for changes in concentration can be explained by the equilibrium law. • The position of equilibrium corresponds to a maximum value of entropy and a minimum in the value of the Gibbs free energy. • The Gibbs free energy change of a reaction and the equilibrium constant can both be used to measure the position of an equilibrium reaction and are related by the equation, $\Delta G^{o} = -RT \ln K$. **Applications and skills:** • Solution of homogeneous equilibrium problems using the expression for K_c. • Relationship between ΔG^{o} and the equilibrium constant. • Calculations using the equation $\Delta G^{o} = -RT \ln K$. **Guidance:** • The expression $\Delta G^{o} = -RT \ln K$ is given in the data booklet in section 1. • Students will not be expected to derive the expression $\Delta G^{o} = -RT \ln K$. • The use of quadratic equations will not be assessed.	**Theory of knowledge:** • The equilibrium law can be deduced by assuming that the order of the forward and backward reaction matches the coefficients in the chemical equation. What is the role of deductive reasoning in science? • We can use mathematics successfully to model equilibrium systems. Is this because we create mathematics to mirror reality or because the reality is intrinsically mathematical? • Many problems in science can only be solved when assumptions are made which simplify the mathematics. What is the role of intuition in problem solving? **Utilization:** • The concept of a closed system in dynamic equilibrium can be applied to a range of systems in the biological, environmental and human sciences. Syllabus and cross-curricular links: Topic 1.3—stoichiometric equations Topic 7.1—equilibrium Topic 18.2—weak acid and base equilibria Option A.10—K_{sp} Options B.7 and D.4—buffer calculations

17.1 The equilibrium law	
	Aims: • **Aim 6**: The equilibrium constant for an esterification reaction and other reactions could be experimentally investigated. • **Aim 7**: The concept of a dynamic equilibrium can be illustrated with computer animations.

Additional higher level

Topic 18: Acids and bases

10 hours

Essential idea: The acid–base concept can be extended to reactions that do not involve proton transfer.

18.1 Lewis acids and bases	
Nature of science: Theories can be supported, falsified or replaced by new theories—acid–base theories can be extended to a wider field of applications by considering lone pairs of electrons. Lewis theory doesn't falsify Brønsted–Lowry but extends it. (2.5)	
Understandings: • A Lewis acid is a lone pair acceptor and a Lewis base is a lone pair donor. • When a Lewis base reacts with a Lewis acid a coordinate bond is formed. • A nucleophile is a Lewis base and an electrophile is a Lewis acid. **Applications and skills:** • Application of Lewis' acid–base theory to inorganic and organic chemistry to identify the role of the reacting species. **Guidance:** • Both organic and inorganic examples should be studied. • Relations between Brønsted–Lowry and Lewis acids and bases should be discussed.	**International-mindedness:** • Acid–base theory has developed from the ideas of people from different parts of the world through both collaboration and competition. **Theory of knowledge:** • The same phenomenon can sometimes be explored from different perspectives, and explained by different theories. For example, do we judge competing theories by their universality, simplicity or elegance? **Utilization:** Syllabus and cross-curricular links: Topics 4.2 and 4.3—covalent molecules and Lewis dot diagrams Topic 13.2—transition metal complexes Topic 20.1—nucleophiles **Aims:** • **Aim 6**: Transition metal complexes could be experimentally explored. • **Aim 7**: Animations can be used to distinguish between the different acid–base theories.

Essential idea: The equilibrium law can be applied to acid–base reactions. Numerical problems can be simplified by making assumptions about the relative concentrations of the species involved. The use of logarithms is also significant here.

<table>
<tr><th colspan="2">18.2 Calculations involving acids and bases</th></tr>
<tr><td colspan="2">Nature of science:
Obtaining evidence for scientific theories—application of the equilibrium law allows strengths of acids and bases to be determined and related to their molecular structure. (1.9)</td></tr>
<tr><td>Understandings:
• The expression for the dissociation constant of a weak acid (K_a) and a weak base (K_b).
• For a conjugate acid base pair, $K_a \times K_b = K_w$.
• The relationship between K_a and pK_a is ($pK_a = -\log K_a$), and between K_b and pK_b is ($pK_b = -\log K_b$).
Applications and skills:
• Solution of problems involving [H^+ (aq)], [OH^-(aq)], pH, pOH, K_a, pK_a, K_b and pK_b.
• Discussion of the relative strengths of acids and bases using values of K_a, pK_a, K_b and pK_b.
Guidance:
• The value K_w depends on the temperature.
• The calculation of pH in buffer solutions will only be assessed in options B.7 and D.4.
• Only examples involving the transfer of one proton will be assessed.
• Calculations of pH at temperatures other than 298 K can be assessed.
• Students should state when approximations are used in equilibrium calculations.
• The use of quadratic equations will not be assessed.</td>
<td>International-mindedness:
• Mathematics is a universal language. The mathematical nature of this topic helps chemists speaking different native languages to communicate more objectively.
Utilization:
Syllabus and cross-curricular links:
Topic 8.1—conjugate acid–base pairs
Topic 8.3—the pH concept
Topic 8.4—strong and weak acids and bases
Options B.7 and D.4—buffers
Aims:
• Aim 6: The properties of strong and weak acids could be investigated experimentally.</td></tr>
</table>

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

18.3 pH curves

Nature of science:

Increased power of instrumentation and advances in available techniques—development in pH meter technology has allowed for more reliable and ready measurement of pH. (3.7)

Understandings:

- The characteristics of the pH curves produced by the different combinations of strong and weak acids and bases.
- An acid–base indicator is a weak acid or a weak base where the components of the conjugate acid–base pair have different colours.
- The relationship between the pH range of an acid–base indicator, which is a weak acid, and its pK_a value.
- The buffer region on the pH curve represents the region where small additions of acid or base result in little or no change in pH.
- The composition and action of a buffer solution.

Applications and skills:

- The general shapes of graphs of pH against volume for titrations involving strong and weak acids and bases with an explanation of their important features.
- Selection of an appropriate indicator for a titration, given the equivalence point of the titration and the end point of the indicator.
- While the nature of the acid–base buffer always remains the same, buffer solutions can be prepared by either mixing a weak acid/base with a solution of a salt containing its conjugate, or by partial neutralization of a weak acid/base with a strong acid/base.
- Prediction of the relative pH of aqueous salt solutions formed by the different combinations of strong and weak acid and base.

Theory of knowledge:

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

Utilization:

Syllabus and cross-curricular links:

Topic 5.1—thermometric/conductiometric titrations

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

Aims:

- **Aim 6**: Experiments could include investigation of pH curves, determination of the pK_a of a weak acid, preparation and investigation of a buffer solution and the determination of the pK_a of an indicator.
- **Aim 7**: Data logging, databases, spreadsheets and simulations can all be used. For example, the equivalence point could be determined by using a conductivity probe or a temperature probe.

18.3 pH curves	
Guidance: • Only examples involving the transfer of one proton will be assessed. Important features are: – intercept with pH axis – equivalence point – buffer region – points where pK_a = pH or pK_b = pOH. • For an indicator which is a weak acid: – $HIn(aq) \rightleftharpoons H^+(aq) + In^-(aq)$ Colour A Colour B – The colour change can be considered to take place over a range of $pK_a \pm 1$. • For an indicator which is a weak base: – $BOH(aq) \rightleftharpoons B^+(aq) + OH^-(aq)$ Colour A Colour B • Examples of indicators are listed in the data booklet in section 22. • Salts formed from the four possible combinations of strong and weak acids and bases should be considered. Calculations are not required.	

Additional higher level

Topic 19: Redox processes

6 hours

Essential idea: Energy conversions between electrical and chemical energy lie at the core of electrochemical cells.

19.1 Electrochemical cells

Nature of science:

Employing quantitative reasoning—electrode potentials and the standard hydrogen electrode. (3.1)

Collaboration and ethical implications—scientists have collaborated to work on electrochemical cell technologies and have to consider the environmental and ethical implications of using fuel cells and microbial fuel cells. (4.5)

Understandings:

- A voltaic cell generates an electromotive force (EMF) resulting in the movement of electrons from the anode (negative electrode) to the cathode (positive electrode) via the external circuit. The EMF is termed the cell potential (E°).
- The standard hydrogen electrode (SHE) consists of an inert platinum electrode in contact with 1 mol dm^{-3} hydrogen ion and hydrogen gas at 100 kPa and 298 K. The standard electrode potential (E°) is the potential (voltage) of the reduction half-equation under standard conditions measured relative to the SHE. Solute concentration is 1 mol dm^{-3} or 100 kPa for gases. E° of the SHE is 0 V.
- When aqueous solutions are electrolysed, water can be oxidized to oxygen at the anode and reduced to hydrogen at the cathode.
- $\Delta G^{\circ} = -nFE^{\circ}$. When E° is positive, ΔG° is negative indicative of a spontaneous process. When E° is negative, ΔG° is positive indicative of a non-spontaneous process. When E° is 0, then ΔG° is 0.
- Current, duration of electrolysis and charge on the ion affect the amount of product formed at the electrodes during electrolysis.
- Electroplating involves the electrolytic coating of an object with a metallic thin layer.

International-mindedness:

- Many electrochemical cells can act as energy sources alleviating the world's energy problems but some cells such as super-efficient microbial fuel cells (MFCs) (also termed biological fuel cells) can contribute to clean-up of the environment. How do national governments and the international community decide on research priorities for funding purposes?

Theory of knowledge:

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

Utilization:

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

Syllabus and cross-curricular links:
Topics 1.2 and 1.3—problems involving Avogadro's constant, amount of substance and the ideal gas equation
Topic 9.1—redox processes

19.1 Electrochemical cells

Applications and skills:

- Calculation of cell potentials using standard electrode potentials.
- Prediction of whether a reaction is spontaneous or not using E^{o} values.
- Determination of standard free-energy changes (ΔG^{o}) using standard electrode potentials.
- Explanation of the products formed during the electrolysis of aqueous solutions.
- Perform lab experiments that could include single replacement reactions in aqueous solutions.
- Determination of the relative amounts of products formed during electrolytic processes.
- Explanation of the process of electroplating.

Guidance:

- Electrolytic processes to be covered in theory should include the electrolysis of aqueous solutions (eg sodium chloride, copper(II) sulfate etc) and water using both inert platinum or graphite electrodes and copper electrodes. Explanations should refer to E° values, nature of the electrode and concentration of the electrolyte.
- $\Delta G^{\circ} = -nFE^{\circ}$ is given in the data booklet in section 1.
- Faraday's constant = 96 500 C mol^{-1} is given in the data booklet in section 2.
- The term "cells in series" should be understood.

Topic 15.2—spontaneity of a reaction
Option C.6—Nernst equation
Biology option B.3—environmental protection; waste treatment and microbial fuel cells

Aims:

- **Aim 8**: Biological fuel cells can produce electrical energy to power electrical devices, houses, factories etc. They can assist in environmental clean-up. Microbial fuel cells (MFCs) powered by microbes in sewage can clean up sewage which may result in cost-free waste water treatment.

Topic 20: Organic chemistry

12 hours

Essential idea: Key organic reaction types include nucleophilic substitution, electrophilic addition, electrophilic substitution and redox reactions. Reaction mechanisms vary and help in understanding the different types of reaction taking place.

20.1 Types of organic reactions

Nature of science:

Looking for trends and discrepancies—by understanding different types of organic reactions and their mechanisms, it is possible to synthesize new compounds with novel properties which can then be used in several applications. Organic reaction types fall into a number of different categories. (3.1)

Collaboration and ethical implications—scientists have collaborated to work on investigating the synthesis of new pathways and have considered the ethical and environmental implications of adopting green chemistry. (4.1, 4.5)

Understandings:

Nucleophilic Substitution Reactions:

- S_N1 represents a nucleophilic unimolecular substitution reaction and S_N2 represents a nucleophilic bimolecular substitution reaction. S_N1 involves a carbocation intermediate. S_N2 involves a concerted reaction with a transition state.
- For tertiary halogenoalkanes the predominant mechanism is S_N1 and for primary halogenoalkanes it is S_N2. Both mechanisms occur for secondary halogenoalkanes.
- The rate determining step (slow step) in an S_N1 reaction depends only on the concentration of the halogenoalkane, rate = *k*[halogenoalkane]. For S_N2, rate = *k*[halogenoalkane][nucleophile]. S_N2 is stereospecific with an inversion of configuration at the carbon.
- S_N2 reactions are best conducted using aprotic, polar solvents and S_N1 reactions are best conducted using protic, polar solvents.

Electrophilic Addition Reactions:

- An electrophile is an electron-deficient species that can accept electron pairs from a nucleophile. Electrophiles are Lewis acids.

International-mindedness:

- What role does green and sustainable chemistry, in relation to organic chemistry, play in a global context?

Utilization:

- Organic synthesis plays a vital role in drug design and drug uptake in medicine and biochemistry.
- Nutrition, food science and biotechnology also are underpinned by organic chemistry.

Syllabus and cross-curricular links:
Topics 10.1 and 10.2—organic chemistry
Topic 14.1—covalent bonding
Topic 14.2—hybridization
Option A.5 and A.9—polymers

Aims:

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

20.1 Types of organic reactions	
• Markovnikov's rule can be applied to predict the major product in electrophilic addition reactions of unsymmetrical alkenes with hydrogen halides and interhalogens. The formation of the major product can be explained in terms of the relative stability of possible carbocations in the reaction mechanism. *Electrophilic Substitution Reactions:* • Benzene is the simplest aromatic hydrocarbon compound (or arene) and has a delocalized structure of π bonds around its ring. Each carbon to carbon bond has a bond order of 1.5. Benzene is susceptible to attack by electrophiles. *Reduction Reactions:* • Carboxylic acids can be reduced to primary alcohols (via the aldehyde). Ketones can be reduced to secondary alcohols. Typical reducing agents are lithium aluminium hydride (used to reduce carboxylic acids) and sodium borohydride. **Applications and skills:** *Nucleophilic Substitution Reactions:* • Explanation of why hydroxide is a better nucleophile than water. • Deduction of the mechanism of the nucleophilic substitution reactions of halogenoalkanes with aqueous sodium hydroxide in terms of S_N1 and S_N2 mechanisms. Explanation of how the rate depends on the identity of the halogen (ie the leaving group), whether the halogenoalkane is primary, secondary or tertiary and the choice of solvent. • Outline of the difference between protic and aprotic solvents. *Electrophilic Addition Reactions:* • Deduction of the mechanism of the electrophilic addition reactions of alkenes with halogens/interhalogens and hydrogen halides.	• **Aim 6**: A range of experiments of organic synthetic reactions exploring various types of reactions and functional group interconversions could be done. Core techniques of organic chemistry could include reflux, distillation, filtration, purification (including chromatographic techniques), separations and extractions. • **Aim 6**: Synthesis (or reaction) in the laboratory of an example of a widely used drug or medicine (eg aspirin) or a household product (eg fading of tomato ketchup—electrophilic addition reaction of bromine).

20.1 Types of organic reactions

Electrophilic Substitution Reactions:

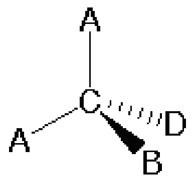
- Deduction of the mechanism of the nitration (electrophilic substitution) reaction of benzene (using a mixture of concentrated nitric acid and sulfuric acid).

Reduction Reactions:

- Writing reduction reactions of carbonyl containing compounds: aldehydes and ketones to primary and secondary alcohols and carboxylic acids to aldehydes, using suitable reducing agents.
- Conversion of nitrobenzene to phenylamine via a two-stage reaction.

Guidance:

- Reference should be made to heterolytic fission for S_N1 reactions.
- The difference between homolytic and heterolytic fission should be understood.
- The difference between curly arrows and fish-hooks in reaction mechanisms should be emphasized.
- Use of partial charges (δ+ and δ-) and wedge-dash three-dimensional representations (using tapered bonds as shown below) should be encouraged where appropriate in explaining reaction mechanisms.



- Typical conditions and reagents of all reactions should be known (eg catalysts, reducing agents, reflux etc.). However, more precise details such as specific temperatures need not be included.

Essential idea: Organic synthesis is the systematic preparation of a compound from a widely available starting material or the synthesis of a compound via a synthetic route that often can involve a series of different steps.

20.2 Synthetic routes

Nature of science:

Scientific method—in synthetic design, the thinking process of the organic chemist is one which invokes retro-synthesis and the ability to think in a reverse-like manner. (1.3)

Understandings:

- The synthesis of an organic compound stems from a readily available starting material via a series of discrete steps. Functional group interconversions are the basis of such synthetic routes.
- Retro-synthesis of organic compounds.

Applications and skills:

- Deduction of multi-step synthetic routes given starting reagents and the product(s).

Guidance:

- Conversions with more than four stages will not be assessed in synthetic routes.
- Reaction types can cover any of the reactions covered in topic 10 and sub-topic 20.1.

International-mindedness:

- How important are natural products to developing countries? Explore some specific examples of natural products available in developing countries which are important to the developed world.

Theory of knowledge:

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

Utilization:

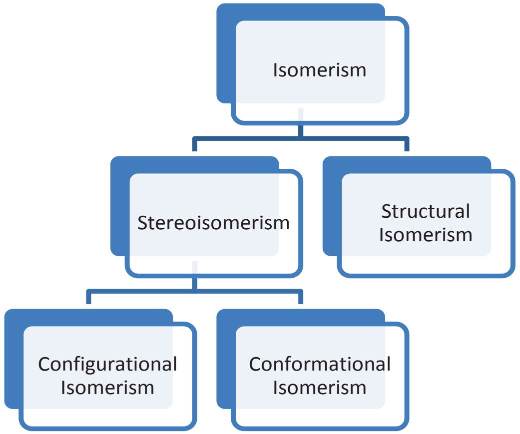
- Natural products are compounds isolated from natural sources and include taxol, mescaline and capsaicin.

Syllabus and cross-curricular links:
Topics 10.1 and 10.2—organic chemistry

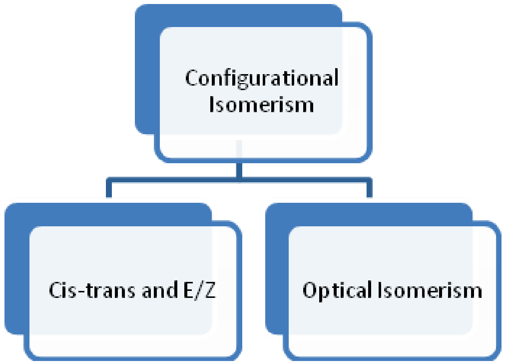
Aims:

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

Essential idea: Stereoisomerism involves isomers which have different arrangements of atoms in space but do not differ in connectivity or bond multiplicity (ie whether single, double or triple) between the isomers themselves.

20.3 Stereoisomerism	
Nature of science: Transdisciplinary—the three-dimensional shape of an organic molecule is the foundation pillar of its structure and often its properties. Much of the human body is chiral. (4.1)	
Understandings: • Stereoisomers are subdivided into two classes—conformational isomers, which interconvert by rotation about a σ bond and configurational isomers that interconvert only by breaking and reforming a bond.  Configurational isomers are further subdivided into cis-trans and E/Z isomers and optical isomers.	**International-mindedness:** • Have drugs and medicines in some countries been sold and administered as racemates instead of as the desired enantiomer with the associated therapeutic activity? Can you think of any drugs or medicines which may serve as good case studies for this? **Theory of knowledge:** • The existence of optical isomers provide indirect evidence for a tetrahedrally bonded carbon atom. Which ways of knowing allow us to connect indirect evidence to our theories? • Stereoisomerism can be investigated by physical and computer models. What is the role of such models in other areas of knowledge? • One of the challenges for the scientist and the artist is to represent the three-dimensional world in two dimensions. What are the similarities and differences in the two approaches? What is the role of the different ways of knowing in the two approaches? **Utilization:** • Many of the drugs derived from natural sources are chiral and include nicotine, dopamine, thyroxine and naproxen. • The role of stereochemistry in vision science and food science. • In many perfumes, stereochemistry often can be deemed more important than chemical composition. Syllabus and cross-curricular links:

20.3 Stereoisomerism



- Cis-trans isomers can occur in alkenes or cycloalkanes (or heteroanalogues) and differ in the positions of atoms (or groups) relative to a reference plane. According to IUPAC, E/Z isomers refer to alkenes of the form R1R2C=CR3R4 (R1 ≠ R2, R3 ≠ R4) where neither R1 nor R2 need be different from R3 or R4.
- A chiral carbon is a carbon joined to four different atoms or groups.
- An optically active compound can rotate the plane of polarized light as it passes through a solution of the compound. Optical isomers are enantiomers. Enantiomers are non-superimposeable mirror images of each other. Diastereomers are not mirror images of each other.
- A racemic mixture (or racemate) is a mixture of two enantiomers in equal amounts and is optically inactive.

Applications and skills:

- Construction of 3-D models (real or virtual) of a wide range of stereoisomers.
- Explanation of stereoisomerism in non-cyclic alkenes and C3 and C4 cycloalkanes.

Topics 10.1 and 10.2—organic chemistry
Option B.4—carbohydrates
Option B.10—stereochemistry in biomolecules
Option D.7—importance of chirality and drug action

Aims

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

20.3 Stereoisomerism	
• Comparison between the physical and chemical properties of enantiomers. • Description and explanation of optical isomers in simple organic molecules. • Distinction between optical isomers using a polarimeter. **Guidance:** • The term geometric isomers as recommended by IUPAC is now obsolete and cis-trans isomers and E/Z isomers should be encouraged in the teaching programme. • In the E/Z system, the group of highest Cahn–Ingold–Prelog priority attached to one of the terminal doubly bonded atoms of the alkene (ie R1 or R2) is compared with the group of highest precedence attached to the other (ie R3 or R4). The stereoisomer is Z if the groups lie on the same side of a reference plane passing through the double bond and perpendicular to the plane containing the bonds linking the groups to the double-bonded atoms; the other stereoisomer is designated as E. • Wedge-dash type representations involving tapered bonds should be used for representations of optical isomers.	

Topic 21: Measurement and analysis

2 hours

Essential idea: Although spectroscopic characterization techniques form the backbone of structural identification of compounds, typically no one technique results in a full structural identification of a molecule.

21.1 Spectroscopic identification of organic compounds	
Nature of science: Improvements in modern instrumentation—advances in spectroscopic techniques (IR, ^{1}H NMR and MS) have resulted in detailed knowledge of the structure of compounds. (1.8)	
Understandings: • Structural identification of compounds involves several different analytical techniques including IR, ^{1}H NMR and MS. • In a high resolution ^{1}H NMR spectrum, single peaks present in low resolution can split into further clusters of peaks. • The structural technique of single crystal X-ray crystallography can be used to identify the bond lengths and bond angles of crystalline compounds. **Applications and skills:** • Explanation of the use of tetramethylsilane (TMS) as the reference standard. • Deduction of the structure of a compound given information from a range of analytical characterization techniques (X-ray crystallography, IR, ^{1}H NMR and MS). **Guidance:** • Students should be able to interpret the following from ^{1}H NMR spectra: number of signals, area under each signal, chemical shift and splitting patterns. Treatment of spin-spin coupling constants will not be assessed but students should be familiar with singlets, doublets, triplets and quartets. • High resolution ^{1}H NMR should be covered.	**International-mindedness:** • The chemical community often shares chemical structural information on the international stage. The Cambridge Crystallographic Database, ChemSpider developed by the *Royal Society of Chemistry* and the *Protein Data Bank (RCSB PDB)* (at Brookhaven National Laboratory, USA) are examples which highlight the international nature of the scientific community. **Theory of knowledge:** • The intensity ratio of the lines in the high resolution NMR spectrum is given by the numbers in Pascal's triangle, a mathematical pattern known independently over a thousand years ago by a number of different cultures. Why is mathematics such an effective tool in science? Is mathematics the science of patterns? **Utilization:** • Protons in water molecules within human cells can be detected by magnetic resonance imaging (MRI), giving a three-dimensional view of organs in the human body. Why is MRI replacing computerized tomography (CT) scans for some applications but is used as a complementary technique for others? • MS (and other techniques such as TLC, GC, GC-MS and HPLC) can be used in forensic investigations at crime scenes. • Analytical techniques can be used to test for drug abuse by high-performance athletes.

21.1 Spectroscopic identification of organic compounds	
• The precise details of single crystal X-ray crystallography need not be known in detail, but students should be aware of the existence of this structural technique in the wider context of structural identification of both inorganic and organic compounds. • The operating principles are not required for any of these methods.	Syllabus and cross-curricular links: Topic 11.3—spectroscopic identification of compounds Option B.2—chromatography and protein separation Option B.9—chromatography and pigments Option D.7—chiral auxiliaries **Aims:** • **Aim 7**: Spectral databases can be used here.

Core topics

Essential idea: Materials science involves understanding the properties of a material, and then applying those properties to desired structures.

<table>
<tr><th colspan="2">A.1 Materials science introduction</th></tr>
<tr><td colspan="2">Nature of science:
Improvements in technology—different materials were used for different purposes before the development of a scientific understanding of their properties. (1.8)
Patterns in science—history has characterized civilizations by the materials they used: Stone Age, Bronze Age and Iron Age. There are various ways of classifying materials according to desired patterns. (3.1)</td></tr>
<tr><td>Understandings:
• Materials are classified based on their uses, properties, or bonding and structure.
• The properties of a material based on the degree of covalent, ionic or metallic character in a compound can be deduced from its position on a bonding triangle.
• Composites are mixtures in which materials are composed of two distinct phases, a reinforcing phase that is embedded in a matrix phase.
Applications and skills:
• Use of bond triangle diagrams for binary compounds from electronegativity data.
• Evaluation of various ways of classifying materials.
• Relating physical characteristics (melting point, permeability, conductivity, elasticity, brittleness) of a material to its bonding and structures (packing arrangements, electron mobility, ability of atoms to slide relative to one another).</td><td>International-mindedness:
• What materials were used by ancient civilizations, such as the Aztecs, Romans, and Chinese? Even though these ancient civilizations were located in geographically diverse locations, the materials they used were similar.
Theory of knowledge:
• Although it is convenient to classify materials into categories no single classification is “perfect”. How do we evaluate the different classification systems we use in the different areas of knowledge? How does our need to categorize the world help and hinder the pursuit of knowledge?
Utilization:
Syllabus and cross-curricular links:
Topic 4.2—the role of electronegativity in bonding types</td></tr>
</table>

A.1 Materials science introduction	
Guidance: • Permeability to moisture should be considered with respect to bonding and simple packing arrangements. • Consider properties of metals, polymers and ceramics in terms of metallic, covalent, and ionic bonding. • See section 29 of the data booklet for a triangular bonding diagram.	**Aims:** • **Aims 1** and **3**: Investigation of tetrahedra of structure and bonding types and where covalent networks and polymers fit on these diagrams. • **Aim 6**: Experiments could include investigating the stretching of rubber bands under different chemical environments, or properties of metals, polymers, ceramics, or composites, making thin concrete slabs from various ratios of cement, gravel, and sand and investigating the breaking strength upon drying.

Essential idea: Metals can be extracted from their ores and alloyed for desired characteristics. ICP-MS/OES Spectroscopy ionizes metals and uses mass and emission spectra for analysis.

<table>
<tr><td colspan="2">A.2 Metals and inductively coupled plasma (ICP) spectroscopy</td></tr>
<tr><td colspan="2">Nature of science:
Development of new instruments and techniques—ICP spectroscopy, developed from an understanding of scientific principles, can be used to identify and quantify trace amounts of metals. (1.8)
Details of data—with the discovery that trace amounts of certain materials can greatly enhance a metal's performance, alloying was initially more of an art than a science. (3.1)</td></tr>
<tr><td>Understandings:
• Reduction by coke (carbon), a more reactive metal, or electrolysis are means of obtaining some metals from their ores.
• The relationship between charge and the number of moles of electrons is given by Faraday's constant, F.
• Alloys are homogeneous mixtures of metals with other metals or non-metals.
• Diamagnetic and paramagnetic compounds differ in electron spin pairing and their behaviour in magnetic fields.
• Trace amounts of metals can be identified and quantified by ionizing them with argon gas plasma in Inductively Coupled Plasma (ICP) Spectroscopy using Mass Spectroscopy ICP-MS and Optical Emission Spectroscopy ICP-OES.
Applications and skills:
• Deduction of redox equations for the reduction of metals.
• Relating the method of extraction to the position of a metal on the activity series.
• Explanation of the production of aluminium by the electrolysis of alumina in molten cryolite
• Explanation of how alloying alters properties of metals.</td>
<td>International-mindedness:
• The use of rare earth metals, or exotic minerals, has grown dramatically. They are used in green technology, medicines, lasers, weapons technology and elsewhere. They are expensive to obtain but growing in demand. What happens if rare earth reserves are controlled only by a few countries but are used by many countries?
Theory of knowledge:
• What factors/outcomes should be used to determine how time, money, and effort is spent on scientific research? Who decides which knowledge is to be pursued?
Utilization:
Syllabus and cross-curricular links:
Topics 2.1 and 12.1—mass spectrometry
Topic 2.2—emission spectra
Topic 9.1—oxidation and reduction
Aims:
• Aim 6: Experiments could include calculating the Faraday constant via electrolysis of aqueous copper sulfate, solving for the concentration of a nickel or copper solution using Beer's law and spectrophotometry. Analysis of alloy composition labs could also be conducted such as colorimetric determination of manganese in a paper clip or gravimetric analysis of silver or copper in a coin.</td></tr>
</table>

A.2 Metals and inductively coupled plasma (ICP) spectroscopy	
• Solving stoichiometric problems using Faraday's constant based on mass deposits in electrolysis. • Discussion of paramagnetism and diamagnetism in relation to electron structure of metals. • Explanation of the plasma state and its production in ICP- MS/OES. • Identify metals and abundances from simple data and calibration curves provided from ICP-MS and ICP-OES. • Explanation of the separation and quantification of metallic ions by MS and OES. • Uses of ICP-MS and ICP-OES. **Guidance:** • Faraday's constant is given in the data booklet in section 2. • Details of operating parts of ICP-MS and ICP-OES instruments will not be assessed. • Only analysis of metals should be covered. • The importance of calibration should be covered.	• **Aim 7**: Animations involving ICP could be used. • **Aim 7**: Simulations and virtual experiments could be used to investigate semiconductors.

Essential idea: Catalysts work by providing an alternate reaction pathway for the reaction. Catalysts always increase the rate of the reaction and are left unchanged at the end of the reaction.

<table>
<tr><th colspan="2">A.3 Catalysts</th></tr>
<tr><td colspan="2">Nature of science:
Use of models—catalysts were used to increase reaction rates before the development of an understanding of how they work. This led to models that are constantly being tested and improved. (1.10)</td></tr>
<tr><td>Understandings:
• Reactants adsorb onto heterogeneous catalysts at active sites and the products desorb.
• Homogeneous catalysts chemically combine with the reactants to form a temporary activated complex or a reaction intermediate.
• Transition metal catalytic properties depend on the adsorption/absorption properties of the metal and the variable oxidation states.
• Zeolites act as selective catalysts because of their cage structure.
• Catalytic particles are nearly always nanoparticles that have large surface areas per unit mass.
Applications and skills:
• Explanation of factors involved in choosing a catalyst for a process.
• Description of how metals work as heterogeneous catalysts.
• Description of the benefits of nanocatalysts in industry.
Guidance:
• Consider catalytic properties such as selectivity for only the desired product, efficiency, ability to work in mild/severe conditions, environmental impact and impurities.
• The use of carbon nanocatalysts should be covered.</td>
<td>International-mindedness:
• Palladium, platinum and rhodium are common catalysts that are used in catalytic converters. Because of the value of these metals, catalytic converter thefts are on the rise.
Theory of knowledge:
• Some materials used as effective catalysts are toxic and harmful to the environment. Is environmental degradation justified in the pursuit of knowledge?
Utilization:
Syllabus and cross-curricular links:
Topics 6.1 and 16.1—reaction mechanisms
Topic 10.2—esterification and hydrogenation reactions
Topic 16.2—activation energy
Option B.10—hydrogenation of fats
Aims:
• Aims 1 and 3: Investigate various catalysts for both the benefits and risks.
• Aim 6: Experiments could include investigating the decomposition of potassium sodium tartrate with cobalt chloride and the decomposition of hydrogen peroxide with manganese (IV) oxide.
• Aim 6: An ion exchange using zeolite could be explored.
• Aim 7: Virtual experiments and simulations involving nanoparticles as catalysts could be done here.</td></tr>
</table>

Essential idea: Liquid crystals are fluids that have physical properties which are dependent on molecular orientation relative to some fixed axis in the material.

A.4 Liquid crystals

Nature of science

Serendipity and scientific discoveries—Friedrich Reinitzer accidently discovered flowing liquid crystals in 1888 while experimenting on cholesterol benzoate. (1.4)

Understandings:

- Liquid crystals are fluids that have physical properties (electrical, optical and elasticity) that are dependent on molecular orientation to some fixed axis in the material.
- Thermotropic liquid-crystal materials are pure substances that show liquid-crystal behaviour over a temperature range.
- Lyotropic liquid crystals are solutions that show the liquid-crystal state over a (certain) range of concentrations.
- Nematic liquid crystal phase is characterized by rod shaped molecules which are randomly distributed but on average align in the same direction.

Applications and skills:

- Discussion of the properties needed for a substance to be used in liquid-crystal displays (LCD).
- Explanation of liquid-crystal behaviour on a molecular level.

Guidance:

- Properties needed for liquid crystals include: chemically stable, a phase which is stable over a suitable temperature range, polar so they can change orientation when an electric field is applied, and rapid switching speed.
- Soap and water is an example of lyotropic liquid crystals and the biphenyl nitriles are examples of thermotropic liquid crystals.
- Liquid crystal behaviour should be limited to the biphenyl nitriles.
- Smectics and other liquid crystals types need not be discussed.

International-mindedness:

- The production of many electronic goods is concentrated in areas of the world where the working conditions may not be ideal. Should there be internationally set labour standards for all workers? What implications would this have on the cost of consumer goods?

Theory of knowledge:

- Developments in technology mean that we can store more and more information available on an increasingly smaller scale. Does this mean that we can access more knowledge?

Utilization:

Syllabus and cross-curricular links:
Topic 20.3—chirality and stereoisomers

Aims:

- **Aim 6**: Experiments could include investigating a thermotropic liquid crystal and the temperature range which affects these crystals.
- **Aim 7**: Computer animations could be used to investigate thermotropic liquid crystals.

Essential idea: Polymers are made up of repeating monomer units which can be manipulated in various ways to give structures with desired properties.

A.5 Polymers	
Nature of science: Advances in technology—as a result of advances in technology (X-ray diffraction, scanning tunnelling electron microscopes, etc), scientists have been able to understand what occurs on the molecular level and manipulate matter in new ways. This allows new polymers to be developed. (3.7) Theories can be superseded—Staudinger's proposal of macromolecules made of many repeating units was integral in the development of polymer science. (1.9) Ethics and risk assessment—polymer development and use has grown quicker than an understanding of the risks involved, such as recycling or possible carcinogenic properties. (4.5)	
Understandings: • Thermoplastics soften when heated and harden when cooled. • A thermosetting polymer is a prepolymer in a soft solid or viscous state that changes irreversibly into a hardened thermoset by curing. • Elastomers are flexible and can be deformed under force but will return to nearly their original shape once the stress is released. • High density polyethene (HDPE) has no branching allowing chains to be packed together. • Low density polyethene (LDPE) has some branching and is more flexible. • Plasticizers added to a polymer increase the flexibility by weakening the intermolecular forces between the polymer chains. • Atom economy is a measure of efficiency applied in green chemistry. • Isotactic addition polymers have substituents on the same side. • Atactic addition polymers have the substituents randomly placed. **Applications and skills:** • Description of the use of plasticizers in polyvinyl chloride and volatile hydrocarbons in the formation of expanded polystyrene.	**International-mindedness:** • Plastics were virtually unheard of prior to the second world war. How has the introduction of plastics affected the world economically, socially and environmentally? **Utilization:** Syllabus and cross-curricular links: Topics 10.2 and 20.1—addition and condensation reactions **Aims:** • **Aim 6**: Physical properties of high and low density polyethene could be investigated or synthesis of a polyester, polyamide or other polymer could be quantitatively performed to measure atom efficiency.

A.5 Polymers	
• Solving problems and evaluating atom economy in synthesis reactions. • Description of how the properties of polymers depend on their structural features. • Description of ways of modifying the properties of polymers, including LDPE and HDPE. • Deduction of structures of polymers formed from polymerizing 2-methylpropene. **Guidance:** • The equation for percent atom economy is provided in the data booklet in section 1. • Consider only polystyrene foams as examples of polymer property manipulation.	

Essential idea: Chemical techniques position atoms in molecules using chemical reactions whilst physical techniques allow atoms/molecules to be manipulated and positioned to specific requirements.

A.6 Nanotechnology

Nature of science:

Improvements in apparatus—high power electron microscopes have allowed for the study of positioning of atoms. (1.8)

The need to regard theories as uncertain—the role of trial and error in the development of nanotubes and their associated theories. (2.2)

"The principles of physics, as far as I can see, do not speak against the possibility of manoeuvring things atom by atom. It is not an attempt to violate any laws; it is something, in principle, that can be done; but in practice, it has not been done because we are too big."
— Richard Feynman, Nobel Prize winner in Physics

Understandings:

- Molecular self-assembly is the bottom-up assembly of nanoparticles and can occur by selectively attaching molecules to specific surfaces. Self-assembly can also occur spontaneously in solution.
- Possible methods of producing nanotubes are arc discharge, chemical vapour deposition (CVD) and high pressure carbon monoxide (HIPCO).
- Arc discharge involves either vaporizing the surface of one of the carbon electrodes, or discharging an arc through metal electrodes submersed in a hydrocarbon solvent, which forms a small rod-shaped deposit on the anode.

Applications and skills:

- Distinguishing between physical and chemical techniques in manipulating atoms to form molecules.
- Description of the structure and properties of carbon nanotubes.
- Explanation of why an inert gas, and not oxygen, is necessary for CVD preparation of carbon nanotubes.
- Explanation of the production of carbon from hydrocarbon solvents in arc discharge by oxidation at the anode.
- Deduction of equations for the production of carbon atoms from HIPCO.

International-mindedness:

- Some studies have shown that inhaling nanoparticle dust can be as harmful as asbestos. Should nanotechnology be regulated or will this hinder research?
- International collaboration in space exploration is growing. Would a carbon nanotube space elevator be feasible, or wanted? What are the implications?

Theory of knowledge:

- The use of the scanning tunnelling microscope has allowed us to "see" individual atoms, which was previously thought to be unattainable. How do these advances in technology change our view of what knowledge is attainable?
- Some people are concerned about the possible implication of nanotechnology. How do we evaluate the possible consequences of future developments in this area? Is the knowledge we need publicly available or do we rely on the authority of experts?

Utilization:

- Protein synthesis in cells is a form of nanotechnology with ribosomes acting as molecular assemblers.

Syllabus and cross-curricular links:
Topics 4.3—molecular polarity

A.6 Nanotechnology	
• Discussion of some implications and applications of nanotechnology. • Explanation of why nanotubes are strong and good conductors of electricity. **Guidance:** • Possible implications of nanotechnology include uncertainty as to toxicity levels on a nanoscale, unknown health risks with new materials, concern that human defence systems are not effective against particles on the nanoscale, responsibilities of the industries and governments involved in this research. • Conductivity of graphene and fullerenes can be explained in terms of delocalization of electrons. An explanation based on hybridization is not required.	**Aims:** • **Aims 1**, **8** and **9**: Investigate the theoretical and large scale manufacturing of nanotechnology products and their implications. Examples could include sporting equipment, medicinal products, construction, environmental cleaning, robotics, weaponry or other theoretical commercial uses. • **Aims 7**, **8** and **9**: Animations, simulations, and videos of nanotube manufacture and uses should be used.

Essential idea: Although materials science generates many useful new products there are challenges associated with recycling of and high levels of toxicity of some of these materials.

A.7 Environmental impact—plastics

Nature of science:

Risks and problems—scientific research often proceeds with perceived benefits in mind, but the risks and implications also need to be considered. (4.8)

Understandings:

- Plastics do not degrade easily because of their strong covalent bonds.
- Burning of polyvinyl chloride releases dioxins, HCl gas and incomplete hydrocarbon combustion products.
- Dioxins contain unsaturated six-member heterocyclic rings with two oxygen atoms, usually in positions 1 and 4.
- Chlorinated dioxins are hormone disrupting, leading to cellular and genetic damage.
- Plastics require more processing to be recycled than other materials.
- Plastics are recycled based on different resin types.

Applications and skills:

- Deduction of the equation for any given combustion reaction.
- Discussion of why the recycling of polymers is an energy intensive process.
- Discussion of the environmental impact of the use of plastics.
- Comparison of the structures of polychlorinated biphenyls (PCBs) and dioxins.
- Discussion of the health concerns of using volatile plasticizers in polymer production.
- Distinguish possible Resin Identification Codes (RICs) of plastics from an IR spectrum.

International-mindedness:

- The international symbol for recycle, reuse and reduce is a Mobius strip designed in the late 1960s. However, global recognition of this symbol ranks well below other symbols. What factors influence the recognition of symbols?
- How can nations address the problem of the plastic gyre in the Pacific Ocean?

Theory of knowledge:

- The products of science and technology can have a negative impact on the environment. Are scientists ethically responsible for the impact of their products?

Utilization:

Syllabus and cross-curricular links:
Topic 9.1—redox reactions
Topic 10.1—organic compounds
Topic 11.3—infrared spectroscopy
Biology option C.3—impact of humans on ecosystems

Aims:

- **Aim 7**: Database of RIC codes and IR spectra can be used.
- **Aim 8**: The development of green chemistry has raised the awareness of the environmental and the ethical implications of using science and technology.

A.7 Environmental impact—plastics

Guidance:

- Dioxins do not decompose in the environment and can be passed on in the food chain.
- Consider polychlorinated dibenzodioxins (PCDD) and PCBs as examples of carcinogenic chlorinated dioxins or dioxin-like substances.
- Consider phthalate esters as examples of plasticizers.
- House fires can release many toxins due to plastics (shower curtains, etc). Low smoke zero halogen cabling is often used in wiring to prevent these hazards.
- Resin Identification Codes (RICs) are in the data booklet in section 30.
- Structures of various materials molecules are in the data booklet in section 31.

Additional higher level topics

Essential idea: Superconductivity is zero electrical resistance and expulsion of magnetic fields. X-ray crystallography can be used to analyse structures.

A.8 Superconducting metals and X-ray crystallography	
Nature of science: Importance of theories—superconducting materials, with zero electrical resistance below a certain temperature, provide a good example of theories needing to be modified to fit new data. It is important to understand the basic scientific principles behind modern instruments. (2.2)	
Understandings: • Superconductors are materials that offer no resistance to electric currents below a critical temperature. • The Meissner effect is the ability of a superconductor to create a mirror image magnetic field of an external field, thus expelling it. • Resistance in metallic conductors is caused by collisions between electrons and positive ions of the lattice. • The Bardeen–Cooper–Schrieffer (BCS) theory explains that below the critical temperature electrons in superconductors form Cooper pairs which move freely through the superconductor. • Type 1 superconductors have sharp transitions to superconductivity whereas Type 2 superconductors have more gradual transitions. • X-ray diffraction can be used to analyse structures of metallic and ionic compounds. • Crystal lattices contain simple repeating unit cells. • Atoms on faces and edges of unit cells are shared. • The number of nearest neighbours of an atom/ion is its coordination number.	**International-mindedness:** • Analytical techniques have applications in forensics, mineral exploration, medicine and elsewhere. How does the unequal access to advanced technology affect world economies? **Theory of knowledge:** • X-ray diffraction has allowed us to probe the world beyond the biological limits of our senses. How reliable is our knowledge of the microscopic world compared to what we know at the macroscopic level? **Utilization:** Syllabus and cross-curricular links: Topic 2.2—Pauli exclusion principle Topic 3.2—atomic radius and periodicity Topic 21.1—X-ray crystallography Physics topic 4.2—travelling waves **Aims:** • **Aim 7**: Animations and simulations would be very useful to explain superconductivity and X-ray crystallography.

A.8 Superconducting metals and X-ray crystallography	
Applications and skills: • Analysis of resistance versus temperature data for Type 1 and Type 2 superconductors. • Explanation of superconductivity in terms of Cooper pairs moving through a positive ion lattice. • Deduction or construction of unit cell structures from crystal structure information. • Application of the Bragg equation, $n\lambda = 2d\sin\theta$, in metallic structures. • Determination of the density of a pure metal from its atomic radii and crystal packing structure. **Guidance:** • Only a simple explanation of BCS theory with Cooper pairs is required. At low temperatures the positive ions in the lattice are distorted slightly by a passing electron. A second electron is attracted to this slight positive deformation and a coupling of these two electrons occurs. • Operating principles of X-ray crystallography are not required. • Only pure metals with simple cubic cells, body centred cubic cells (BCC) and face centred cubic cells (FCC) should be covered. • Perovskite crystalline structures of many superconductors can be analysed by X-ray crystallography but these will not be assessed. • Bragg's equation will only be applied to simple cubic structures.	

Essential idea: Condensation polymers are formed by the loss of small molecules as functional groups from monomers join.

A.9 Condensation polymers	
Nature of science: Speculation—we have had the Stone Age, Iron Age and Bronze Age. Is it possible that today's age is the Age of Polymers, as science continues to manipulate matter for desired purposes? (1.5)	
Understandings: • Condensation polymers require two functional groups on each monomer. • NH_3, HCl and H_2O are possible products of condensation reactions. • Kevlar® is a polyamide with a strong and ordered structure. The hydrogen bonds between O and N can be broken with the use of concentrated sulfuric acid. **Applications and skills:** • Distinguishing between addition and condensation polymers. • Completion and descriptions of equations to show how condensation polymers are formed. • Deduction of the structures of polyamides and polyesters from their respective monomers. • Explanation of Kevlar®'s strength and its solubility in concentrated sulfuric acid. **Guidance:** • Consider green chemistry polymers.	**International-mindedness:** • Does science, economics or politics play the most essential role in research, such as the development of new polymers? **Utilization:** Syllabus and cross-curricular links: Topic 10.2—addition and condensation reactions Topic 20.2—synthesis techniques Option A.5—polymers **Aims:** • **Aim 6**: Synthesis of nylon could be performed.

Essential idea: Toxicity and carcinogenic properties of heavy metals are the result of their ability to form coordinated compounds, have various oxidation states and act as catalysts in the human body.

A.10 Environmental impact—heavy metals	
Nature of science: Risks and problems—scientific research often proceeds with perceived benefits in mind, but the risks and implications also need to be considered. (4.8)	
Understandings: • Toxic doses of transition metals can disturb the normal oxidation/reduction balance in cells through various mechanisms. • Some methods of removing heavy metals are precipitation, adsorption, and chelation. • Polydentate ligands form more stable complexes than similar monodentate ligands due to the chelate effect, which can be explained by considering entropy changes. **Applications and skills:** • Explanation of how chelating substances can be used to remove heavy metals. • Deduction of the number of coordinate bonds a ligand can form with a central metal ion. • Calculations involving K_{sp} as an application of removing metals in solution. • Compare and contrast the Fenton and Haber–Weiss reaction mechanism. **Guidance:** • Ethane-1,2-diamine acts as a bidentate ligand and $EDTA^{4-}$ acts as hexadentate ligand. • The Haber–Weiss reaction generates free radicals naturally in biological processes. Transition metals can catalyse the reaction with the iron-catalysed (Fenton) reaction being the mechanism for generating reactive hydroxyl radicals. • K_{sp} values are in the data booklet in section 32.	**Theory of knowledge:** • What responsibility do scientists have for the impact of their endeavours on the planet? **Utilization:** Syllabus and cross-curricular links: Topic 9.1—redox reactions Topic 13.2—transition metal complexes Biology option C.3—impact of humans on ecosystems **Aims:** • **Aims 1** and **8**: Investigations of waste water treatment. • **Aim 6**: Experiments could include investigations of K_{sp}.

Core topics

Essential idea: Metabolic reactions involve a complex interplay between many different components in highly controlled environments.

<table>
<tr><th colspan="2">B.1 Introduction to biochemistry</th></tr>
<tr><td colspan="2">Nature of science:
Use of data—biochemical systems have a large number of different reactions occurring in the same place at the same time. As technologies have developed, more data has been collected leading to the discovery of patterns of reactions in metabolism. (3.1)</td></tr>
<tr><td>Understandings:
• The diverse functions of biological molecules depend on their structures and shapes.
• Metabolic reactions take place in highly controlled aqueous environments.
• Reactions of breakdown are called catabolism and reactions of synthesis are called anabolism.
• Biopolymers form by condensation reactions and are broken down by hydrolysis reactions.
• Photosynthesis is the synthesis of energy-rich molecules from carbon dioxide and water using light energy.
• Respiration is a complex set of metabolic processes providing energy for cells.
Applications and skills :
• Explanation of the difference between condensation and hydrolysis reactions.
• The use of summary equations of photosynthesis and respiration to explain the potential balancing of oxygen and carbon dioxide in the atmosphere.
Guidance:
• Intermediates of aerobic respiration and photosynthesis are not required.</td><td>International-mindedness:
• Metabolic reactions in the human body are dependent on the supply of nutrients through a regular balanced diet. Globally there are significant differences in the availability of nutritious food, which have major and diverse impacts on human health.
Utilization:
• Biochemistry is fundamental to the study of many other subjects, including genetics, immunology, pharmacology, nutrition and agriculture.
Syllabus and cross-curricular links:
Topic 10.2—S_N reactions (condensation and hydrolysis)
Topic 13.2 and Option B.9—metal complexes and light absorption
Option C.8—electronic conjugation and light absorption</td></tr>
</table>

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

B.2 Proteins and enzymes

Nature of science:

Collaboration and peer review—several different experiments on several continents led to the conclusion that DNA, and not protein as originally thought, carried the information for inheritance. (4.4)

Understandings:

- Proteins are polymers of 2-amino acids, joined by amide links (also known as peptide bonds).
- Amino acids are amphoteric and can exist as zwitterions, cations and anions.
- Protein structures are diverse and are described at the primary, secondary, tertiary and quaternary levels.
- A protein's three-dimensional shape determines its role in structural components or in metabolic processes.
- Most enzymes are proteins that act as catalysts by binding specifically to a substrate at the active site.
- As enzyme activity depends on the conformation, it is sensitive to changes in temperature and pH and the presence of heavy metal ions.
- Chromatography separation is based on different physical and chemical principles.

Applications and skills:

- Deduction of the structural formulas of reactants and products in condensation reactions of amino acids, and hydrolysis reactions of peptides.
- Explanation of the solubilities and melting points of amino acids in terms of zwitterions.
- Application of the relationships between charge, pH and isoelectric point for amino acids and proteins.

International-mindedness:

- The Universal Protein Resource (UniProt) is a consortium of bioinformatics institutes. Its mission is to act as a resource for the scientific community by providing comprehensive, high-quality and freely accessible data on protein sequence and functional information.

Utilization:

- Many synthetic materials are polyamides. Examples include nylon and Kevlar®.
- Electrophoresis is used in some medical diagnostics to identify patterns of unusual protein content in blood serum or urine.
- The first protein to be sequenced was insulin by Frederick Sanger in 1951, in a process that took over ten years. Today, protein sequencing is a routine and very efficient process, and is a major part of the study known as proteomics.

Syllabus and cross-curricular links:
Topics 8.3 and 18.2—pH and pK_a and pK_b values
Topic 20.3—stereoisomerism
Option A.9—condensation polymers
Option B.9—chromatography
Biology topics 2.4, 2.5 and 8.1—proteins and enzymes

Aims:

- **Aim 6**: Experiments could involve hydrolysis of a protein, separation and identification of amino acid mixtures by paper chromatography, or gel electrophoresis of proteins and DNA.
- **Aim 7**: Data logging experiments involving absorption/concentration studies for protein content using the Biuret reagent.

B.2 Proteins and enzymes	
• Description of the four levels of protein structure, including the origin and types of bonds and interactions involved. • Deduction and interpretation of graphs of enzyme activity involving changes in substrate concentration, pH and temperature. • Explanation of the processes of paper chromatography and gel electrophoresis in amino acid and protein separation and identification. **Guidance:** • The names and structural formulas of the amino acids are given in the data booklet in section 33. • Reference should be made to alpha helix and beta pleated sheet, and to fibrous and globular proteins with examples of each. • In paper chromatography the use of R_f values and locating agents should be covered. • In enzyme kinetics K_m and V_{max} are not required.	• **Aim 7**: Simulations can be used for gel electrophoresis.

Essential idea: Lipids are a broad group of biomolecules that are largely non-polar and therefore insoluble in water.

B.3 Lipids

Nature of science:

Significance of science explanations to the public—long-term studies have led to knowledge of the negative effects of diets high in saturated fat, cholesterol, and *trans*-fat. This has led to new food products. (5.2)

Understandings:

- Fats are more reduced than carbohydrates and so yield more energy when oxidized.
- Triglycerides are produced by condensation of glycerol with three fatty acids and contain ester links. Fatty acids can be saturated, monounsaturated or polyunsaturated.
- Phospholipids are derivatives of triglycerides.
- Hydrolysis of triglycerides and phospholipids can occur using enzymes or in alkaline or acidic conditions.
- Steroids have a characteristic fused ring structure, known as a steroidal backbone.
- Lipids act as structural components of cell membranes, in energy storage, thermal and electrical insulation, as transporters of lipid soluble vitamins and as hormones.

Applications and skills:

- Deduction of the structural formulas of reactants and products in condensation and hydrolysis reactions between glycerol and fatty acids and/or phosphate.
- Prediction of the relative melting points of fats and oils from their structures.
- Comparison of the processes of hydrolytic and oxidative rancidity in fats with respect to the site of reactivity in the molecules and the conditions that favour the reaction.

International-mindedness:

- There are large global and cultural differences in the dietary sources of lipids and methods used to prevent rancidity.

Theory of knowledge:

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

Utilization:

- Alkaline hydrolysis of fats is used in the process of soap-making, known as saponification.
- Steroid abuse, especially in sports, and methods for detection.

Syllabus and cross-curricular links:
Topics 10.1 and 10.2—functional groups, hydrogenation of alkenes
Topic 10.2—free radical mechanisms
Topic 20.3—configurational isomerism
Biology topic 2.3—lipids

B.3 Lipids	
• Application of the concept of iodine number to determine the unsaturation of a fat. • Comparison of carbohydrates and lipids as energy storage molecules with respect to their solubility and energy density. • Discussion of the impact of lipids on health, including the roles of dietary high-density lipoprotein (HDL) and low-density lipoprotein (LDL) cholesterol, saturated, unsaturated and *trans*-fat and the use and abuse of steroids. **Guidance:** • The structures of some fatty acids are given in the data booklet in section 34. • Specific named examples of fats and oils do not have to be learned. • The structural differences between *cis*- and *trans*-fats are not required.	**Aims:** • **Aim 6**: Experiments could include the calculation of the iodine number of fats to measure degree of unsaturation, calorimetric experiments on different fats and oils, or the separation of lipids from common food sources using different solvents and a separating funnel.

Essential idea: Carbohydrates are oxygen-rich biomolecules, which play a central role in metabolic reactions of energy transfer.

B.4 Carbohydrates

Nature of science:

Construct models/visualizations—understanding the stereochemistry of carbohydrates is essential to understanding their structural roles in cells. Haworth projections help focus on the nature and position of attached groups by making carbon and hydrogen implicit. (1.10)

Obtaining evidence for scientific theories—consider the structural role of carbohydrates. (1.8)

Understandings:

- Carbohydrates have the general formula $C_x(H_2O)_y$.
- Haworth projections represent the cyclic structures of monosaccharides.
- Monosaccharides contain either an aldehyde group (aldose) or a ketone group (ketose) and several –OH groups.
- Straight chain forms of sugars cyclize in solution to form ring structures containing an ether linkage.
- Glycosidic bonds form between monosaccharides forming disaccharides and polysaccharides.
- Carbohydrates are used as energy sources and energy reserves.

Applications and skills:

- Deduction of the structural formulas of disaccharides and polysaccharides from given monosaccharides.
- Relationship of the properties and functions of monosaccharides and polysaccharides to their chemical structures.

International-mindedness:

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

Theory of knowledge:

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

B.4 Carbohydrates	
Guidance: • The straight chain and α-ring forms of glucose and fructose are given in the data booklet in section 34. • The component monosaccharides of specific disaccharides and the linkage details of polysaccharides are not required. • The distinction between α- and β- forms and the structure of cellulose are not required.	**Utilization:** • Carbohydrates are used in the pharmaceutical industry to bind preparations into tablets. • Ethanol is produced as a biofuel from the fermentation of carbohydrates in crops such as corn or sugar cane. Syllabus and cross-curricular links: Topics 10.1 and 10.2—organic functional groups Topic 20.1—organic reactions Topic 20.3—stereoisomerism Option C.4—biofuels Biology topic 2.3—carbohydrates **Aims:** • **Aim 6**: Experiments could include using Benedict's or Fehling's solution tests to distinguish between reducing sugars and non-reducing sugars or using iodine solution to test for the presence of starch. • **Aim 8**: The production of biofuels from crops raises many questions about related issues such as deforestation, soil erosion and sustainability. The "food vs fuel" debate refers to the controversies arising from developments that divert agricultural crops into biofuel production.

Essential idea: Vitamins are organic micronutrients with diverse functions that must be obtained from the diet.

<table>
<tr><th colspan="2">B.5 Vitamins</th></tr>
<tr><td colspan="2">Nature of science:

Making observations and evaluating claims—the discovery of vitamins (vital amines) is an example of scientists seeking a cause for specific observations. This resulted in the explanation of deficiency diseases (eg scurvy and beriberi). (1.8)</td></tr>
<tr><td>Understandings:
• Vitamins are organic micronutrients which (mostly) cannot be synthesized by the body but must be obtained from suitable food sources.
• The solubility (water or fat) of a vitamin can be predicted from its structure.
• Most vitamins are sensitive to heat.
• Vitamin deficiencies in the diet cause particular diseases and affect millions of people worldwide.
Applications and skills:
• Comparison of the structures of vitamins A, C and D.
• Discussion of the causes and effects of vitamin deficiencies in different countries and suggestion of solutions.
Guidance:
• The structures of vitamins A, C and D are provided in the data booklet section 35.
• Specific food sources of vitamins or names of deficiency diseases do not have to be learned.</td><td>International-mindedness:
• The food supplements industry, especially the sale of vitamin pills, has become very lucrative in many countries.
• Vitamin D deficiency is increasing, partly as a result of greater protection of the skin from sunlight.
Theory of knowledge:
• What are the ethical considerations in adding supplements to commonly consumed foods, such as fluoride to water or iodine to salt? Public bodies can protect the individual but also limit their freedom. How do we know what is best for society and the individual?
• Linus Pauling is the only man to win two individual Nobel Prizes. His claim that vitamin C supplements could prevent diseases such as the common cold led to their widespread use. What is the role of authority in communicating scientific knowledge to the public?
Utilization:
Syllabus and cross-curricular links:
Topics 4.1, 4.2 and 4.3—structure and physical properties
Topic 10.1—organic functional groups
Topic 20.3—configurational isomerism
Biology option D.2—human nutrition and health
Aims:
• Aim 6: Experiments could include the DCPIP determination of vitamin C levels in foods.</td></tr>
</table>

Essential idea: Our increasing knowledge of biochemistry has led to several environmental problems, while also helping to solve others.

B.6 Biochemistry and the environment

Nature of science:

Risk assessment, collaboration, ethical considerations—it is the responsibility of scientists to consider the ways in which products of their research and findings negatively impact the environment, and to find ways to counter this. For example, the use of enzymes in biological detergents and to break up oil spills, and green chemistry in general. (4.8)

Understandings:

- Xenobiotics refer to chemicals that are found in an organism that are not normally present there.
- Biodegradable/compostable plastics can be consumed or broken down by bacteria or other living organisms.
- Host–guest chemistry involves the creation of synthetic host molecules that mimic some of the actions performed by enzymes in cells, by selectively binding to specific guest species, such as toxic materials in the environment.
- Enzymes have been developed to help in the breakdown of oil spills and other industrial wastes.
- Enzymes in biological detergents can improve energy efficiency by enabling effective cleaning at lower temperatures.
- Biomagnification is the increase in concentration of a substance in a food chain.
- Green chemistry, also called sustainable chemistry, is an approach to chemical research and engineering that seeks to minimize the production and release to the environment of hazardous substances.

Applications and skills:

- Discussion of the increasing problem of xenobiotics such as antibiotics in sewage treatment plants.
- Description of the role of starch in biodegradable plastics.

International-mindedness:

- The term green chemistry was first coined in 1991, and acceptance of its philosophy has led to developments in education and legislation in many countries.
- Use of the pesticide DDT is banned in most countries due to its toxic effects and biomagnification. Its use continues, however, in countries where malaria remains a major public health challenge.

Utilization:

Syllabus and cross-curricular links:
Topic 4.4—intermolecular forces
Topic 10.1—natural and synthetic organic compounds
Options A.5 and A.7—environmental impact of plastics
Option D.2—antibiotics

Aims:

- **Aim 6**: Experiments could include the comparison of the breakdown of biodegradable and non-biodegradable plastics in the environment.
- **Aim 6**: Risk assessment, including the risks to the environment, is an essential part of all experimental work.
- **Aim 8**: The development of the science of green chemistry has raised awareness of the environmental and ethical implications of using science and technology.

B.6 Biochemistry and the environment	
• Application of host–guest chemistry to the removal of a specific pollutant in the environment. • Description of an example of biomagnification, including the chemical source of the substance. Examples could include heavy metals or pesticides. • Discussion of the challenges and criteria in assessing the “greenness” of a substance used in biochemical research, including the atom economy. **Guidance:** • Specific names of “green chemicals” such as solvents are not expected. • The emphasis in explanations of host–guest chemistry should be on non-covalent bonding within the supramolecule.	

Additional higher level topics

Essential idea: Analyses of protein activity and concentration are key areas of biochemical research.

B.7 Proteins and enzymes	
Nature of science: Theories can be superseded—“lock and key” hypothesis to “induced fit” model for enzymes. (1.9) Collaboration and ethical considerations—scientists collaborate to synthesize new enzymes and to control desired reactions (ie waste control). (4.5)	
Understandings: • Inhibitors play an important role in regulating the activities of enzymes. • Amino acids and proteins can act as buffers in solution. • Protein assays commonly use UV-vis spectroscopy and a calibration curve based on known standards. **Applications and skills:** • Determination of the maximum rate of reaction (V_{max}) and the value of the Michaelis constant (K_m) for an enzyme by graphical means, and explanation of its significance. • Comparison of competitive and non-competitive inhibition of enzymes with reference to protein structure, the active site and allosteric site. • Explanation of the concept of product inhibition in metabolic pathways. • Calculation of the pH of buffer solutions, such as those used in protein analysis and in reactions involving amino acids in solution. • Determination of the concentration of a protein in solution from a calibration curve using the Beer–Lambert law.	**International-mindedness:** • Technologies based on enzyme activity go back to ancient times in many parts of the world. Brewing and cheese-making are often associated with particular place names. **Theory of knowledge:** • The term “lock-and-key” is an effective metaphor but the “induced fit” model is a better model. How are metaphors and models used in the construction of knowledge? **Utilization:** • Enzymes are widely used in industrial and domestic applications. Examples include biological detergents, textiles, foods and beverages, and biodegradable plastics. Advances in protein engineering have led to the synthesis of enzymes that are effective in a wide range of conditions. Syllabus and cross-curricular links: Topic 6.1—chemical kinetics Topics 8.1, 8.3 and 8.4—the pH scale and conjugate acids and bases Topics 18.2 and 18.3—acid–base calculations and pH curves

B.7 Proteins and enzymes	
Guidance: • The effects of competitive and non-competitive inhibitors on K_m and V_{max} values should be covered. • The Henderson–Hasselbalch equation is given in the data booklet in section 1. • For UV-vis spectroscopy, knowledge of particular reagents and wavelengths is not required.	**Aims:** • **Aim 6**: Experiments could include measuring enzyme activity with changing conditions of temperature, pH and heavy metal ion concentration. • **Aim 7**: Data-logging experiments with temperature or pH probes to investigate enzyme activity under different conditions; or computer modelling of enzyme–substrate interactions. • **Aim 8**: Many enzyme technologies help mitigate damaging environmental effects of chemicals, such as from leather, paper and oil industries.

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

B.8 Nucleic acids

Nature of science:

Scientific method—the discovery of the structure of DNA is a good example of different approaches to solving the same problem. Scientists used models and diffraction experiments to develop the structure of DNA. (1.3)

Developments in scientific research follow improvements in apparatus—double helix from X-ray diffraction provides explanation for known functions of DNA. (3.7)

Understandings:

- Nucleotides are the condensation products of a pentose sugar, phosphoric acid and a nitrogenous base—adenine (A), guanine (G), cytosine (C), thymine (T) or uracil (U).
- Polynucleotides form by condensation reactions.
- DNA is a double helix of two polynucleotide strands held together by hydrogen bonds.
- RNA is usually a single polynucleotide chain that contains uracil in place of thymine, and a sugar ribose in place of deoxyribose.
- The sequence of bases in DNA determines the primary structure of proteins synthesized by the cell using a triplet code, known as the genetic code, which is universal.
- Genetically modified organisms have genetic material that has been altered by genetic engineering techniques, involving transferring DNA between species.

Applications and skills:

- Explanation of the stability of DNA in terms of the interactions between its hydrophilic and hydrophobic components.
- Explanation of the origin of the negative charge on DNA and its association with basic proteins (histones) in chromosomes.
- Deduction of the nucleotide sequence in a complementary strand of DNA or a molecule of RNA from a given polynucleotide sequence.

International-mindedness:

- The Human Genome Project was an international research programme whose goal was to complete the mapping and sequencing of all the genes in the human genome.
- The policies on the labelling of genetically modified (GM) foods vary greatly in different countries.
- Most of the genetically modified organisms are protected by international patents. What effect does this have on the global economy and scientific community?

Theory of knowledge:

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

B.8 Nucleic acids	
• Explanation of how the complementary pairing between bases enables DNA to replicate itself exactly. • Discussion of the benefits and concerns of using genetically modified foods. **Guidance:** • Structures of the nitrogenous bases and ribose and deoxyribose sugars are given in the data booklet in section 34. • Knowledge of the different forms of RNA is not required. • Details of the process of DNA replication are not required. • Limit expression of DNA to the concept of a four-unit base code determining a twenty-unit amino acid sequence. Details of transcription and translation are not required.	**Utilization:** • Knowledge of DNA sequencing has transformed several aspects of legal enquiry, including forensics and paternity cases. It is also widely used in studies of ancestry and human migration. • DNA sequencing is an important aspect of the study of biochemical evolution. Syllabus and cross-curricular links: Topic 4.4—hydrogen bonding, intermolecular interactions Topic 8.1—acid–base interactions Biology topics 2.6 and 7.1—DNA and RNA structure **Aims:** • **Aim 5**: The story of the rivalry between the different teams involved in the elucidation of DNA structure in the 1950s is an example of a failure of effective collaboration and communication during scientific activities. • **Aim 6**: Experiments could include DNA extraction from cells and investigation of its physical properties, and model building exercises of DNA structure, including the specific base pairings between a purine and a pyrimidine. • **Aim 7**: Databases exist of genetic sequences from different organisms. • **Aim 8**: Many ethical questions are raised by our knowledge of the human genome, including cloning, genetic engineering, gene therapy, and so on.

Essential idea: Biological pigments include a variety of chemical structures with diverse functions which absorb specific wavelengths of light.

B.9 Biological pigments

Nature of science:

Use of data—quantitative measurements of absorbance are a reliable means of communicating data based on colour, which was previously subjective and difficult to replicate. (3.1)

Understandings:

- Biological pigments are coloured compounds produced by metabolism.
- The colour of pigments is due to highly conjugated systems with delocalized electrons, which have intense absorption bands in the visible region.
- Porphyrin compounds, such as hemoglobin, myoglobin, chlorophyll and many cytochromes are chelates of metals with large nitrogen-containing macrocyclic ligands.
- Hemoglobin and myoglobin contain heme groups with the porphyrin group bound to an iron(II) ion.
- Cytochromes contain heme groups in which the iron ion interconverts between iron(II) and iron(III) during redox reactions.
- Anthocyanins are aromatic, water-soluble pigments widely distributed in plants. Their specific colour depends on metal ions and pH.
- Carotenoids are lipid-soluble pigments, and are involved in harvesting light in photosynthesis. They are susceptible to oxidation, catalysed by light.

Applications and skills:

- Explanation of the sigmoidal shape of hemoglobin's oxygen dissociation curve in terms of the cooperative binding of hemoglobin to oxygen.
- Discussion of the factors that influence oxygen saturation of hemoglobin, including temperature, pH and carbon dioxide.
- Description of the greater affinity of oxygen for foetal hemoglobin.

International-mindedness:

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

Theory of knowledge:

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

Utilization:

- Different tones of skin, eye and hair colour are the result of differences in the concentration of the pigment melanin.
- People whose ancestors have lived at high altitude for many generations have developed hemoglobin with a higher affinity for oxygen.
- The purplish-red colour of meat is largely due to the presence of myoglobin. The change in colour to brown on cooking occurs as the iron ion becomes oxidized to Fe^{3+}.
- Anthocyanins and carotenoids provide visible signals for plants to attract insects and birds for pollination and seed dispersal. They also protect plants from damage caused by UV light.

Syllabus and cross-curricular links:
Topic 8.2—indicators
Topic 13.2—complex ions
Option C.8—electronic conjugation and dye-sensitized solar cells

B.9 Biological pigments	
• Explanation of the action of carbon monoxide as a competitive inhibitor of oxygen binding. • Outline of the factors that affect the stabilities of anthocyanins, carotenoids and chlorophyll in relation to their structures. • Explanation of the ability of anthocyanins to act as indicators based on their sensitivity to pH. • Description of the function of photosynthetic pigments in trapping light energy during photosynthesis. • Investigation of pigments through paper and thin layer chromatography. **Guidance:** • The structures of chlorophyll, heme B and specific examples of anthocyanins and carotenoids are given in the data booklet in section 35; details of other pigment names and structures are not required. • Explanation of cooperative binding in hemoglobin should be limited to conformational changes occurring in one polypeptide when it becomes oxygenated. • Knowledge of specific colour changes with changing conditions is not required.	**Aims:** • **Aim 6**: Experiments could include the extraction and isolation of pigments from plant sources using solvents and separating funnel or the use of anthocyanins as pH indicators. • **Aim 7**: Use of data loggers for collecting absorption data.

Essential idea: Most biochemical processes are stereospecific and involve only molecules with certain configuration of chiral carbon atoms.

B.10 Stereochemistry in biomolecules

Nature of science:

Theories used to explain natural phenomena/evaluate claims—biochemistry involves many chiral molecules with biological activity specific to one enantiomer. Chemical reactions in a chiral environment act as a guiding distinction between living and non-living matter. (2.2)

Understandings:

- With one exception, amino acids are chiral, and only the L-configuration is found in proteins.
- Naturally occurring unsaturated fat is mostly in the *cis* form, but food processing can convert it into the *trans* form.
- D and L stereoisomers of sugars refer to the configuration of the chiral carbon atom furthest from the aldehyde or ketone group, and D forms occur most frequently in nature.
- Ring forms of sugars have isomers, known as α and β, depending on whether the position of the hydroxyl group at carbon 1 (glucose) or carbon 2 (fructose) lies below the plane of the ring (α) or above the plane of the ring (β).
- Vision chemistry involves the light activated interconversion of *cis*- and *trans*-isomers of retinal.

Applications and skills:

- Description of the hydrogenation and partial hydrogenation of unsaturated fats, including the production of *trans*-fats, and a discussion of the advantages and disadvantages of these processes.
- Explanation of the structure and properties of cellulose, and comparison with starch.
- Discussion of the importance of cellulose as a structural material and in the diet.
- Outline of the role of vitamin A in vision, including the roles of opsin, rhodopsin

International-mindedness:

- Different countries have very different standards of food labelling with respect to its chemical content, including the type of fats present.

Utilization:

Syllabus and cross-curricular links:
Topic 10.1—organic functional groups
Topic 20.1—organic reactions
Topic 20.3—stereoisomerism
Option A.4—intermolecular/London forces

Aims:

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

B.10 Stereochemistry in biomolecules	
and *cis*- and *trans*-retinal. **Guidance:** • Names of the enzymes involved in the visual cycle are not required. • Relative melting points of saturated and *cis*-/*trans*-unsaturated fats should be covered.	

Core topics

Essential idea: Societies are completely dependent on energy resources. The quantity of energy is conserved in any conversion but the quality is degraded.

C.1 Energy sources

Nature of science:

Use theories to explain natural phenomena—energy changes in the world around us result from potential and kinetic energy changes at the molecular level.

Energy has both quantity and quality. (2.2)

Understandings:

- A useful energy source releases energy at a reasonable rate and produces minimal pollution.
- The quality of energy is degraded as heat is transferred to the surroundings. Energy and materials go from a concentrated into a dispersed form. The quantity of the energy available for doing work decreases.
- Renewable energy sources are naturally replenished. Non-renewable energy sources are finite.
- $\text{Energy density} = \frac{\text{energy released from fuel}}{\text{volume of fuel consumed}}$.
- $\text{Specific energy} = \frac{\text{energy released from fuel}}{\text{mass of fuel consumed}}$.
- $\text{The effeciency of an energy transfer} = \frac{\text{useful output energy}}{\text{total input energy}} \text{ x } 100\%$.

Applications and skills:

- Discussion of the use of different sources of renewable and non-renewable energy.
- Determination of the energy density and specific energy of a fuel from the enthalpies of combustion, densities and the molar mass of fuel.
- Discussion of how the choice of fuel is influenced by its energy density or specific energy.

International-mindedness:

- The International Energy Agency is an autonomous organization based in Paris which works to ensure reliable, affordable and clean energy for its 28 member countries and beyond.
- The International Renewable Energy Agency (IRENA), based in Abu Dhabi, UAE, was founded in 2009 to promote increased adoption and sustainable use of renewable energy sources (bioenergy, geothermal energy, hydropower, ocean, solar and wind energy).

Theory of knowledge:

- "I have no doubt that we will be successful in harnessing the sun's energy. If sunbeams were weapons of war we would have had solar energy centuries ago." (Lord George Porter). In what ways might social, political, cultural and religious factors affect the types of research that are financed and undertaken, or rejected?
- There are many ethical issues raised by energy generation and its consequent contributions to pollution and climate change.What is the influence of political pressure on different areas of knowledge?

Utilization:

Syllabus and cross-curricular links:
Topic 5.1—enthalpies of combustion
Topic 10.2—the combustion of hydrocarbons
Environmental systems and societies topics—3.2, 3.3, 3.5 and 3.6
Physics topic 8.1—energy density

C.1 Energy sources	
• Determination of the efficiency of an energy transfer process from appropriate data. • Discussion of the advantages and disadvantages of the different energy sources in C.2 through to C.8.	**Aims:** • **Aim 1**: Discussions of the possible energy sources provide opportunities for scientific study and creativity within a global context. • **Aim 6**: The energy density of different fuels could be investigated experimentally. • **Aim 7**: Databases of energy statistics on a global and national scale can be explored here. • **Aim 8**: Energy production has global economic and environmental dimensions. The choices made in this area have moral and ethical implications.

Essential idea: The energy of fossil fuels originates from solar energy which has been stored by chemical processes over time. These abundant resources are non-renewable but provide large amounts of energy due to the nature of chemical bonds in hydrocarbons.

C.2 Fossil fuels

Nature of science:

Scientific community and collaboration—the use of fossil fuels has had a key role in the development of science and technology. (4.1)

Understandings:

- Fossil fuels were formed by the reduction of biological compounds that contain carbon, hydrogen, nitrogen, sulfur and oxygen.
- Petroleum is a complex mixture of hydrocarbons that can be split into different component parts called fractions by fractional distillation.
- Crude oil needs to be refined before use. The different fractions are separated by a physical process in fractional distillation.
- The tendency of a fuel to auto-ignite, which leads to "knocking" in a car engine, is related to molecular structure and measured by the octane number.
- The performance of hydrocarbons as fuels is improved by the cracking and catalytic reforming reactions.
- Coal gasification and liquefaction are chemical processes that convert coal to gaseous and liquid hydrocarbons.
- A carbon footprint is the total amount of greenhouse gases produced during human activities. It is generally expressed in equivalent tons of carbon dioxide.

Applications and skills:

- Discussion of the effect of chain length and chain branching on the octane number.
- Discussion of the reforming and cracking reactions of hydrocarbons and explanation how these processes improve the octane number.
- Deduction of equations for cracking and reforming reactions, coal gasification and liquefaction.

International-mindedness:

- The choice of fossil fuel used by different countries depends on availability, and economic, societal, environmental and technological factors.
- Different fuel rating systems (RON, MON or PON) are used in different countries.
- Ocean drilling, oil pipelines and oil spills are issues that demand international cooperation and agreement.

Utilization:

Syllabus and cross-curricular links:
Topics 5.1 and 5.3—enthalpy changes of combustion
Topics 10.1 and 20.3—hydrocarbons and isomerism
Topic 10.2 and option C.5—global warming
Option C.8—solar cells
Biology topic 4.3—carbon cycling

Aims:

- **Aim 6**: Possible experiments include fractional distillation and catalytic cracking reactions.
- **Aim 7**: Databases of energy statistics on a global and national scale can be explored here.
- **Aim 7**: Many online calculators are available to calculate carbon footprints.
- **Aim 8**: Consideration of the advantages and disadvantages of fossil fuels illustrates the economic and environmental implications of using science and technology.

C.2 Fossil fuels	
• Discussion of the advantages and disadvantages of the different fossil fuels. • Identification of the various fractions of petroleum, their relative volatility and their uses. • Calculations of the carbon dioxide added to the atmosphere, when different fuels burn and determination of carbon footprints for different activities. **Guidance:** • The cost of production and availability (reserves) of fossil fuels and their impact on the environment should be considered.	

Essential idea: The fusion of hydrogen nuclei in the sun is the source of much of the energy needed for life on Earth. There are many technological challenges in replicating this process on Earth but it would offer a rich source of energy. Fission involves the splitting of a large unstable nucleus into smaller stable nuclei.

C.3 Nuclear fusion and fission

Nature of science:

Assessing the ethics of scientific research—widespread use of nuclear fission for energy production would lead to a reduction in greenhouse gas emissions. Nuclear fission is the process taking place in the atomic bomb and nuclear fusion that in the hydrogen bomb. (4.5)

Understandings:

Nuclear fusion

- Light nuclei can undergo fusion reactions as this increases the binding energy per nucleon.
- Fusion reactions are a promising energy source as the fuel is inexpensive and abundant, and no radioactive waste is produced.
- Absorption spectra are used to analyse the composition of stars.

Nuclear fission

- Heavy nuclei can undergo fission reactions as this increases the binding energy per nucleon.
- ^{235}U undergoes a fission chain reaction:
  $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U \rightarrow X + Y + \text{neutrons}.$
- The critical mass is the mass of fuel needed for the reaction to be self-sustaining.
- ^{239}Pu, used as a fuel in “breeder reactors”, is produced from ^{238}U by neutron capture.
- Radioactive waste may contain isotopes with long and short half-lives.
- Half-life is the time it takes for half the number of atoms to decay.

International-mindedness:

- The use of nuclear energy is monitored internationally by the International Atomic Energy Agency.
- High-energy particle physics research involves international collaboration. There are accelerator facilities at CERN, DESY, SLAC, Fermi lab and Brookhaven. Results are disseminated and shared by scientists in many countries.
- The ITER project is a collaboration between many countries and aims to demonstrate that fusion is an energy source of the future.

Theory of knowledge:

- The use of nuclear energy carries risks as well as benefits. Who should ultimately be responsible for assessing these? How do we know what is best for society and the individual?

Utilization:

Syllabus and cross-curricular links:
Topic 2.1—isotopes
Topic 2.2—the emission spectrum of hydrogen
Physics topic 7.2—nuclear fusion

Aims:

- **Aim 7**: Computer animations and simulations of radioactive decay, and nuclear fusion and fission reactions.
- **Aim 8**: Consideration of the environmental impact of nuclear energy illustrating

C.3 Nuclear fusion and fission	
Applications and skills: *Nuclear fusion* • Construction of nuclear equations for fusion reactions. • Explanation of fusion reactions in terms of binding energy per nucleon. • Explanation of the atomic absorption spectra of hydrogen and helium, including the relationships between the lines and electron transitions. *Nuclear fission* • Deduction of nuclear equations for fission reactions. • Explanation of fission reactions in terms of binding energy per nucleon. • Discussion of the storage and disposal of nuclear waste. • Solution of radioactive decay problems involving integral numbers of half-lives. **Guidance:** • Students are not expected to recall specific fission reactions. • The workings of a nuclear power plant are not required. • Safety and risk issues include: health, problems associated with nuclear waste and core meltdown, and the possibility that nuclear fuels may be used in nuclear weapons. • The equations, $N = N_0 e^{-\lambda t}$ and $t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$ are given in section 1 of the data booklet.	the implications of using science and technology.

Essential idea: Visible light can be absorbed by molecules that have a conjugated structure with an extended system of alternating single and multiple bonds. Solar energy can be converted to chemical energy in photosynthesis.

<table>
<tr><td colspan="2">C.4 Solar energy</td></tr>
<tr><td colspan="2">Nature of science:

Public understanding—harnessing the sun's energy is a current area of research and challenges still remain. However, consumers and energy companies are being encouraged to make use of solar energy as an alternative energy source. (5.2)</td></tr>
<tr><td>Understandings:

• Light can be absorbed by chlorophyll and other pigments with a conjugated electronic structure.

• Photosynthesis converts light energy into chemical energy:
$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

• Fermentation of glucose produces ethanol which can be used as a biofuel:
$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

• Energy content of vegetable oils is similar to that of diesel fuel but they are not used in internal combustion engines as they are too viscous.

• Transesterification between an ester and an alcohol with a strong acid or base catalyst produces a different ester:
$RCOOR^1 + R^2OH \rightarrow RCOOR^2 + R^1OH$

• In the transesterification process, involving a reaction with an alcohol in the presence of a strong acid or base, the triglyceride vegetable oils are converted to a mixture mainly comprising of alkyl esters and glycerol, but with some fatty acids.

• Transesterification with ethanol or methanol produces oils with lower viscosity that can be used in diesel engines.

Applications and skills:

• Identification of features of the molecules that allow them to absorb visible light.</td>
<td>Theory of knowledge:

• The claims of "cold fusion" were dismissed as the results are not reproducible. Is it always possible to obtain replicable results in the natural sciences? Are reproducible results possible in other areas of knowledge?

Utilization:

Syllabus and cross-curricular links:
Topic 5.3—bond enthalpies
Topic 20.1—mechanism of nuclear substitution reactions
Biology topic 2.9—photosynthesis

Aims:

• Aim 2: The conversion of solar energy is important in a number of different technologies.

• Aim 6: Experiments could include those involving photosynthesis, fermentation and transesterification.

• Aim 8: Transesterification reactions, with waste cooking oil, could reduce waste and produce excellent biofuels.</td></tr>
</table>

C.4 Solar energy	
• Explanation of the reduced viscosity of esters produced with methanol and ethanol. • Evaluation of the advantages and disadvantages of the use of biofuels. • Deduction of equations for transesterification reactions. **Guidance:** • Only a conjugated system with alternating double bonds needs to be covered.	

Essential idea: Gases in the atmosphere that are produced by human activities are changing the climate as they are upsetting the balance between radiation entering and leaving the atmosphere.

<table>
<tr><td colspan="2">C.5 Environmental impact—global warming</td></tr>
<tr><td colspan="2">Nature of science:
Transdisciplinary—the study of global warming encompasses a broad range of concepts and ideas and is transdisciplinary. (4.1)
Collaboration and significance of science explanations to the public—reports of the Intergovernmental Panel on Climate Change (IPCC). (5.2)
Correlation and cause and understanding of science—CO_2 levels and Earth average temperature show clear correlation but wide variations in the surface temperature of the Earth have occurred frequently in the past. (2.8)</td></tr>
<tr><td>Understandings:
• Greenhouse gases allow the passage of incoming solar short wavelength radiation but absorb the longer wavelength radiation from the Earth. Some of the absorbed radiation is re-radiated back to Earth.
• There is a heterogeneous equilibrium between concentration of atmospheric carbon dioxide and aqueous carbon dioxide in the oceans.
• Greenhouse gases absorb IR radiation as there is a change in dipole moment as the bonds in the molecule stretch and bend.
• Particulates such as smoke and dust cause global dimming as they reflect sunlight, as do clouds.
Applications and skills:
• Explanation of the molecular mechanisms by which greenhouse gases absorb infrared radiation.
• Discussion of the evidence for the relationship between the increased concentration of gases and global warming.
• Discussion of the sources, relative abundance and effects of different greenhouse gases.
• Discussion of the different approaches to the control of carbon dioxide emissions.</td><td>International-mindedness:
• This issue involves the international community working together to research and reduce the effects of global warming. Such attempts include the Intergovernmental Panel on Climate Change (IPCC) and the Kyoto Protocol which was extended in Qatar.
Theory of knowledge:
• Some people question the reality of climate change, and question the motives of scientists who have “exaggerated” the problem. How do we assess the evidence collected and the models used to predict the impact of human activities?
Utilization:
Syllabus and cross-curricular links:
Topics 7.1 and 17.1—equilibrium systems
Topic 8.2—acid–base equilibria
Topic 11.3—infrared spectra
Topic 13.2—transition metal complexes
Biology topic 4.4—climate change
Physics topic 8.1—thermal energy transfer
Aims:
• Aim 6: The equilibrium between aqueous and gaseous carbon dioxide could be experimentally investigated.</td></tr>
</table>

C.5 Environmental impact—global warming	
• Discussion of pH changes in the ocean due to increased concentration of carbon dioxide in the atmosphere. **Guidance:** • Greenhouse gases to be considered are CH_4, H_2O and CO_2.	• **Aim 7**: Computer modelling is a powerful tool by which knowledge can be gained about the greenhouse effect. • **Aim 8**: Discussions of climate change and green chemistry raise awareness of the ethical, economic and environmental implications of using science and technology.

Additional higher level topics

Essential idea: Chemical energy from redox reactions can be used as a portable source of electrical energy.

C.6 Electrochemistry, rechargeable batteries and fuel cells	
Nature of science: Environmental problems—redox reactions can be used as a source of electricity but disposal of batteries has environmental consequences. (4.8)	
Understandings: • An electrochemical cell has internal resistance due to the finite time it takes for ions to diffuse. The maximum current of a cell is limited by its internal resistance. • The voltage of a battery depends primarily on the nature of the materials used while the total work that can be obtained from it depends on their quantity. • In a primary cell the electrochemical reaction is not reversible. Rechargeable cells involve redox reactions that can be reversed using electricity. • A fuel cell can be used to convert chemical energy, contained in a fuel that is consumed, directly to electrical energy. • Microbial fuel cells (MFCs) are a possible sustainable energy source using different carbohydrates or substrates present in waste waters as the fuel. • The Nernst equation, $E = E^0 - \left(\frac{RT}{nF}\right) \ln Q$, can be used to calculate the potential of a half-cell in an electrochemical cell, under non-standard conditions. • The electrodes in a concentration cell are the same but the concentration of the electrolyte solutions at the cathode and anode are different. **Applications and skills:** • Distinction between fuel cells and primary cells. • Deduction of half equations for the electrode reactions in a fuel cell.	**International-mindedness:** • Are battery recycling programmes equivalent in different areas of the globe? **Theory of knowledge:** • Does scientific language and vocabulary have primarily a descriptive or an interpretative function? Are the terms “electric current” and “internal resistance” accurate descriptions of reality or metaphors? **Utilization:** Syllabus and cross-curricular links: Topic 9.1—redox reactions Topic 19.1—electrochemical cells Biology topic 6.5—muscle and nerve cells discussed in biology are concentration cells Physics topic 5.3—the relationship between electrical power, voltage, resistance and current **Aims:** • **Aim 2**: The conversion of chemical energy to electricity is important in a number of different technologies. • **Aim 6**: The factors that affect the voltage of a cell and the lead–acid battery could be investigated experimentally.

C.6 Electrochemistry, rechargeable batteries and fuel cells	
• Comparison between fuel cells and rechargeable batteries. • Discussion of the advantages of different types of cells in terms of size, mass and voltage. • Solution of problems using the Nernst equation. • Calculation of the thermodynamic efficiency ($\Delta G/\Delta H$) of a fuel cell. • Explanation of the workings of rechargeable and fuel cells including diagrams and relevant half-equations. **Guidance:** • A battery should be considered as a portable electrochemical source made up of one or more voltaic (galvanic) cells connected in series. • The Nernst equation is given in the data booklet in section 1. • Hydrogen and methanol should be considered as fuels for fuel cells. The operation of the cells under acid and alkaline conditions should be considered. Students should be familiar with proton-exchange membrane (PEM) fuel cells. • The *Geobacter* species of bacteria, for example, can be used in some cells to oxidize the ethanoate ions (CH_3COO^-) under anaerobic conditions. • The lead–acid storage battery, the nickel–cadmium (NiCad) battery and the lithium–ion battery should be considered. • Students should be familiar with the anode and cathode half-equations and uses of the different cells.	• **Aim 8**: Consideration of the advantages and disadvantages of the different energy sources shows the economic and environmental implications of using science and technology. The environmental aspects of fuel cells, especially with regard to methanol, could be discussed. • **Aim 8**: Disposal of primary batteries and the chemicals they use can introduce land and water pollution problems. Appreciation of the environmental impact of cadmium and lead pollution. • **Aim 8**: Bacterial fuel cells use substrates found in waste water as the fuel and so can be used to clean up the environment.

Essential idea: Large quantities of energy can be obtained from small quantities of matter.

<table>
<tr><td colspan="2">C.7 Nuclear fusion and nuclear fission</td></tr>
<tr><td colspan="2">Nature of science:
Trends and discrepancies—our understanding of nuclear processes came from both theoretical and experimental advances. Intermolecular forces in UF_6 are anomalous and do not follow the normal trends. (3.1)</td></tr>
<tr><td>Understandings:
Nuclear fusion:
• The mass defect (Δm) is the difference between the mass of the nucleus and the sum of the masses of its individual nucleons.
• The nuclear binding energy (ΔE) is the energy required to separate a nucleus into protons and neutrons.
Nuclear fission:
• The energy produced in a fission reaction can be calculated from the mass difference between the products and reactants using the Einstein mass–energy equivalence relationship $E = mc^2$.
• The different isotopes of uranium in uranium hexafluoride can be separated, using diffusion or centrifugation causing fuel enrichment.
• The effusion rate of a gas is inversely proportional to the square root of the molar mass (Graham's Law).
• Radioactive decay is kinetically a first order process with the half-life related to the decay constant by the equation $\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$.
• The dangers of nuclear energy are due to the ionizing nature of the radiation it produces which leads to the production of oxygen free radicals such as superoxide (O_2^-), and hydroxyl ($HO^\cdot$). These free radicals can initiate chain reactions that can damage DNA and enzymes in living cells.</td>
<td>International-mindedness:
• There are only a very small number of countries that have developed nuclear weapons and the International Atomic Energy Agency strives to limit the spread of this technology. There are disputes about whether some countries are developing nuclear energy for peaceful or non-peaceful purposes.
• Nuclear incidents have a global effect; the accidents at Three Mile Island and Chernobyl and the problems at Fukushima caused by a tsunami could be discussed to illustrate the potential dangers.
Theory of knowledge:
• "There is no likelihood that humans will ever tap the power of the atom." (Robert Millikan, Nobel Laureate Physics 1923 quoted in 1928). How can the impact of new technologies be predicted? How reliable are these predictions? How important are the opinions of experts in the search for knowledge?
• The release of energy during fission reactions can be used in times of peace to generate energy, but also can lead to destruction in time of war. Should scientists be held morally responsible for the applications of their discoveries? Is there any area of scientific knowledge the pursuit of which is morally unacceptable?
Utilization:
Syllabus and cross-curricular links:
Topics 4.1 and 4.3—structure and bonding
Topic 16.1—first order reactions
Physics topic 7.2—nuclear fusion
Geography—the different polices and attitudes to nuclear energy are discussed in resources sections in the guide</td></tr>
</table>

C.7 Nuclear fusion and nuclear fission	
Applications and skills: *Nuclear fusion:* • Calculation of the mass defect and binding energy of a nucleus. • Application of the Einstein mass–energy equivalence relationship, $E = mc^2$, to determine the energy produced in a fusion reaction. *Nuclear fission:* • Application of the Einstein mass–energy equivalence relationship to determine the energy produced in a fission reaction. • Discussion of the different properties of UO_2 and UF_6 in terms of bonding and structure. • Solution of problems involving radioactive half-life. • Explanation of the relationship between Graham's law of effusion and the kinetic theory. • Solution of problems on the relative rate of effusion using Graham's law. **Guidance:** • Students are not expected to recall specific fission reactions. • The workings of a nuclear power plant are not required. • Safety and risk issues include: health, problems associated with nuclear waste, and the possibility that nuclear fuels may be used in nuclear weapons. • Graham's law of effusion is given in the data booklet in section 1. • Decay relationships are given in the data booklet in section 1. • A binding energy curve is given in the data booklet in section 36.	**Aims**: • **Aim 7**: Computer animations and simulations of radioactive decay, and nuclear fusion and fission reactions. • **Aim 8**: Consideration of the advantages and disadvantages of nuclear fusion illustrates the economic and environmental implications of using science and technology. The use of fusion reactions in the hydrogen bomb can also be discussed.

Essential idea: When solar energy is converted to electrical energy the light must be absorbed and charges must be separated. In a photovoltaic cell both of these processes occur in the silicon semiconductor, whereas these processes occur in separate locations in a dye-sensitized solar cell (DSSC).

<table>
<tr><th colspan="2">C.8 Photovoltaic cells and dye-sensitized solar cells (DSSC)</th></tr>
<tr><td colspan="2">Nature of science:
Transdisciplinary—a dye-sensitized solar cell, whose operation mimics photosynthesis and makes use of TiO_2 nanoparticles, illustrates the transdisciplinary nature of science and the link between chemistry and biology. (4.1)
Funding—the level of funding and the source of the funding is crucial in decisions regarding the type of research to be conducted. The first photovoltaic cells were produced by NASA for space probes and were only later used on Earth. (4.7)</td></tr>
<tr><td>Understandings:
• Molecules with longer conjugated systems absorb light of longer wavelength.
• The electrical conductivity of a semiconductor increases with an increase in temperature whereas the conductivity of metals decreases.
• The conductivity of silicon can be increased by doping to produce n-type and p-type semiconductors.
• Solar energy can be converted to electricity in a photovoltaic cell.
• DSSCs imitate the way in which plants harness solar energy. Electrons are "injected" from an excited molecule directly into the TiO_2 semiconductor.
• The use of nanoparticles coated with light-absorbing dye increases the effective surface area and allows more light over a wider range of the visible spectrum to be absorbed.
Applications and skills:
• Relation between the degree of conjugation in the molecular structure and the wavelength of the light absorbed.
• Explanation of the operation of the photovoltaic and dye-sensitized solar cell.
• Explanation of how nanoparticles increase the efficiency of DSSCs.
• Discussion of the advantages of the DSSC compared to the silicon-based</td>
<td>International-mindedness:
• The harnessing of solar energy could change the economic fortunes of countries with good supplies of sunlight and unused land.
Theory of knowledge:
• A conjugated system has some similarities with a violin string. How useful is this metaphor? What are the underlying reasons for these similarities? What role do models and metaphors play in the acquisition of knowledge?
Utilization:
Syllabus and cross-curricular links:
Topic 3.2—patterns in ionization energy
Topic 9.1—redox reactions
Biology topic 2.9—photosynthesis
Aims:
• Aim 6: Students could build an inexpensive dye-sensitized solar cell and investigate their photovoltaic properties.
• Aim 7: The properties of DSSCs can be best investigated using data loggers.</td></tr>
</table>

C.8 Photovoltaic cells and dye-sensitized solar cells (DSSC)	
photovoltaic cell. **Guidance:** • The relative conductivity of metals and semiconductors should be related to ionization energies. • Only a simple treatment of the operation of the cells is needed. In p-type semiconductors, electron holes in the crystal are created by introducing a small percentage of a group 3 element. In n-type semiconductors inclusion of a group 5 element provides extra electrons. • In a photovoltaic cell the light is absorbed and the charges separated in the silicon semiconductor. The processes of absorption and charge separation are separated in a dye-sensitized solar cell. • Specific redox and electrode reactions in the newer Grätzel DSSC should be covered. An example is the reduction of I_2/I_3^- ions to I^-.	

Core topics

Essential idea: Medicines and drugs have a variety of different effects on the functioning of the body.

D.1 Pharmaceutical products and drug action

Nature of science:

Risks and benefits—medicines and drugs go through a variety of tests to determine their effectiveness and safety before they are made commercially available. Pharmaceutical products are classified for their use and abuse potential. (4.8)

Understandings:

- In animal studies, the therapeutic index is the lethal dose of a drug for 50% of the population (*LD50*) divided by the minimum effective dose for 50% of the population (*ED50*).
- In humans, the therapeutic index is the toxic dose of a drug for 50% of the population (*TD50*) divided by the minimum effective dose for 50% of the population (*ED50*).
- The therapeutic window is the range of dosages between the minimum amounts of the drug that produce the desired effect and a medically unacceptable adverse effect.
- Dosage, tolerance, addiction and side effects are considerations of drug administration.
- Bioavailability is the fraction of the administered dosage that reaches the target part of the human body.
- The main steps in the development of synthetic drugs include identifying the need and structure, synthesis, yield and extraction.
- Drug–receptor interactions are based on the structure of the drug and the site of activity.

International-mindedness:

- In some countries certain drugs are only available with prescription while in other countries these same drugs are available over the counter.

Theory of knowledge:

- The same drug can be identified by different names. Are names simply labels or do they influence our other ways of knowing?
- Drugs trials use double blind tests. When is it ethically acceptable to deceive people?
- All drugs carry risks as well as benefits. Who should ultimately be responsible for assessing these? Public bodies can protect the individual but also limit their freedom. How do we know what is best for society and the individual?

Aims:

- **Aim 9**: There have been advances in the development of pharmaceuticals, but there are many limitations to their impact and reach.
- **Aim 10**: The development of new medicines is often done in collaboration with biologists and physicists.

D.1 Pharmaceutical products and drug action	
Applications and skills: • Discussion of experimental foundations for therapeutic index and therapeutic window through both animal and human studies. • Discussion of drug administration methods. • Comparison of how functional groups, polarity and medicinal administration can affect bioavailability. **Guidance:** • For ethical and economic reasons, animal and human tests of drugs (for LD_{50}/ED_{50} and TD_{50}/ED_{50} respectively) should be kept to a minimum.	

Essential idea: Natural products with useful medicinal properties can be chemically altered to produce more potent or safer medicines.

D.2 Aspirin and penicillin	
Nature of science: Serendipity and scientific discovery—the discovery of penicillin by Sir Alexander Fleming. (1.4) Making observations and replication of data—many drugs need to be isolated, identified and modified from natural sources. For example, salicylic acid from bark of willow tree for relief of pain and fever. (1.8)	
Understandings: *Aspirin:* • Mild analgesics function by intercepting the pain stimulus at the source, often by interfering with the production of substances that cause pain, swelling or fever. • Aspirin is prepared from salicylic acid. • Aspirin can be used as an anticoagulant, in prevention of the recurrence of heart attacks and strokes and as a prophylactic. *Penicillin:* • Penicillins are antibiotics produced by fungi. • A beta-lactam ring is a part of the core structure of penicillins. • Some antibiotics work by preventing cross-linking of the bacterial cell walls. • Modifying the side-chain results in penicillins that are more resistant to the penicillinase enzyme.	**International-mindedness:** • Aspirin is used in many different ways across the globe. • The first antibacterial changed the way that disease was treated across the globe. **Theory of knowledge:** • Different painkillers act in different ways. How do we perceive pain, and how are our perceptions influenced by the other ways of knowing? • "Chance favours only the prepared mind." (Louis Pasteur). Fleming's discovery of penicillin is often described as serendipitous but the significance of his observations would have been missed by non-experts. What influence does an open-minded attitude have on our perceptions? **Utilization:** Syllabus and cross-curricular links: Topic 1.3—yield of reaction Topic 10.2—functional groups Biology topic 6.3—defence against infectious disease

D.2 Aspirin and penicillin	
Applications and skills: *Aspirin* • Description of the use of salicylic acid and its derivatives as mild analgesics. • Explanation of the synthesis of aspirin from salicylic acid, including yield, purity by recrystallization and characterization using IR and melting point. • Discussion of the synergistic effects of aspirin with alcohol. • Discussion of how the aspirin can be chemically modified into a salt to increase its aqueous solubility and how this facilitates its bioavailability. *Penicillin* • Discussion of the effects of chemically modifying the side-chain of penicillins. • Discussion of the importance of patient compliance and the effects of the over-prescription of penicillin. • Explanation of the importance of the beta-lactam ring on the action of penicillin. **Guidance:** • Students should be aware of the ability of acidic (carboxylic) and basic (amino) groups to form ionic salts, for example soluble aspirin. • Structures of aspirin and penicillin are available in the data booklet in section 37.	**Aims:** • **Aim 6**: Experiments could include the synthesis of aspirin. • **Aim 8**: Discuss the use/overuse of antibiotics for animals.

Essential idea: Potent medical drugs prepared by chemical modification of natural products can be addictive and become substances of abuse.

D.3 Opiates

Nature of science:

Data and its subsequent relationships—opium and its many derivatives have been used as a painkiller in a variety of forms for thousands of years. One of these derivatives is diamorphine. (3.1)

Understandings:

- The ability of a drug to cross the blood–brain barrier depends on its chemical structure and solubility in water and lipids.
- Opiates are natural narcotic analgesics that are derived from the opium poppy.
- Morphine and codeine are used as strong analgesics. Strong analgesics work by temporarily bonding to receptor sites in the brain, preventing the transmission of pain impulses without depressing the central nervous system.
- Medical use and addictive properties of opiate compounds are related to the presence of opioid receptors in the brain.

Applications and skills:

- Explanation of the synthesis of codeine and diamorphine from morphine.
- Description and explanation of the use of strong analgesics.
- Comparison of the structures of morphine, codeine and diamorphine (heroin).
- Discussion of the advantages and disadvantages of using morphine and its derivatives as strong analgesics.
- Discussion of side effects and addiction to opiate compounds.
- Explanation of the increased potency of diamorphine compared to morphine based on their chemical structure and solubility.

Guidance:

- Structures of morphine, codeine and diamorphine can be found in the data booklet in section 37.

International-mindedness:

- Many illegal drugs are cultivated or produced in a small number of countries and then sold and distributed globally. Cultural and economic viewpoints differ on the production and sale of opiates around the world.

Theory of knowledge:

- Cultures often clash over different perspectives and ideas. Is there any knowledge which is independent of culture?

Utilization:

Syllabus and cross-curricular links:
Topic 10.2—functional groups

Aims:

- **Aim 7**: Use computer animations for the investigation of 3-D visualizations of drugs and receptor sites.

Essential idea: Excess stomach acid is a common problem that can be alleviated by compounds that increase the stomach pH by neutralizing or reducing its secretion.

D.4 pH regulation of the stomach

Nature of science:

Collecting data through sampling and trialling—one of the symptoms of dyspepsia is the overproduction of stomach acid. Medical treatment of this condition often includes the prescription of antacids to instantly neutralize the acid, or H_2-receptor antagonists or proton pump inhibitors which prevent the production of stomach acid. (2.8)

Understandings:

- Non-specific reactions, such as the use of antacids, are those that work to reduce the excess stomach acid.
- Active metabolites are the active forms of a drug after it has been processed by the body.

Applications and skills:

- Explanation of how excess acidity in the stomach can be reduced by the use of different bases.
- Construction and balancing of equations for neutralization reactions and the stoichiometric application of these equations.
- Solving buffer problems using the Henderson–Hasselbalch equation.
- Explanation of how compounds such as ranitidine (Zantac) can be used to inhibit stomach acid production.
- Explanation of how compounds like omeprazole (Prilosec) and esomeprazole (Nexium) can be used to suppress acid secretion in the stomach.

Guidance:

- Antacid compounds should include calcium hydroxide, magnesium hydroxide, aluminium hydroxide, sodium carbonate and sodium bicarbonate.
- Structures for ranitidine and esomeprazole can be found in the data booklet in section 37.

International-mindedness:

- Different cultures (ie diet, lifestyle, etc) and genetics can affect the need for pH regulation of the stomach.

Theory of knowledge:

- Sometimes we utilize different approaches to solve the same problem. How do we decide between competing evidence and approaches?

Utilization:

Syllabus and cross-curricular links:
Topic 1.3—calculations involving solutions
Topics 8.2 and 8.4—neutralization
Topic 10.2—functional groups
Topic 20.3—enantiomers
Option B.7—amino acid buffers
Biology option D.1—digestion

Aims:

- **Aim 6**: Experiments could include titrations to test the effectiveness of various antacids.

Essential idea: Antiviral medications have recently been developed for some viral infections while others are still being researched.

D.5 Antiviral medications	
Nature of science: Scientific collaboration—recent research in the scientific community has improved our understanding of how viruses invade our systems. (4.1)	
Understandings: • Viruses lack a cell structure and so are more difficult to target with drugs than bacteria. • Antiviral drugs may work by altering the cell's genetic material so that the virus cannot use it to multiply. Alternatively, they may prevent the viruses from multiplying by blocking enzyme activity within the host cell. **Applications and skills:** • Explanation of the different ways in which antiviral medications work. • Description of how viruses differ from bacteria. • Explanation of how oseltamivir (Tamiflu) and zanamivir (Relenza) work as a preventative agent against flu viruses. • Comparison of the structures of oseltamivir and zanamivir. • Discussion of the difficulties associated with solving the AIDS problem. **Guidance:** • Structures for oseltamivir and zanamivir can be found in the data booklet in section 37.	**International-mindedness:** • How has the AIDS epidemic changed since its discovery in the early 1980s? What is needed to stop the spread of the disease? What is the global impact of this disease? **Utilization:** Syllabus and cross-curricular links: Options B.2 and B.7—proteins and enzymes Biology topic 11.1—vaccination **Aims:** • **Aim 8**: The control and treatment of HIV is exacerbated by the high price of anti-retroviral agents and sociocultural issues.

Essential idea: The synthesis, isolation, and administration of medications can have an effect on the environment.

D.6 Environmental impact of some medications	
Nature of science: Ethical implications and risks and problems—the scientific community must consider both the side effects of medications on the patient and the side effects of the development, production and use of medications on the environment (ie disposal of nuclear waste, solvents and antibiotic waste). (4.8)	
Understandings: • High-level waste (HLW) is waste that gives off large amounts of ionizing radiation for a long time. • Low-level waste (LLW) is waste that gives off small amounts of ionizing radiation for a short time. • Antibiotic resistance occurs when micro-organisms become resistant to antibacterials. **Applications and skills:** • Describe the environmental impact of medical nuclear waste disposal. • Discussion of environmental issues related to left-over solvents. • Explanation of the dangers of antibiotic waste, from improper drug disposal and animal waste, and the development of antibiotic resistance. • Discussion of the basics of green chemistry (sustainable chemistry) processes. • Explanation of how green chemistry was used to develop the precursor for Tamiflu (oseltamivir). **Guidance:** • The structure of oseltamivir is provided in the data booklet in section 37.	**International-mindedness:** • Consider how pharmaceutical companies determine how to spend research funds to develop new medications. • Do pharmaceutical companies have a responsibility to do research on rare diseases that will not provide them with significant financial profit? • Production of a drug typically involves a number of different organic reactions. What are the ethics governing the design (synthesis) of drugs? Do standards and practices vary by country and region? **Theory of knowledge:** • How do we balance ethical concerns that appear to be at odds with each other when trying to formulate a solution to the problem? **Aims:** • **Aim 8**: How do we safely dispose of medicinal nuclear waste? • **Aim 8**: The Pacific yew tree which is the source of the chemotherapy drug Taxol is facing extinction. • **Aim 8**: Solvent disposal is a growing environmental problem.

Additional higher level topics

Essential idea: Chiral auxiliaries allow the production of individual enantiomers of chiral molecules.

D.7 Taxol—a chiral auxiliary case study	
Nature of science: Advances in technology—many of these natural substances can now be produced in laboratories in high enough quantities to satisfy the demand. (3.7) Risks and problems—the demand for certain drugs has exceeded the supply of natural substances needed to synthesize these drugs. (4.8)	
Understandings: • Taxol is a drug that is commonly used to treat several different forms of cancer. • Taxol naturally occurs in yew trees but is now commonly synthetically produced. • A chiral auxiliary is an optically active substance that is temporarily incorporated into an organic synthesis so that it can be carried out asymmetrically with the selective formation of a single enantiomer. **Applications and skills:** • Explanation of how taxol (paclitaxel) is obtained and used as a chemotherapeutic agent. • Description of the use of chiral auxiliaries to form the desired enantiomer. • Explanation of the use of a polarimeter to identify enantiomers. **Guidance:** • The structure of taxol is provided in the data booklet in section 37.	**International-mindedness:** • There is an unequal availability and distribution of certain drugs and medicines around the globe. **Utilization:** Syllabus and cross-curricular links: Topic 20.2—synthetic routes Topic 20.3—stereoisomerism **Aims:** • **Aim 8**: Consider the ethical implications of using synthetic drugs instead of natural sources.

Essential idea: Nuclear radiation, whilst dangerous owing to its ability to damage cells and cause mutations, can also be used to both diagnose and cure diseases.

D.8 Nuclear medicine

Nature of science:

Risks and benefits—it is important to try and balance the risk of exposure to radiation with the benefit of the technique being considered. (4.8)

Understandings:

- Alpha, beta, gamma, proton, neutron and positron emissions are all used for medical treatment.
- Magnetic resonance imaging (MRI) is an application of NMR technology.
- Radiotherapy can be internal and/or external.
- Targeted Alpha Therapy (TAT) and Boron Neutron Capture Therapy (BNCT) are two methods which are used in cancer treatment.

Applications and skills:

- Discussion of common side effects from radiotherapy.
- Explanation of why technetium-99m is the most common radioisotope used in nuclear medicine based on its half-life, emission type and chemistry.
- Explanation of why lutetium-177 and yttrium-90 are common isotopes used for radiotherapy based on the type of radiation emitted.
- Balancing nuclear equations involving alpha and beta particles.
- Calculation of the percentage and amount of radioactive material decayed and remaining after a certain period of time using the nuclear half-life equation.
- Explanation of TAT and how it might be used to treat diseases that have spread throughout the body.

Guidance:

- Common side effects discussed should include hair loss, nausea, fatigue and sterility. Discussion should include the damage to DNA and growing or regenerating tissue.
- Isotopes used in nuclear medicine including; Tc-99m, Lu-177, Y-90, I-131 and Pb-212.

International-mindedness:

- The use of nuclear technology in medical treatments is not consistent across the globe. Culture, cost, availability and beliefs are some factors that can influence its use.

Theory of knowledge:

- There is often no reference to the term “nuclear” in MRI. Are names simply labels or do they influence our other ways of knowing? How does public perception influence scientific progress and implementation?

Utilization:

Syllabus and cross-curricular links:
Topics 11.3 and 21.1—NMR
Options C.3 and C.7—nuclear reactions and half-life
Physics option C.4—medical imaging.

Essential idea: A variety of analytical techniques is used for detection, identification, isolation and analysis of medicines and drugs.

D.9 Drug detection and analysis	
Nature of science: Advances in instrumentation—advances in technology (IR, MS and NMR) have assisted in drug detection, isolation and purification. (3.7)	
Understandings: • Organic structures can be analysed and identified through the use of infrared spectroscopy, mass spectroscopy and proton NMR. • The presence of alcohol in a sample of breath can be detected through the use of either a redox reaction or a fuel cell type of breathalyser. **Applications and skills:** • Interpretation of a variety of analytical spectra to determine an organic structure including infrared spectroscopy, mass spectroscopy and proton NMR. • Description of the process of extraction and purification of an organic product. Consider the use of fractional distillation, Raoult's law, the properties on which extractions are based and explaining the relationship between organic structure and solubility. • Description of the process of steroid detection in sport utilizing chromatography and mass spectroscopy. • Explanation of how alcohol can be detected with the use of a breathalyser. **Guidance:** • Students should be able to identify common organic functional groups in a given compound by recognition of common drug structures and from IR (section 26 of the data booklet), ^{1}H NMR (section 27 of the data booklet) and mass spectral fragment (section 28 of the data booklet) data. • A common steroid structure is provided in section 34 in the data booklet.	**International-mindedness:** • The misuse of drugs in sport is an international problem. **Theory of knowledge:** • Developments in technology have increased the chances of people being caught using illegal substances. How do changes in technology influence our ethical choices? **Utilization:** Syllabus and cross-curricular links: Topic 10.2—functional groups **Aims:** • **Aim 4**: A variety of spectroscopy techniques can be used to identify newly developed molecules. • **Aim 7**: Computer databases with spectroscopy data could be used to confirm the identity of newly synthesized molecules. • **Aim 8**: Developments in technology have increased the chances of people being caught using illegal substances. How do changes in technology influence our ethical choices?

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 are that it should support curricular goals and encourage appropriate student learning. Both external and internal assessments are used in the Diploma Programme. 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.
- Summative assessment gives an overview of previous learning and is concerned with measuring student achievement.

The Diploma Programme primarily focuses on summative assessment designed to record student achievement at, or towards the end of, the course of study. However, many of the assessment instruments can also be used formatively during the course of teaching and learning, and teachers are encouraged to do this. A comprehensive assessment plan is viewed as being integral with teaching, learning and course organization. For further information, see the IB *Programme standards and practices* (2010) document.

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 Diploma Programme please refer to the publication *Diploma Programme assessment: principles and practice* (2009).

To support teachers in the planning, delivery and assessment of the Diploma Programme courses, a variety of resources can be found on the OCC or purchased from the IB store (http://store.ibo.org). Additional publications such as specimen papers and markschemes, teacher support materials, subject reports and grade descriptors can also be found on the OCC. 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 assessment arrangements

Inclusive assessment arrangements are available for candidates with assessment access requirements. These arrangements enable candidates with diverse needs to access the examinations and demonstrate their knowledge and understanding of the constructs being assessed.

The IB document *Candidates with assessment access requirements* provides details on all the inclusive assessment arrangements available to candidates with learning support requirements. The IB document *Learning diversity and the IB programmes: Special educational needs within the International Baccalaureate programmes* 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 IB documents *General regulations: Diploma Programme* (2011) and the *Handbook of procedures for the Diploma Programme* provide 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 *Candidates with assessment access requirements* and *Learning diversity and the IB programmes: Special educational needs within the International Baccalaureate programmes*.

Assessment outline—SL

First assessment 2016

Component	Overall weighting (%)	Approximate weighting of objectives (%)		Duration (hours)
		1+2	3	
Paper 1	20	10	10	¾
Paper 2	40	20	20	1¼
Paper 3	20	10	10	1
Internal assessment	20	Covers objectives 1, 2, 3 and 4		10

Assessment outline—HL

First assessment 2016

Component	Overall weighting (%)	Approximate weighting of objectives (%)		Duration (hours)
		1+2	3	
Paper 1	20	10	10	1
Paper 2	36	18	18	2¼
Paper 3	24	12	12	1¼
Internal assessment	20	Covers objectives 1, 2, 3 and 4		10

External assessment

Detailed markschemes specific to each examination paper are used to assess students.

External assessment details—SL

Paper 1

Duration: 3/4 hour
Weighting: 20%
Marks: 30

- 30 multiple-choice questions on core, about 15 of which are common with HL.
- The questions on paper 1 test assessment objectives 1, 2 and 3.
- The use of calculators is not permitted.
- Students will be provided with a periodic table.
- No marks are deducted for incorrect answers.

Paper 2

Duration: 1¼ hours
Weighting: 40%
Marks: 50

- Short-answer and extended-response questions on core material.
- The questions on paper 2 test assessment objectives 1, 2 and 3.
- The use of calculators is permitted. (See calculator section on the OCC.)
- A chemistry data booklet is to be provided by the school.

Paper 3

Duration: 1 hour
Weighting: 20%
Marks: 35

- This paper will have questions on core and SL option material.
- Section A: one data-based question and several short-answer questions on experimental work.
- Section B: short-answer and extended-response questions from one option.
- The questions on paper 3 test assessment objectives 1, 2 and 3.
- The use of calculators is permitted. (See calculator section on the OCC.)
- A chemistry data booklet is to be provided by the school.

External assessment details—HL

Paper 1

Duration: 1 hour
Weighting: 20%
Marks: 40

- 40 multiple-choice questions on core and AHL, about 15 of which are common with SL.
- The questions on paper 1 test assessment objectives 1, 2 and 3.
- The use of calculators is not permitted.
- Students will be provided with a periodic table.
- No marks are deducted for incorrect answers.

Paper 2

Duration: 2¼ hours
Weighting: 36%
Marks: 95

- Short-answer and extended-response questions on the core and AHL material.
- The questions on paper 2 test assessment objectives 1, 2 and 3.
- The use of calculators is permitted. (See calculator section on the OCC.)
- A chemistry data booklet is to be provided by the school.

Paper 3

Duration: 1¼ hours
Weighting: 24%
Marks: 45

- This paper will have questions on core, AHL and option material.
- Section A: one data-based question and several short-answer questions on experimental work.
- Section B: short-answer and extended-response questions from one option.
- The questions on paper 3 test assessment objectives 1, 2 and 3.
- The use of calculators is permitted. (See calculator section on the OCC.)
- A chemistry data booklet is to be provided by the school.

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. This internal assessment section of the guide should be read in conjunction with the internal assessment section of the teacher support materials.

Guidance and authenticity

The work 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 IB animal experimentation policy
- 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 honesty, 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 academic misconduct. Each student must confirm that the work is his or her 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 publication *Academic honesty* (2011), *The Diploma Programme: From principles into practice* (2009) and the relevant articles in *General regulations: Diploma Programme* (2011).

Authenticity may be checked by discussion with the student on the content of the work, and 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 http://www.turnitin.com.

The same piece of work cannot be submitted to meet the requirements of both the internal assessment and the extended essay.

Group work

Each investigation is an individual piece of work based on different data collected or measurements generated. Ideally, students should work on their own when collecting data. In some cases, data collected or measurements made can be from a group experiment, provided each student collected his or her own data or made his or her own measurements. In chemistry, in some cases, group data or measurements may be combined to provide enough for individual analysis. Even in this case, each student should have collected and recorded their own data and they should clearly indicate which data are theirs.

It should be made clear to students that all work connected with the investigation should be their own. It is therefore helpful if teachers try to encourage in students a sense of responsibility for their own learning so that they accept a degree of ownership and take pride in their own work.

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 of teaching time for both SL and HL 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

While teachers are responsible for following national or local guidelines, which may differ from country to country, attention should be given to the guidelines below, which were developed for the International Council of Associations for Science Education (ICASE) Safety Committee by The Laboratory Safety Institute (LSI).

It is a basic responsibility of everyone involved to make safety and health an ongoing commitment. Any advice given will acknowledge the need to respect the local context, the varying educational and cultural traditions, the financial constraints and the legal systems of differing countries.

The Laboratory Safety Institute's Laboratory Safety Guidelines ...

40 suggestions for a safer lab

Steps Requiring Minimal Expense

1. Have a written health, safety and environmental affairs (HS&E) policy statement.
2. Organize a departmental HS&E committee of employees, management, faculty, staff and students that will meet regularly to discuss HS&E issues.
3. Develop an HS&E orientation for all new employees and students.
4. Encourage employees and students to care about their health and safety and that of others.
5. Involve every employee and student in some aspect of the safety program and give each specific responsibilities.
6. Provide incentives to employees and students for safety performance.
7. Require all employees to read the appropriate safety manual. Require students to read the institution's laboratory safety rules. Have both groups sign a statement that they have done so, understand the contents, and agree to follow the procedures and practices. Keep these statements on file in the department office.
8. Conduct periodic, unannounced laboratory inspections to identify and correct hazardous conditions and unsafe practices. Involve students and employees in simulated OSHA inspections.
9. Make learning how to be safe an integral and important part of science education, your work, and your life.
10. Schedule regular departmental safety meetings for all students and employees to discuss the results of inspections and aspects of laboratory safety.
11. When conducting experiments with hazards or potential hazards, ask yourself these questions:
    - What are the hazards?
    - What are the worst possible things that could go wrong?
    - How will I deal with them?
    - What are the prudent practices, protective facilities and equipment necessary to minimize the risk of exposure to the hazards?
12. Require that all accidents (incidents) be reported, evaluated by the departmental safety committee, and discussed at departmental safety meetings.
13. Require every pre-lab/pre-experiment discussion to include consideration of the health and safety aspects.
14. Don't allow experiments to run unattended unless they are failsafe.
15. Forbid working alone in any laboratory and working without prior knowledge of a staff member.
16. Extend the safety program beyond the laboratory to the automobile and the home.
17. Allow only minimum amounts of flammable liquids in each laboratory.
18. Forbid smoking, eating and drinking in the laboratory.
19. Do not allow food to be stored in chemical refrigerators.

20. Develop plans and conduct drills for dealing with emergencies such as fire, explosion, poisoning, chemical spill or vapour release, electric shock, bleeding and personal contamination.
21. Require good housekeeping practices in all work areas.
22. Display the phone numbers of the fire department, police department, and local ambulance either on or immediately next to every phone.
23. Store acids and bases separately. Store fuels and oxidizers separately.
24. Maintain a chemical inventory to avoid purchasing unnecessary quantities of chemicals.
25. Use warning signs to designate particular hazards.
26. Develop specific work practices for individual experiments, such as those that should be conducted only in a ventilated hood or involve particularly hazardous materials. When possible most hazardous experiments should be done in a hood.

Steps Requiring Moderate Expense

27. Allocate a portion of the departmental budget to safety.
28. Require the use of appropriate eye protection at all times in laboratories and areas where chemicals are transported.
29. Provide adequate supplies of personal protective equipment—safety glasses, goggles, face shields, gloves, lab coats and bench top shields.
30. Provide fire extinguishers, safety showers, eye wash fountains, first aid kits, fire blankets and fume hoods in each laboratory and test or check monthly.
31. Provide guards on all vacuum pumps and secure all compressed gas cylinders.
32. Provide an appropriate supply of first aid equipment and instruction on its proper use.
33. Provide fireproof cabinets for storage of flammable chemicals.
34. Maintain a centrally located departmental safety library:
    - "Safety in School Science Labs", Clair Wood, 1994, Kaufman & Associates, 101 Oak Street, Wellesley, MA 02482
    - "The Laboratory Safety Pocket Guide", 1996, Genium Publisher, One Genium Plaza, Schnectady, NY
    - "Safety in Academic Chemistry Laboratories", ACS, 1155 Sixteenth Street NW, Washington, DC 20036
    - "Manual of Safety and Health Hazards in The School Science Laboratory", "Safety in the School Science Laboratory", "School Science Laboratories: A guide to Some Hazardous Substances" Council of State Science Supervisors (now available only from LSI.)
    - "Handbook of Laboratory Safety", 4th Edition, CRC Press, 2000 Corporate Boulevard NW, Boca Raton, FL 33431
    - "Fire Protection Guide on Hazardous Materials", National Fire Protection Association, Batterymarch Park, Quincy, MA 02269
    - "Prudent Practices in the Laboratory: Handling and Disposal of Hazardous Chemicals", 2nd Edition, 1995
    - "Biosafety in the Laboratory", National Academy Press, 2101 Constitution Avenue, NW, Washington, DC 20418
    - "Learning By Accident", Volumes 1-3, 1997-2000, The Laboratory Safety Institute, Natick, MA 01760

    (All are available from LSI.)

35. Remove all electrical connections from inside chemical refrigerators and require magnetic closures.

36. Require grounded plugs on all electrical equipment and install ground fault interrupters (GFIs) where appropriate.

37. Label all chemicals to show the name of the material, the nature and degree of hazard, the appropriate precautions, and the name of the person responsible for the container.

38. Develop a program for dating stored chemicals and for recertifying or discarding them after predetermined maximum periods of storage.

39. Develop a system for the legal, safe and ecologically acceptable disposal of chemical wastes.

40. Provide secure, adequately spaced, well ventilated storage of chemicals.

LSi The Laboratory Safety Institute

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.

- Assessment criteria are the same for both 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 or more 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.

Practical work and internal assessment

General introduction

The internal assessment requirements are the same for biology, chemistry and physics. The internal assessment, worth 20% of the final assessment, consists of one scientific investigation. The individual investigation should cover a topic that is commensurate with the level of the course of study.

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

> **Note:** Any investigation that is to be used to assess students should be specifically designed to match the assessment criteria.

The internal assessment task will be one scientific investigation taking about 10 hours and the write-up should be about 6 to 12 pages long. Investigations exceeding this length will be penalized in the communication criterion as lacking in conciseness.

The practical investigation, with generic criteria, will allow a wide range of practical activities satisfying the varying needs of biology, chemistry and physics. The investigation addresses many of the learner profile attributes well. See section on "Approaches to the teaching of chemistry" for further links.

The task produced should be complex and commensurate with the level of the course. It should require a purposeful research question and the scientific rationale for it. The marked exemplar material in the teacher support materials will demonstrate that the assessment will be rigorous and of the same standard as the assessment in the previous courses.

Some of the possible tasks include:

- a hands-on laboratory investigation
- using a spreadsheet for analysis and modelling
- extracting data from a database and analysing it graphically
- producing a hybrid of spreadsheet/database work with a traditional hands-on investigation
- using a simulation provided it is interactive and open-ended.

Some tasks may consist of relevant and appropriate qualitative work combined with quantitative work.

The tasks include the traditional hands-on practical investigations as in the previous course. The depth of treatment required for hands-on practical investigations is unchanged from the previous internal assessment and will be shown in detail in the teacher support materials. In addition, detailed assessment of specific aspects of hands-on practical work will be assessed in the written papers as detailed in the relevant topic(s) in the "Syllabus content" section of the guide.

The task will have the same assessment criteria for SL and HL. The five assessment criteria are personal engagement, exploration, analysis, evaluation and communication.

Internal assessment details

Internal assessment component

Duration: 10 hours

Weighting: 20%

- Individual investigation
- This investigation covers assessment objectives 1, 2, 3 and 4.

Internal assessment criteria

The new assessment model uses five criteria to assess the final report of the individual investigation with the following raw marks and weightings assigned:

Personal engagement	Exploration	Analysis	Evaluation	Communication	Total
2 (8%)	6 (25%)	6 (25%)	6 (25%)	4 (17%)	24 (100%)

Levels of performance are described using multiple indicators per level. In many cases the indicators occur together in a specific level, but not always. Also, not all indicators are always present. This means that a candidate can demonstrate performances that fit into different levels. To accommodate this, the IB assessment models use markbands and advise examiners and teachers to use a **best-fit approach** in deciding the appropriate mark for a particular criterion.

Teachers should read the guidance on using markbands shown above in the section called "Using assessment criteria for internal assessment" before starting to mark. It is also essential to be fully acquainted with the marking of the exemplars in the teacher support material. The precise meaning of the command terms used in the criteria can be found in the glossary of the subject guides.

Personal engagement

This criterion assesses the extent to which the student engages with the exploration and makes it their own. Personal engagement may be recognized in different attributes and skills. These could include addressing personal interests or showing evidence of independent thinking, creativity or initiative in the designing, implementation or presentation of the investigation.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1	**The evidence of personal engagement with the exploration is limited with little independent thinking, initiative or creativity**. The justification given for choosing the research question and/or the topic under investigation does not demonstrate **personal significance**, **interest or curiosity**. There is little evidence of **personal input and initiative** in the designing, implementation or presentation of the investigation.
2	**The evidence of personal engagement with the exploration is clear with significant independent thinking, initiative or creativity.** The justification given for choosing the research question and/or the topic under investigation demonstrates **personal significance**, **interest or curiosity**. There is evidence of **personal input and initiative** in the designing, implementation or presentation of the investigation.

Exploration

This criterion assesses the extent to which the student establishes the scientific context for the work, states a clear and focused research question and uses concepts and techniques appropriate to the Diploma Programme level. Where appropriate, this criterion also assesses awareness of safety, environmental, and ethical considerations.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1–2	The topic of the investigation is identified and a research question of some relevance is **stated but it is not focused**. The background information provided for the investigation is **superficial** or of limited relevance and does not aid the understanding of the context of the investigation. The methodology of the investigation is only appropriate to address the research question to a very limited extent since it takes into consideration few of the significant factors that may influence the relevance, reliability and sufficiency of the collected data. The report shows evidence of limited awareness of the significant safety, ethical or environmental issues that are **relevant to the methodology of the investigation***.
3–4	The topic of the investigation is identified and a relevant but not fully focused research question is described. The background information provided for the investigation is mainly appropriate and relevant and aids the understanding of the context of the investigation. The methodology of the investigation is mainly appropriate to address the research question but has limitations since it takes into consideration only some of the significant factors that may influence the relevance, reliability and sufficiency of the collected data. The report shows evidence of some awareness of the significant safety**,** ethical or environmental issues that are **relevant to the methodology of the investigation.***

Mark	Descriptor
5–6	The topic of the investigation is identified and a relevant and fully focused research question is clearly described. The background information provided for the investigation is entirely appropriate and relevant and enhances the understanding of the context of the investigation. The methodology of the investigation is highly appropriate to address the research question because it takes into consideration all, or nearly all, of the significant factors that may influence the relevance, reliability and sufficiency of the collected data. The report shows evidence of full awareness of the significant safety, ethical or environmental issues that are **relevant to the methodology of the investigation**.*

* This indicator should only be applied when appropriate to the investigation. See exemplars in TSM.

Analysis

This criterion assesses the extent to which the student's report provides evidence that the student has selected, recorded, processed and **interpreted** the data in ways that are relevant to the research question and can support a conclusion.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1–2	The report includes **insufficient relevant** raw data to support a valid conclusion to the research question. Some **basic** data processing is carried out but is either too **inaccurate or too insufficient to lead to a valid** conclusion. The report shows evidence of little consideration of the impact of measurement uncertainty on the analysis. The processed data is incorrectly or insufficiently interpreted so that the conclusion is invalid or very incomplete.
3–4	The report includes relevant but incomplete quantitative and qualitative raw data that could support a simple or partially valid conclusion to the research question. Appropriate and sufficient data processing is carried out that could lead to a broadly valid conclusion but there are significant inaccuracies and inconsistencies in the processing. The report shows evidence of some consideration of the impact of measurement uncertainty on the analysis. The processed data is interpreted so that a broadly valid but incomplete or limited conclusion to the research question can be deduced.
5–6	The report includes sufficient relevant quantitative and qualitative raw data that could support a detailed and valid conclusion to the research question. Appropriate and sufficient data processing is carried out with **the accuracy** required to enable a conclusion to the research question to be drawn that is fully **consistent** with the experimental data. The report shows evidence of full and appropriate consideration of the impact of measurement uncertainty on the analysis. The processed data is correctly interpreted so that a completely valid and detailed conclusion to the research question can be deduced.

Evaluation

This criterion assesses the extent to which the student's report provides evidence of evaluation of the investigation and the results with regard to the research question and the accepted scientific context.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1–2	A conclusion is **outlined** which is not relevant to the research question or is not supported by the data presented. The conclusion makes superficial comparison to the accepted scientific context. Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are **outlined** but are restricted to an **account** of **the practical** or **procedural issues** faced. The student has **outlined** very few realistic and relevant suggestions for the improvement and extension of the investigation.
3–4	A conclusion is **described** which is relevant to the research question and supported by the data presented. A conclusion is described which makes some relevant comparison to the accepted scientific context. Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are **described** and provide evidence of some awareness of the **methodological issues*** involved in establishing the conclusion. The student has **described** some realistic and relevant suggestions for the improvement and extension of the investigation.
5–6	A detailed conclusion is **described and justified** which is entirely relevant to the research question and fully supported by the data presented. A conclusion is correctly **described and justified** through relevant comparison to the accepted scientific context. Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are **discussed** and provide evidence of a clear understanding of the **methodological issues*** involved in establishing the conclusion. The student has **discussed** realistic and relevant suggestions for the improvement and extension of the investigation.

*See exemplars in TSM for clarification.

Communication

This criterion assesses whether the investigation is presented and reported in a way that supports effective communication of the focus, process and outcomes.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1–2	**The presentation of the investigation is unclear, making it difficult to understand the focus, process and outcomes.** The report is not well structured and is unclear: the necessary information on focus, process and outcomes is missing or is presented in an incoherent or disorganized way. The understanding of the focus, process and outcomes of the investigation is obscured by the presence of inappropriate or irrelevant information. There are many errors in the use of subject specific terminology and conventions*.
3–4	**The presentation of the investigation is clear. Any errors do not hamper understanding of the focus, process and outcomes**. The report is well structured and clear: the necessary information on focus, process and outcomes is present and presented in a coherent way. The report is relevant and concise thereby facilitating a ready understanding of the focus, process and outcomes of the investigation. The use of subject specific terminology and conventions is appropriate and correct. Any errors do not hamper understanding.

*For example, incorrect/missing labelling of graphs, tables, images; use of units, decimal places. For issues of referencing and citations refer to the "Academic honesty" section.

Rationale for practical work

Although the requirements for IA are centred on the investigation, the different types of practical activities that a student may engage in serve other purposes, including:

- illustrating, teaching and reinforcing theoretical concepts
- developing an appreciation of the essential hands-on nature of much scientific work
- developing an appreciation of scientists' use of secondary data from databases
- developing an appreciation of scientists' use of modelling
- developing an appreciation of the benefits and limitations of scientific methodology.

Practical scheme of work

The practical scheme of work (PSOW) is the practical course planned by the teacher and acts as a summary of all the investigative activities carried out by a student. Students at SL and HL in the same subject may carry out some of the same investigations.

Syllabus coverage

The range of practical work carried out should reflect the breadth and depth of the subject syllabus at each level, but it is not necessary to carry out an investigation for every syllabus topic. However, all students must participate in the group 4 project and the IA investigation.

Planning your practical scheme of work

Teachers are free to formulate their own practical schemes of work by choosing practical activities according to the requirements outlined. Their choices should be based on:

- subjects, levels and options taught
- the needs of their students
- available resources
- teaching styles.

Each scheme must include some complex experiments that make greater conceptual demands on students. A scheme made up entirely of simple experiments, such as ticking boxes or exercises involving filling in tables, will not provide an adequate range of experience for students.

Teachers are encouraged to use the online curriculum centre (OCC) to share ideas about possible practical activities by joining in the discussion forums and adding resources in the subject home pages.

Flexibility

The practical programme is flexible enough to allow a wide variety of practical activities to be carried out. These could include:

- short labs or projects extending over several weeks
- computer simulations
- using databases for secondary data
- developing and using models
- data-gathering exercises such as questionnaires, user trials and surveys
- data-analysis exercises
- fieldwork.

Practical work documentation

Details of the practical scheme of work are recorded on *Form 4/PSOW* provided in the *Handbook of procedures*. A copy of the class *4/PSOW* form must be included with any sample set sent for moderation. For an SL only class or an HL only class, only one 4/PSOW is required, but for a mixed SL/HL class, separate 4/PSOW forms are required for SL and HL.

Time allocation for practical work

The recommended teaching times for all Diploma Programme courses are 150 hours at SL and 240 hours at HL. Students at SL are required to spend 40 hours, and students at HL 60 hours, on practical activities (excluding time spent writing up work). These times include 10 hours for the group 4 project and 10 hours for the internal assessment investigation. (Only 2–3 hours of investigative work can be carried out after the deadline for submitting work to the moderator and still be counted in the total number of hours for the practical scheme of work.)

The group 4 project

The group 4 project is an interdisciplinary activity in which all Diploma Programme science students must participate. The intention is that students from the different group 4 subjects analyse a common topic or problem. The exercise should be a collaborative experience where the emphasis is on the processes involved in, rather than the products of, such an activity.

In most cases students in a school would be involved in the investigation of the same topic. Where there are large numbers of students, it is possible to divide them into several smaller groups containing representatives from each of the science subjects. Each group may investigate the same topic or different topics—that is, there may be several group 4 projects in the same school.

Students studying environmental systems and societies are not required to undertake the group 4 project.

Summary of the group 4 project

The group 4 project is a collaborative activity where students from different group 4 subjects work together on a scientific or technological topic, allowing for concepts and perceptions from across the disciplines to be shared in line with aim 10—that is, to "develop an understanding of the relationships between scientific disciplines and their influence on other areas of knowledge". The project can be practically or theoretically based. Collaboration between schools in different regions is encouraged.

The group 4 project allows students to appreciate the environmental, social and ethical implications of science and technology. It may also allow them to understand the limitations of scientific study, for example, the shortage of appropriate data and/or the lack of resources. The emphasis is on interdisciplinary cooperation and the processes involved in scientific investigation, rather than the products of such investigation.

The choice of scientific or technological topic is open but the project should clearly address aims 7, 8 and 10 of the group 4 subject guides.

Ideally, the project should involve students collaborating with those from other group 4 subjects at all stages. To this end, it is not necessary for the topic chosen to have clearly identifiable separate subject components. However, for logistical reasons, some schools may prefer a separate subject "action" phase (see the following "Project stages" section).

Project stages

The 10 hours allocated to the group 4 project, which are part of the teaching time set aside for developing the practical scheme of work, can be divided into three stages: planning, action and evaluation.

Planning

This stage is crucial to the whole exercise and should last about two hours.

- The planning stage could consist of a single session, or two or three shorter ones.
- This stage must involve all group 4 students meeting to "brainstorm" and discuss the central topic, sharing ideas and information.

- The topic can be chosen by the students themselves or selected by the teachers.
- Where large numbers of students are involved, it may be advisable to have more than one mixed subject group.

After selecting a topic or issue, the activities to be carried out must be clearly defined before moving from the planning stage to the action and evaluation stages.

A possible strategy is that students define specific tasks for themselves, either individually or as members of groups, and investigate various aspects of the chosen topic. At this stage, if the project is to be experimentally based, apparatus should be specified so that there is no delay in carrying out the action stage. Contact with other schools, if a joint venture has been agreed, is an important consideration at this time.

Action

This stage should last around six hours and may be carried out over one or two weeks in normal scheduled class time. Alternatively, a whole day could be set aside if, for example, the project involves fieldwork.

- Students should investigate the topic in mixed-subject groups or single subject groups.
- There should be collaboration during the action stage; findings of investigations should be shared with other students within the mixed/single-subject group. During this stage, in any practically based activity, it is important to pay attention to safety, ethical and environmental considerations.

Note: Students studying two group 4 subjects are not required to do two separate action phases.

Evaluation

The emphasis during this stage, for which two hours are probably necessary, is on students sharing their findings, both successes and failures, with other students. How this is achieved can be decided by the teachers, the students or jointly.

- One solution is to devote a morning, afternoon or evening to a symposium where all the students, as individuals or as groups, give brief presentations.
- Alternatively, the presentation could be more informal and take the form of a science fair where students circulate around displays summarizing the activities of each group.

The symposium or science fair could also be attended by parents, members of the school board and the press. This would be especially pertinent if some issue of local importance has been researched. Some of the findings might influence the way the school interacts with its environment or local community.

Addressing aims 7 and 8

Aim 7: "develop and apply 21st century communication skills in the study of science."

Aim 7 may be partly addressed at the planning stage by using electronic communication within and between schools. It may be that technology (for example, data logging, spreadsheets, databases and so on) will be used in the action phase and certainly in the presentation/evaluation stage (for example, use of digital images, presentation software, websites, digital video and so on).

Aim 8: "become critically aware, as global citizens, of the ethical implications of using science and technology."

Addressing the international dimension

There are also possibilities in the choice of topic to illustrate the international nature of the scientific endeavour and the increasing cooperation required to tackle global issues involving science and technology. An alternative way to bring an international dimension to the project is to collaborate with a school in another region.

Types of project

While addressing aims 7, 8 and 10 the project must be based on science or its applications. The project may have a hands-on practical action phase or one involving purely theoretical aspects. It could be undertaken in a wide range of ways:

- designing and carrying out a laboratory investigation or fieldwork.
- carrying out a comparative study (experimental or otherwise) in collaboration with another school.
- collating, manipulating and analysing data from other sources, such as scientific journals, environmental organizations, science and technology industries and government reports.
- designing and using a model or simulation.
- contributing to a long-term project organized by the school.

Logistical strategies

The logistical organization of the group 4 project is often a challenge to schools. The following models illustrate possible ways in which the project may be implemented.

Models A, B and C apply within a single school, and model D relates to a project involving collaboration between schools.

Model A: mixed-subject groups and one topic

Schools may adopt mixed-subject groups and choose one common topic. The number of groups will depend on the number of students.

Model B: mixed-subject groups adopting more than one topic

Schools with large numbers of students may choose to do more than one topic.

Model C: single-subject groups

For logistical reasons some schools may opt for single-subject groups, with one or more topics in the action phase. This model is less desirable as it does not show the mixed subject collaboration in which many scientists are involved.

Model D: collaboration with another school

The collaborative model is open to any school. To this end, the IB provides an electronic collaboration board on the OCC where schools can post their project ideas and invite collaboration from other schools. This could range from merely sharing evaluations for a common topic to a full-scale collaborative venture at all stages.

For schools with few Diploma Programme (course) students it is possible to work with non-Diploma Programme or non-group 4 students or undertake the project once every two years. However, these schools are encouraged to collaborate with another school. This strategy is also recommended for individual students who may not have participated in the project, for example, through illness or because they have transferred to a new school where the project has already taken place.

Timing

The 10 hours that the IB recommends be allocated to the project may be spread over a number of weeks. The distribution of these hours needs to be taken into account when selecting the optimum time to carry out the project. However, it is possible for a group to dedicate a period of time exclusively to project work if all/most other schoolwork is suspended.

Year 1

In the first year, students' experience and skills may be limited and it would be inadvisable to start the project too soon in the course. However, doing the project in the final part of the first year may have the advantage of reducing pressure on students later on. This strategy provides time for solving unexpected problems.

Year 1–Year 2

The planning stage could start, the topic could be decided upon, and provisional discussion in individual subjects could take place at the end of the first year. Students could then use the vacation time to think about how they are going to tackle the project and would be ready to start work early in the second year.

Year 2

Delaying the start of the project until some point in the second year, particularly if left too late, increases pressure on students in many ways: the schedule for finishing the work is much tighter than for the other options; the illness of any student or unexpected problems will present extra difficulties. Nevertheless, this choice does mean students know one another and their teachers by this time, have probably become accustomed to working in a team and will be more experienced in the relevant fields than in the first year.

Combined SL and HL

Where circumstances dictate that the project is only carried out every two years, HL beginners and more experienced SL students can be combined.

Selecting a topic

Students may choose the topic or propose possible topics and the teacher then decides which one is the most viable based on resources, staff availability and so on. Alternatively, the teacher selects the topic or proposes several topics from which students make a choice.

Student selection

Students are likely to display more enthusiasm and feel a greater sense of ownership for a topic that they have chosen themselves. A possible strategy for student selection of a topic, which also includes part of the planning stage, is outlined here. At this point, subject teachers may provide advice on the viability of proposed topics.

- Identify possible topics by using a questionnaire or a survey of students.
- Conduct an initial "brainstorming" session of potential topics or issues.
- Discuss, briefly, two or three topics that seem interesting.
- Select one topic by consensus.
- Students make a list of potential investigations that could be carried out. All students then discuss issues such as possible overlap and collaborative investigations.

A reflective statement written by each student on their involvement in the group 4 project must be included on the coversheet for each internal assessment investigation. See *Handbook of procedures* for more details.

Glossary of command terms

Command terms for chemistry

Students should be familiar with the following key terms and phrases used in examination questions, which are to be understood as described below. 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
Classify	Arrange or order by class or category.
Define	Give the precise meaning of a word, phrase, concept or physical quantity.
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.
Label	Add labels to a diagram.
List	Give a sequence of brief answers with no explanation.
Measure	Obtain a value for a quantity.
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.
Apply	Use an idea, equation, principle, theory or law in relation to a given problem or issue.
Calculate	Obtain a numerical answer showing the relevant stages in the working.
Describe	Give a detailed account.
Distinguish	Make clear the differences between two or more concepts or items.
Estimate	Obtain an approximate value.
Formulate	Express precisely and systematically the relevant concept(s) or argument(s).

Command term	Definition
Identify	Provide an answer from a number of possibilities.
Outline	Give a brief account or summary.

Assessment objective 3

Command term	Definition
Analyse	Break down in order to bring out the essential elements or structure.
Comment	Give a judgment 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.
Compare and contrast	Give an account of similarities and differences between two (or more) items or situations, referring to both (all) of them throughout.
Construct	Display information in a diagrammatic or logical form.
Deduce	Reach a conclusion from the information given.
Demonstrate	Make clear by reasoning or evidence, illustrating with examples or practical application.
Derive	Manipulate a mathematical relationship to give a new equation or relationship.
Design	Produce a plan, simulation or model.
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.
Evaluate	Make an appraisal by weighing up the strengths and limitations.
Examine	Consider an argument or concept in a way that uncovers the assumptions and interrelationships of the issue.
Explain	Give a detailed account including reasons or causes.
Explore	Undertake a systematic process of discovery.
Interpret	Use knowledge and understanding to recognize trends and draw conclusions from given information.
Justify	Give valid reasons or evidence to support an answer or conclusion.
Predict	Give an expected result.
Show	Give the steps in a calculation or derivation.
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.

Command term	Definition
Solve	Obtain the answer(s) using algebraic and/or numerical and/or graphical methods.
Suggest	Propose a solution, hypothesis or other possible answer.

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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.

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