Chemistry

First examinations 2009

Diploma Programme

Guide

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Chemistry Guide

First examinations 2009

International Baccalaureate Organization

Buenos Aires Cardiff Geneva New York Singapore

Diploma Programme
Chemistry—guide

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IBO mission statement

The International Baccalaureate Organization 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 IBO 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.

IB learners strive to be:

Inquirers They develop their natural curiosity. They acquire the skills necessary to conduct inquiry and research and show independence in learning. They actively enjoy learning and this love of learning will be sustained throughout their lives.

Knowledgeable They explore concepts, ideas and issues that have local and global significance. In so doing, they acquire in-depth knowledge and develop understanding across a broad and balanced range of disciplines.

Thinkers They exercise initiative in applying thinking skills critically and creatively to recognize and approach complex problems, and make reasoned, ethical decisions.

Communicators They understand and express ideas and information confidently and creatively in more than one language and in a variety of modes of communication. They work effectively and willingly in collaboration with others.

Principled They act with integrity and honesty, with a strong sense of fairness, justice and respect for the dignity of the individual, groups and communities. They take responsibility for their own actions and the consequences that accompany them.

Open-minded They understand and appreciate their own cultures and personal histories, and are open to the perspectives, values and traditions of other individuals and communities. They are accustomed to seeking and evaluating a range of points of view, and are willing to grow from the experience.

Caring They show empathy, compassion and respect towards the needs and feelings of others. They have a personal commitment to service, and act to make a positive difference to the lives of others and to the environment.

Risk-takers They approach unfamiliar situations and uncertainty with courage and forethought, and have the independence of spirit to explore new roles, ideas and strategies. They are brave and articulate in defending their beliefs.

Balanced They understand the importance of intellectual, physical and emotional balance to achieve personal well-being for themselves and others.

Reflective They give thoughtful consideration to their own learning and experience. They are able to assess and understand their strengths and limitations in order to support their learning and personal development.

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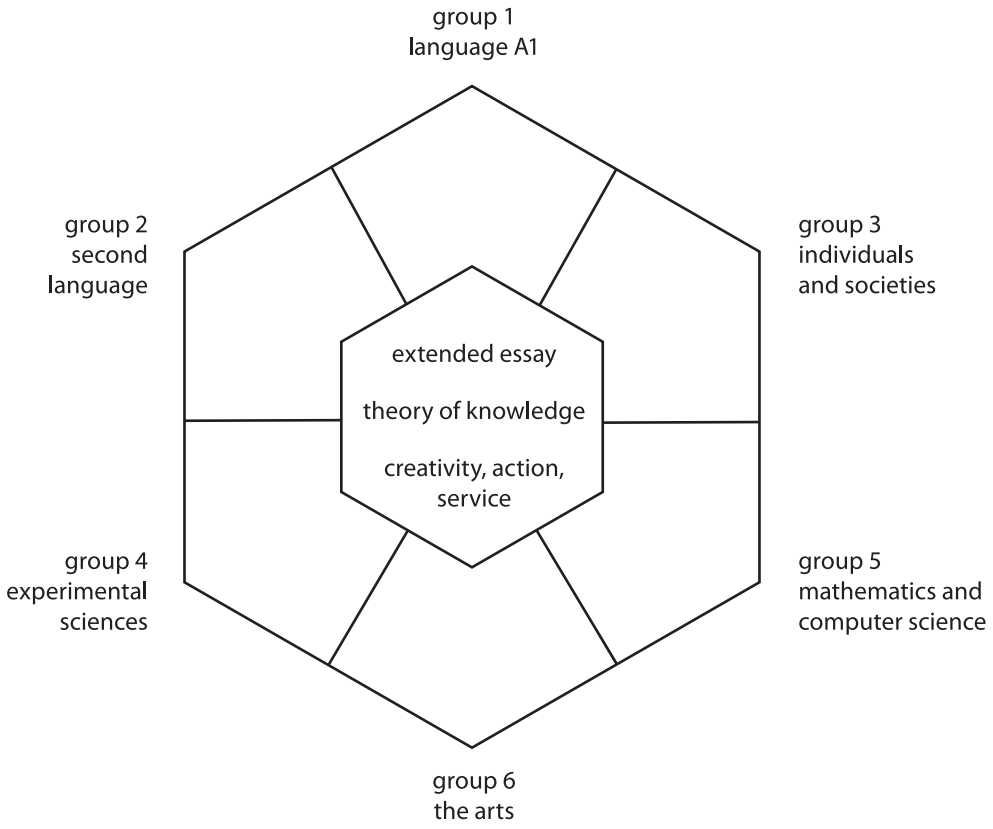
The Diploma Programme

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 hexagon

The course is presented as six academic areas enclosing a central core. It encourages the concurrent study of a broad range of academic areas. Students study: two modern languages (or a modern language and a classical language); a humanities or social science subject; an experimental science; mathematics; 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.



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Choosing the right combination

Students are required to choose one subject from each of the six academic areas, although they can choose a second subject from groups 1 to 5 instead of a group 6 subject. Normally, three subjects (and not more than four) are taken at higher level (HL), and the others are taken at standard level (SL). The IBO 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 course is available for examinations in English, French and Spanish.

The core of the hexagon

All Diploma Programme students participate in the three course requirements that make up the core of the hexagon. Reflection on all these activities is a principle that lies at the heart of the thinking behind the Diploma Programme.

The theory of knowledge (TOK) course encourages students to think about the nature of knowledge, to reflect on the process of learning in all the subjects they study as part of their Diploma Programme course, and to make connections across the academic areas. The extended essay, a substantial piece of writing of up to 4,000 words, enables students to investigate a topic of special interest that they have chosen themselves. It also encourages them to develop the skills of independent research that will be expected at university. Creativity, action, service (CAS) involves students in experiential learning through a range of artistic, sporting, physical and service activities.

The IBO 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 IBO, 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.

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Nature of group 4 subjects

Difference 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 options studied. They are presented with a syllabus that encourages the development of certain skills, attributes and attitudes, as described in the "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, to study additional topics and to study extension material of a more demanding nature in the common options. The distinction between SL and HL is one of breadth and depth.

Group 4 subjects and 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 study, characterized by the specific IB learner profile attributes—inquirers, thinkers and communicators—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 the specific group 4 subject would be necessary. Specific topic details are not specified but students who have undertaken the IB Middle Years Programme (MYP) or studied an international GCSE science subject would be well prepared. Other national science qualifications or a school-based science course would also be suitable preparation for study of a group 4 subject at HL.

Group 4 subjects and the MYP

Students who have undertaken the MYP sciences, technology and mathematics courses will be well prepared for group 4 subjects. The MYP science objectives and assessment criteria A–F are aligned with the group 4 objectives and IA criteria, and allow for a smooth transition from the MYP to Diploma Programme. In particular, the "One world" objective in MYP sciences is further developed in group 4 science with the increased emphasis on aim 8—that is, to "raise awareness of the moral, ethical, social, economic and environmental implications of using science and technology". There are specific references to aim 8 implications in assessment statements and teacher's notes in the syllabus details sections in all group 4 guides.

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Group 4 subjects and TOK

In looking at the ways of knowing described in the *Theory of knowledge guide* (March 2006), scientists could legitimately claim that science encompasses all these. Driven by emotion, using sense perception, enhanced by technology and combined with reason, it communicates through language, principally the universal language of mathematics.

There is no one scientific method, in the strict Popperian sense, of gaining knowledge, of finding explanations for the behaviour of the natural world. Science works through a variety of approaches to produce these explanations, but they all rely on data from observations and experiments and have a common underpinning rigour, whether using inductive or deductive reasoning. The explanation may be in the form of a theory, sometimes requiring a model that contains elements not directly observable. Producing these theories often requires an imaginative, creative leap. Where such a predictive theoretical model is not possible, the explanation may consist of identifying a correlation between a factor and an outcome. This correlation may then give rise to a causal mechanism that can be experimentally tested, leading to an improved explanation. All these explanations require an understanding of the limitations of data, and the extent and limitations of our knowledge. Science requires freedom of thought and open-mindedness, and an essential part of the process of science is the way the international scientific community subjects the findings of scientists to intense critical scrutiny through the repetition of experiments and the peer review of results in scientific journals and at conferences. The syllabus details sections in the group 4 guides give references in teacher's notes to appropriate topics where these aspects of the scientific way of knowing can be addressed.

Group 4 subjects 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 time-line web sites. The scientific method in its widest sense, with its emphasis on peer review, open-mindedness and freedom of thought, transcends politics, religion and nationality. Where appropriate within certain topics, the syllabus details sections in the group 4 guides contain assessment statements and teacher's notes 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 experimental science 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 students are encouraged to access the extensive web sites of these international scientific organizations to enhance their appreciation of the international dimension.

Increasingly, however, there is a recognition that many scientific problems, from climate change to AIDS, 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. Some topics in the group 4 guides are specifically written to bring out this global research.

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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 IBO 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.

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Curriculum model

A common curriculum model applies to all the Diploma Programme group 4 subjects: biology, chemistry, physics and design technology. (There are some differences in this model for design technology and these arise from the design project, which is a unique feature of this subject.) Students at both SL and HL study a core syllabus, and this is supplemented by the study of options. Students at HL also study additional higher level (AHL) material. Students at both SL and HL study two options. There are three kinds of options: those specific to SL students, those specific to HL students and those that can be taken by both SL and HL students.

Students at SL are required to spend 40 hours, and students at HL 60 hours, on practical/investigative work. This includes 10 hours for the group 4 project.

SL group 4 curriculum model

SL	Total teaching hours	150
Theory		**110**
	Core	80
	Options	30
Practical work		**40**
	Investigations	30
	Group 4 project	10

HL group 4 curriculum model

HL	Total teaching hours	240
Theory		**180**
	Core	80
	Additional higher level (AHL)	55
	Options	45
Practical work		**60**
	Investigations	50
	Group 4 project	10

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Format of the syllabus details

Note: The order in which the syllabus content is presented is not intended to represent the order in which it should be taught.

The format of the syllabus details section of the group 4 guides is the same for each subject. The structure is as follows.

Topics or options

Topics are numbered and options are indicated by a letter (for example, "Topic 8: Acids and bases", or "Option D: Medicines and drugs").

Sub-topics

Sub-topics are numbered and the estimated teaching time required to cover the material is indicated (for example, "8.1 Theories of acids and bases (2 hours)"). The times are for guidance only and do not include time for practical/investigative work.

Assessment statements (AS)

Assessment statements, which are numbered, are expressed in terms of the outcomes that are expected of students at the end of the course (for example, "8.1.1 Define *acids* and *bases* according to the Brønsted–Lowry and Lewis theories"). These are intended to prescribe to examiners what can be assessed by means of the written examinations. Each one is classified as objective 1, 2 or 3 (see the "Objectives" section) according to the command terms used (see the "Command terms" section). The objective levels are relevant for the examinations and for balance within the syllabus, while the command terms indicate the depth of treatment required for a given assessment statement. It is important that students are made aware of the meanings of the command terms because these will be used in examination questions. (When the command term "define" is used, the word(s) or phrase to be defined is in italics. When the command term "distinguish" is used, the terms or concepts to be distinguished are also in italics.)

Teacher's notes

Teacher's notes, which are included alongside some assessment statements, provide further guidance to teachers.

They may also suggest ideas for the promotion of aim 7, aim 8, TOK and the international dimension (Int).

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Topic 1: Quantitative chemistry (12.5 hours)

Topic or option

1.1 The mole concept and Avogadro's constant

Sub-topic

2 hours

TOK: Assigning numbers to the masses of the chemical elements allowed chemistry to develop into a physical science and use mathematics to express relationships between reactants and products.

	Assessment statement	Obj	Teacher's notes
1.1.1	Apply the mole concept to substances.	2	The mole concept applies to all kinds of particles: atoms, molecules, ions, electrons, formula units, and so on. The amount of substance is measured in moles (mol). The approximate value of Avogadro's constant (L), 6.02×10^{23} mol^{-1}, should be known. **TOK:** Chemistry deals with enormous differences in scale. The magnitude of Avogadro's constant is beyond the scale of our everyday experience.
1.1.2	Determine the number of particles and the amount of substance (in moles).	3	Convert between the amount of substance (in moles) and the number of atoms, molecules, ions, electrons and formula units.

Assessment statement

1.2 Formulas

3 hours

	Assessment statement	Obj	Teacher's notes
1.2.1	Define the terms *relative atomic mass* (A_r) and *relative molecular mass* (M_r).	1	
1.2.2	Calculate the mass of one mole of a species from its formula.	2	The term molar mass (in g mol^{-1}) will be used.
1.2.3	Solve problems involving the relationship between the amount of substance in moles, mass and molar mass.	3	
1.2.4	Distinguish between the terms *empirical formula* and *molecular formula*.	2	
1.2.5	Determine the empirical formula from the percentage composition or from other experimental data.	3	**Aim 7:** Virtual experiments can be used to demonstrate this.
1.2.6	Determine the molecular formula when given both the empirical formula and experimental data.	3	

Teacher's notes

Objective

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Aims

Through studying any of the group 4 subjects, 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 distinguishes the group 4 subjects from other disciplines and characterizes each of the subjects within group 4.

It is in this context that all the Diploma Programme experimental science courses should aim to:

1. provide opportunities for scientific study and creativity within a global context that will stimulate and challenge students
2. provide a body of knowledge, methods and techniques that characterize science and technology
3. enable students to 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. engender an awareness of the need for, and the value of, effective collaboration and communication during scientific activities
6. develop experimental and investigative scientific skills
7. develop and apply the students' information and communication technology skills in the study of science
8. raise awareness of the moral, ethical, social, economic and environmental implications of using science and technology
9. develop an appreciation of the possibilities and limitations associated with science and scientists
10. encourage an understanding of the relationships between scientific disciplines and the overarching nature of the scientific method.

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Objectives

The objectives for all group 4 subjects reflect those parts of the aims that will be assessed. Wherever appropriate, the assessment will draw upon environmental and technological contexts and identify the social, moral and economic effects of science.

It is the intention of all the Diploma Programme experimental science courses that students achieve the following objectives.

1. Demonstrate an understanding of:
    a. scientific facts and concepts
    b. scientific methods and techniques
    c. scientific terminology
    d. methods of presenting scientific information.
2. Apply and use:
    a. scientific facts and concepts
    b. scientific methods and techniques
    c. scientific terminology to communicate effectively
    d. appropriate methods to present scientific information.
3. Construct, analyse and evaluate:
    a. hypotheses, research questions and predictions
    b. scientific methods and techniques
    c. scientific explanations.
4. Demonstrate the personal skills of cooperation, perseverance and responsibility appropriate for effective scientific investigation and problem solving.
5. Demonstrate the manipulative skills necessary to carry out scientific investigations with precision and safety.

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Command terms

These command terms indicate the depth of treatment required for a given assessment statement. These command terms will be used in examination questions, so it is important that students are familiar with the following definitions.

Objective 1

Define	Give the precise meaning of a word, phrase or physical quantity.
Draw	Represent by means of pencil lines.
Label	Add labels to a diagram.
List	Give a sequence of names or other brief answers with no explanation.
Measure	Find a value for a quantity.
State	Give a specific name, value or other brief answer without explanation or calculation.

Objective 2

Annotate	Add brief notes to a diagram or graph.
Apply	Use an idea, equation, principle, theory or law in a new situation.
Calculate	Find a numerical answer showing the relevant stages in the working (unless instructed not to do so).
Describe	Give a detailed account.
Distinguish	Give the differences between two or more different items.
Estimate	Find an approximate value for an unknown quantity.
Identify	Find an answer from a given number of possibilities.
Outline	Give a brief account or summary.

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Objective 3

Analyse	Interpret data to reach conclusions.
Comment	Give a judgment based on a given statement or result of a calculation.
Compare	Give an account of similarities and differences between two (or more) items, referring to both (all) of them throughout.
Construct	Represent or develop in graphical form.
Deduce	Reach a conclusion from the information given.
Derive	Manipulate a mathematical relationship(s) to give a new equation or relationship.
Design	Produce a plan, simulation or model.
Determine	Find the only possible answer.
Discuss	Give an account including, where possible, a range of arguments for and against the relative importance of various factors, or comparisons of alternative hypotheses.
Evaluate	Assess the implications and limitations.
Explain	Give a detailed account of causes, reasons or mechanisms.
Predict	Give an expected result.
Show	Give the steps in a calculation or derivation.
Sketch	Represent by means of a graph showing a line and labelled but unscaled axes but with important features (for example, intercept) clearly indicated.
Solve	Obtain an answer using algebraic and/or numerical methods.
Suggest	Propose a hypothesis or other possible answer.

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Assessment outline

SL assessment specifications

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Component	Overall weighting (%)	Approximate weighting of objectives (%)		Duration (hours)	Format and syllabus coverage
		1+2	**3**		
Paper 1	20	20		¾	30 multiple-choice questions on the core
Paper 2	32	16	16	1¼	Section A: one data-based question and several short-answer questions on the core (all compulsory) Section B: one extended-response question on the core (from a choice of three)
Paper 3	24	12	12	1	Several short-answer questions in each of the two options studied (all compulsory)

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HL assessment specifications

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Component	Overall weighting (%)	Approximate weighting of objectives (%)		Duration (hours)	Format and syllabus coverage
		1+2	**3**		
Paper 1	20	20		1	40 multiple-choice questions (±15 common to SL plus about five more on the core and about 20 more on the AHL)
Paper 2	36	18	18	2¼	Section A: one data-based question and several short-answer questions on the core and the AHL (all compulsory) Section B: two extended-response questions on the core and the AHL (from a choice of four)
Paper 3	20	10	10	1¼	Several short-answer questions and one extended-response question in each of the two options studied (all compulsory)

In addition to addressing objectives 1, 2 and 3, the internal assessment scheme for both SL and HL addresses objective 4 (personal skills) using the personal skills criterion to assess the group 4 project, and objective 5 (manipulative skills) using the manipulative skills criterion to assess practical work. For both SL and HL, calculators are not permitted in paper 1 but are required in papers 2 and 3.

A clean copy of the *Chemistry data booklet* is required for papers 2 and 3 at both SL and HL.

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External assessment

The external assessment consists of three written papers.

Paper 1

Paper 1 is made up of multiple-choice questions that test knowledge of the core only for students at SL and the core and AHL material for students at HL. The questions are designed to be short, one- or two-stage problems that address objectives 1 and 2 (see the "Objectives" section). No marks are deducted for incorrect responses. Calculators are not permitted, but students are expected to carry out simple calculations.

Paper 2

Paper 2 tests knowledge of the core only for students at SL and the core and AHL material for students at HL. The questions address objectives 1, 2 and 3 and the paper is divided into two sections.

In section A, there is a data-based question that requires students to analyse a given set of data. The remainder of section A is made up of short-answer questions.

In section B, students at SL are required to answer one question from a choice of three, and students at HL are required to answer two questions from a choice of four. These extended-response questions may involve writing a number of paragraphs, solving a substantial problem, or carrying out a substantial piece of analysis or evaluation. A calculator is required for this paper.

Paper 3

Paper 3 tests knowledge of the options and addresses objectives 1, 2 and 3. Students at SL are required to answer several short-answer questions in each of the two options studied. Students at HL are required to answer several short-answer questions and an extended-response question in each of the two options studied. A calculator is required for this paper.

A clean copy of the *Chemistry data booklet* is required for papers 2 and 3 at both SL and HL.

Note: Wherever possible, teachers should use, and encourage students to use, the Système International d'Unités (International System of Units—SI units).

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Practical work and internal assessment

General introduction

The internal assessment (IA) requirements are the same for all group 4 subjects, with the exception of design technology, which has an additional element. The IA, worth 24% of the final assessment (or 36% for design technology), consists of an interdisciplinary project, a mixture of short- and long-term investigations (such as practicals and subject-specific projects) and, for design technology only, the design project.

Student work is internally assessed by the teacher and externally moderated by the IBO. The performance in IA at both SL and HL is marked against assessment criteria, with each criterion having a maximum mark of 6.

Rationale for practical work

Although the requirements for IA are mainly centred on the assessment of practical skills, the different types of experimental work 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 scientific work
- developing an appreciation of the benefits and limitations of scientific methodology.

Therefore, there may be good justification for teachers to conduct further experimental work beyond that required for the IA scheme.

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 investigations 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 activities should ideally include a spread of content material from the core, options and, where relevant, AHL material. A minimum number of investigations to be carried out is not specified.

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Choosing investigations

Teachers are free to formulate their own practical schemes of work by choosing investigations 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 investigations 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 investigations by joining in the discussion forums and adding resources in the subject home pages.

Note: Any investigation or part investigation that is to be used to assess students should be specifically designed to match the relevant assessment criteria.

Flexibility

The IA model is flexible enough to allow a wide variety of investigations to be carried out. These could include:

- short laboratory practicals over one or two lessons and long-term practicals or projects extending over several weeks
- computer simulations
- data-gathering exercises such as questionnaires, user trials and surveys
- data-analysis exercises
- general laboratory work and fieldwork.

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 scientific investigation rather than the **products** of such investigation.

In most cases all 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.

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Practical work documentation

Details of an individual student's practical scheme of work are recorded on **form 4/PSOW** provided in section 4 of the *Vade Mecum*. Electronic versions may be used as long as they include all necessary information. In addition, the laboratory work corresponding to the best two marks achieved by each student when assessed using the internal assessment criteria (design, data collection and processing, and conclusion and evaluation) and the instructions given by the teacher for the laboratory work must be retained for possible inclusion in the sample work sent to an internal assessment moderator.

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. 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.

Note: For design technology, students at SL are required to spend 55 hours, and students at HL 81 hours, on practical activities.

Only some of the 40/60 hours of practical work need be allocated to the practical work that is assessed using the IA criteria. This will normally be done during the latter part of the course when students have become more familiar with the criteria and can be assessed in complex practical work.

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Guidance and authenticity

All students should be familiar with the requirements for IA. It should be made clear to them that they are entirely responsible for their own work. It is helpful if teachers encourage students to develop a sense of responsibility for their own learning so that they accept a degree of ownership and take pride in their own work.

In responding to specific questions from students concerning investigations, teachers should (where appropriate) guide students into more productive routes of inquiry rather than respond with a direct answer. As part of the learning process, teachers can give general advice to students on a first draft of their work for IA. However, constant drafting and redrafting is not allowed and the next version handed to the teacher after the first draft must be the final one. This is marked by the teacher using the IA criteria. It is useful to annotate this work with the levels awarded for each aspect—"c" for complete, "p" for partial and "n" for not at all, to assist the moderator should the work be selected as part of the sample.

In assessing student work using the IA criteria, teachers should only mark and annotate the final draft.

When completing an investigation outside the classroom, students should work independently. Teachers are required to ensure that work submitted is the student's own. If any doubt exists, authenticity may be checked by one or more of the following methods.

- Discussion with the student
- Asking the student to explain the methods used and to summarize the results
- Asking the student to repeat the investigation

Teachers are required to sign the IA coversheet to confirm that the work of each student is his or her own unaided work.

Safety

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

ICASE Safety Committee

Mission statement

> The mission of the ICASE Safety Committee is to promote good quality, exciting practical science, which will stimulate students and motivate their teachers, in a safe and healthy learning environment. In this way, all individuals (teachers, students, laboratory assistants, supervisors, visitors) involved in science education are entitled to work under the safest possible practicable conditions in science classrooms and laboratories. Every reasonable effort needs to be made by administrators to provide and maintain a safe and healthy learning

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environment and to establish and require safe methods and practices at all times. Safety rules and regulations need to be developed and enforced for the protection of those individuals carrying out their activities in science classrooms and laboratories, and experiences in the field. Alternative science activities are encouraged in the absence of sufficiently safe conditions.

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.

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Internal assessment criteria

General information

The method of assessment used for internal assessment is criterion-related. That is to say, the method of assessment judges each student in relation to identified assessment criteria and not in relation to the work of other students.

The internal assessment component in all group 4 courses is assessed according to sets of assessment criteria and achievement level descriptors. The internal assessment criteria are for the use of teachers.

- For each assessment criterion, there are a number of descriptors that each describes a specific level of achievement.
- The descriptors concentrate on positive achievement, although for the lower levels failure to achieve may be included in the description.

Using the internal assessment criteria

Teachers should judge the internal assessment exercise against the descriptors for each criterion. The same internal assessment criteria are used for both SL and HL.

- The aim is to find, for each criterion, the descriptor that conveys most adequately the achievement level attained by the student. The process, therefore, is one of approximation. In the light of any one criterion, a student's work may contain features denoted by a high achievement level descriptor combined with features appropriate to a lower one. A professional judgment should be made in identifying the descriptor that approximates most closely to the work.
- Having scrutinized the work to be assessed, the descriptors for each criterion should be read, starting with level 0, until one is reached that describes an achievement level that the work being assessed does not match as well as the previous level. The work is, therefore, best described by the preceding achievement level descriptor and this level should be recorded. Only whole numbers should be used, not partial points such as fractions or decimals.
- The highest descriptors do not imply faultless performance and moderators and teachers should not hesitate to use the extremes, including zero, if they are appropriate descriptions of the work being assessed.
- Descriptors should not be considered as marks or percentages, although the descriptor levels are ultimately added together to obtain a total. It should not be assumed that there are other arithmetical relationships; for example, a level 2 performance is not necessarily twice as good as a level 1 performance.
- A student who attains a particular achievement level in relation to one criterion will not necessarily attain similar achievement levels in relation to the others. It should not be assumed that the overall assessment of the students will produce any particular distribution of scores.
- The assessment criteria should be available to students at all times.

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Criteria and aspects

There are five assessment criteria that are used to assess the work of both SL and HL students.

- Design—D
- Data collection and processing—DCP
- Conclusion and evaluation—CE
- Manipulative skills—MS
- Personal skills—PS

The first three criteria—design (D), data collection and processing (DCP) and conclusion and evaluation (CE)—are each assessed twice.

Manipulative skills (MS) is assessed summatively over the whole course and the assessment should be based on a wide range of manipulative skills.

Personal skills (PS) is assessed once only and this should be during the group 4 project.

Each of the assessment criteria can be separated into three **aspects** as shown in the following sections. Descriptions are provided to indicate what is expected in order to meet the requirements of a given aspect **completely (c)** and **partially (p)**. A description is also given for circumstances in which the requirements are not satisfied, **not at all (n)**.

A **"complete"** is awarded 2 marks, a **"partial"** 1 mark and a **"not at all"** 0 marks.

The maximum mark for each criterion is 6 (representing three "completes").

D	$\times 2 = 12$
DCP	$\times 2 = 12$
CE	$\times 2 = 12$
MS	$\times 1 = 6$
PS	$\times 1 = 6$

This makes a total mark out of 48.

The marks for each of the criteria are added together to determine the final mark out of 48 for the IA component. This is then scaled at IBCA to give a total out of 24%.

General regulations and procedures relating to IA can be found in the *Vade Mecum* for the year in which the IA is being submitted.

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Design

Levels/marks	Aspect 1	Aspect 2	Aspect 3
	Defining the problem and selecting variables	Controlling variables	Developing a method for collection of data
Complete/2	Formulates a focused problem/research question and identifies the relevant variables.	Designs a method for the effective control of the variables.	Develops a method that allows for the collection of sufficient relevant data.
Partial/1	Formulates a problem/research question that is incomplete **or** identifies only some relevant variables.	Designs a method that makes some attempt to control the variables.	Develops a method that allows for the collection of insufficient relevant data.
Not at all/0	Does not identify a problem/research question **and** does not identify any relevant variables.	Designs a method that does not control the variables.	Develops a method that does not allow for any relevant data to be collected.

Data collection and processing

Levels/marks	Aspect 1	Aspect 2	Aspect 3
	Recording raw data	Processing raw data	Presenting processed data
Complete/2	Records appropriate quantitative and associated qualitative raw data, including units and uncertainties where relevant.	Processes the quantitative raw data correctly.	Presents processed data appropriately and, where relevant, includes errors and uncertainties.
Partial/1	Records appropriate quantitative and associated qualitative raw data, but with some mistakes or omissions.	Processes quantitative raw data, but with some mistakes and/or omissions.	Presents processed data appropriately, but with some mistakes and/or omissions.
Not at all/0	Does not record any appropriate quantitative raw data **or** raw data is incomprehensible.	No processing of quantitative raw data is carried out **or** major mistakes are made in processing.	Presents processed data inappropriately **or** incomprehensibly.

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Conclusion and evaluation

Levels/marks	Aspect 1	Aspect 2	Aspect 3
	Concluding	Evaluating procedure(s)	Improving the investigation
Complete/2	States a conclusion, with justification, based on a reasonable interpretation of the data.	Evaluates weaknesses and limitations.	Suggests realistic improvements in respect of identified weaknesses and limitations.
Partial/1	States a conclusion based on a reasonable interpretation of the data.	Identifies some weaknesses and limitations, but the evaluation is weak or missing.	Suggests only superficial improvements.
Not at all/0	States no conclusion **or** the conclusion is based on an unreasonable interpretation of the data.	Identifies irrelevant weaknesses and limitations.	Suggests unrealistic improvements.

Manipulative skills (assessed summatively)

This criterion addresses objective 5.

Levels/marks	Aspect 1	Aspect 2	Aspect 3
	Following instructions*	Carrying out techniques	Working safely
Complete/2	Follows instructions accurately, adapting to new circumstances (seeking assistance when required).	Competent and methodical in the use of a range of techniques and equipment.	Pays attention to safety issues.
Partial/1	Follows instructions but requires assistance.	Usually competent and methodical in the use of a range of techniques and equipment.	Usually pays attention to safety issues.
Not at all/0	Rarely follows instructions **or** requires constant supervision.	Rarely competent and methodical in the use of a range of techniques and equipment.	Rarely pays attention to safety issues.

*Instructions may be in a variety of forms: oral, written worksheets, diagrams, photographs, videos, flow charts, audio tapes, models, computer programs, and so on, and need not originate from the teacher.

See “The group 4 project” section for the personal skills criterion.

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Clarifications of the IA criteria

Design

Aspect 1: defining the problem and selecting variables

It is essential that teachers give an open-ended problem to investigate, where there are several independent variables from which a student could choose one that provides a suitable basis for the investigation. This should ensure that a range of plans will be formulated by students and that there is sufficient scope to identify both independent and controlled variables.

Although the general aim of the investigation may be given by the teacher, students must identify a focused problem or specific research question. Commonly, students will do this by modifying the general aim provided and indicating the variable(s) chosen for investigation.

The teacher may suggest the general research question only. Asking students to investigate some property of a reaction system such as esterification, where no variables are given, would be an acceptable teacher prompt. This could then be focused by the student as follows: "How does changing the carboxylic acid affect the equilibrium constant of the esterification reaction with ethanol?" or "How does changing the acid catalyst concentration affect the rate of the esterification reaction between ethanol and ethanoic acid?".

Alternatively, the teacher may suggest the general research question and specify the dependent variable or a quantity derived from the dependent variable. An example of such a teacher prompt would be to ask the student to investigate factors influencing retention in thin-layer chromatography. This could then be focused by the student as follows: "How does the mole composition of a propanone/water binary solvent mixture affect the retention of methyl orange indicator in thin-layer chromatography?" or "How does changing the aqueous solvent pH affect the retention of acid–base indicators in thin-layer chromatography?".

It is not sufficient for the student merely to restate the research question provided by the teacher.

Variables are factors that can be measured and/or controlled. Independent variables are those that are manipulated, and the result of this manipulation leads to the measurement of the dependent variable. A controlled variable is one that should be held constant so as not to obscure the effect of the independent variable on the dependent variable.

The variables need to be explicitly identified by the student as the dependent (measured), independent (manipulated) and controlled variables (constants). Relevant variables are those that can reasonably be expected to affect the outcome. For example, in the investigation "How does changing the acid catalyst concentration affect the rate of the esterification reaction between ethanol and ethanoic acid?", the student must clearly state that the independent variable is the catalyst concentration and the dependent variable is the concentration of ethanoic acid after a fixed time interval. The relevant controlled variables are temperature and the initial concentrations in the reaction mixture of ethanol and ethanoic acid. The student should not be penalized for identifying further control variables that may not be so immediately relevant.

Students should **not** be:

- given a focused research question
- told the outcome of the investigation

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- told which independent variable to select
- told which variables to hold constant.

Aspect 2: controlling variables

"Control of variables" refers to the manipulation of the independent variable and the attempt to maintain the controlled variables at a constant value. The method should include explicit reference to how the control of variables is achieved. If the control of variables is not practically possible, some effort should be made to monitor the variable(s).

A standard measurement technique may be used as part of a wider investigation but it should not be the focus of that investigation. Students should be assessed on their individual design of the wider investigation. If a standard measurement technique is used it should be referenced. For example, while planning an investigation to study the factors that influence the rate of oxidation of vitamin C in fruit juices, the student may have adapted a method for vitamin C determination from a literature source. A standard reference would then be expected as a footnote.

Students should **not** be told:

- which apparatus to select
- the experimental method.

Aspect 3: developing a method for collection of data

The definition of "sufficient relevant data" depends on the context. The planned investigation should anticipate the collection of sufficient data so that the aim or research question can be suitably addressed and an evaluation of the reliability of the data can be made.

Example considerations when assessing sufficiency of data could be the following: If a trend line is to be plotted though a scattergraph then at least five data points are needed, or the plan should allow for repeated measurements to calculate a mean (for example, repeat calorimetric determinations when investigating an enthalpy of reaction). The plan should show an appreciation of the need for a trial run and repeats until consistent results are obtained in titrimetric determinations.

Students should **not** be told:

- how to collect the data
- how much data to collect.

Data collection and processing

Ideally, students should work on their own when collecting data.

When data collection is carried out in groups, the actual recording and processing of data should be independently undertaken if this criterion is to be assessed. Recording class or group data is only appropriate if the data-sharing method does not suggest a presentation format for the students.

Aspect 1: recording raw data

Raw data is the actual data measured. This may include associated qualitative data. It is permissible to convert handwritten raw data into word-processed form. The term "quantitative data" refers to numerical measurements of the variables associated with the investigation. Associated qualitative data are considered to be those observations that would enhance the interpretation of results.

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Uncertainties are associated with all raw data and an attempt should always be made to quantify uncertainties. For example, when students say there is an uncertainty in a stopwatch measurement because of reaction time, they must estimate the magnitude of the uncertainty. Within tables of quantitative data, columns should be clearly annotated with a heading, units and an indication of the uncertainty of measurement. The uncertainty need not be the same as the manufacturer's stated precision of the measuring device used. Significant digits in the data and the uncertainty in the data must be consistent. This applies to all measuring devices, for example, digital meters, stopwatches, and so on. The number of significant digits should reflect the precision of the measurement.

There should be no variation in the precision of raw data. For example, the same number of decimal places should be used. For data derived from processing raw data (for example, means), the level of precision should be consistent with that of the raw data.

The recording of the level of precision would be expected from the point where the student takes over the manipulation. For example, students would not be expected to state the level of precision in the concentration of a solution prepared for them.

Students should **not** be told how to record the raw data. For example, they should not be given a pre-formatted table with any columns, headings, units or uncertainties.

Aspect 2: processing raw data

Data processing involves, for example, combining and manipulating raw data to determine the value of a physical quantity (such as adding, subtracting, squaring, dividing), and taking the average of several measurements and transforming data into a form suitable for graphical representation. It might be that the data is already in a form suitable for graphical presentation, for example, light absorbance readings plotted against time readings. If the raw data is represented in this way and a best-fit line graph is drawn and the gradient determined, then the raw data has been processed. Plotting raw data (without a graph line) does not constitute processing data.

The recording and processing of data may be shown in one table provided they are clearly distinguishable.

Students should **not** be told:

- how to process the data
- what quantities to graph/plot.

Aspect 3: presenting processed data

When data is processed, the uncertainties associated with the data must also be considered. If the data is combined and manipulated to determine the value of a physical quantity (for example, specific heat capacity), then the uncertainties in the data must be propagated (see topic 11). Calculating the percentage difference between the measured value and the literature value does not constitute error analysis.

Students are expected to decide upon a suitable presentation format themselves (for example, spreadsheet, table, graph, chart, flow diagram, and so on). There should be clear, unambiguous headings for calculations, tables or graphs. Graphs need to have appropriate scales, labelled axes with units, and accurately plotted data points with a suitable best-fit line or curve (not a scattergraph with data-point to data-point connecting lines). Students should present the data so that all the stages to the final result can be followed. Inclusion of metric/SI units is expected for final derived quantities, which should be expressed to the correct number of significant figures. The treatment of uncertainties in graphical analysis requires the construction of appropriate best-fit lines.

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The complete fulfillment of aspect 3 does **not** require students to draw lines of minimum and maximum fit to the data points, to include error bars or to combine errors through root mean squared calculations. Although error bars on data points (for example, standard error) are not expected, they are a perfectly acceptable way of expressing the degree of uncertainty in the data.

In order to completely fulfill aspect 3, students should include a treatment of uncertainties and errors with their processed data.

The treatment of uncertainties should be in accordance with assessment statements 11.2.1 and 11.2.2 of this guide.

Conclusion and evaluation

Aspect 1: concluding

Conclusions that are supported by the data are acceptable even if they appear to contradict accepted theories. However, the conclusion must take into account any systematic or random errors and uncertainties. A percentage error should be compared with the total estimated random error as derived from the propagation of uncertainties.

In justifying their conclusion, students should discuss whether systematic error or further random errors were encountered. The direction of any systematic errors should be appreciated. Analysis may include comparisons of different graphs or descriptions of trends shown in graphs. The explanation should contain observations, trends or patterns revealed by the data.

When measuring an already known and accepted value of a physical quantity, students should draw a conclusion as to their confidence in their result by comparing the experimental value with the textbook or literature value. The literature consulted should be fully referenced.

Aspect 2: evaluating procedure(s)

The design and method of the investigation must be commented upon as well as the quality of the data. The student must not only list the weaknesses but must also appreciate how significant the weaknesses are. Comments about the precision and accuracy of the measurements are relevant here. When evaluating the procedure used, the student should specifically look at the processes, use of equipment and management of time.

Aspect 3: improving the investigation

Suggestions for improvement should be based on the weaknesses and limitations identified in aspect 2. Modifications to the experimental techniques and the data range can be addressed here. The modifications should address issues of precision, accuracy and reproducibility of the results. Students should suggest how to reduce random error, remove systematic error and/or obtain greater control of variables. The modifications proposed should be realistic and clearly specified. It is not sufficient to state generally that more precise equipment should be used.

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Manipulative skills

(This criterion must be assessed summatively.)

Aspect 1: following instructions

Indications of manipulative ability are the amount of assistance required in assembling equipment, the orderliness of carrying out the procedure(s) and the ability to follow the instructions accurately. The adherence to safe working practices should be apparent in all aspects of practical activities.

A wide range of complex tasks should be included in the scheme of work.

Aspect 2: carrying out techniques

It is expected that students will be exposed to a variety of different investigations during the course that enables them to experience a variety of experimental situations.

Aspect 3: working safely

The student's approach to safety during investigations in the laboratory or in the field must be assessed. Nevertheless, the teacher must not put students in situations of unacceptable risk.

The teacher should judge what is acceptable and legal under local regulations and with the facilities available. See the "Safety" section in this guide under "Guidance and authenticity".

Personal skills

Note: The personal skills criterion is assessed in the group 4 project only and is to be found in "The group 4 project" section.

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The use of ICT

In accordance with aim 7—that is, to "develop and apply the students' information and communication technology skills in the study of science"—the use of information and communication technology (ICT) is encouraged in practical work throughout the course, whether the investigations are assessed using the IA criteria or otherwise.

Section A: use of ICT in assessment

Data-logging software may be used in experiments/investigations assessed using the IA criteria provided that the following principle is applied.

The student's contribution to the experiment must be evident so that this alone can be assessed by the teacher. This student's contribution can be in the selection of settings used by the data-logging and graphing equipment, or can be demonstrated in subsequent stages of the experiment.

(When data logging is used, raw data is defined as any data produced by software and extracted by the student from tables or graphs to be subsequently processed by the student.)

The following categories of experiments exemplify the application of this principle.

1. Data logging within a narrowly focused task

Data-logging software may be used to perform a traditional experiment in a new way.

Use of data-logging software is appropriate with respect to assessment if the student decides and inputs most of the relevant software settings. For example, a pH probe and drop counter can be used to directly obtain a titration curve for a weak acid/strong base titration with the aim of determining the pK_a value of the weak acid from the half-equivalence point.

Data-logging software that automatically determines the various settings and generates the graphs is inappropriate with regard to assessment because the remaining student input required to calculate pK_a is minimal. This would be appropriate if the student is responsible for choosing the number of data points to be collected, and for scaling and labelling axes prior to determining the pH at the half-equivalence point.

If the experiment is suitable for assessment the following guidelines must be followed for the DCP criterion.

Data collection and processing: aspect 1

Students may present raw data collected using data logging as long as they are responsible for the majority of software settings. The numerical raw data may be presented as a table, or, where a large amount of data has been generated, by graphical means. Students must annotate the data correctly, for example, by means of table or graph titles, columns or graph axes labelled with units, indications of uncertainties, associated qualitative observations, and so on.

The number of decimal places used in recorded data should not exceed that expressed by the sensitivity of the instrument used. In the case of electronic probes used in data logging, students will be expected to record the sensitivity of the instrument.

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Data collection and processing: aspects 2 and 3

Use of software for graph drawing is appropriate as long as the student is responsible for most of the decisions, such as:

- what to graph
- selection of quantities for axes
- appropriate units
- graph title
- appropriate scale
- how to graph, for example, linear graph line and not scatter.

Note: A computer-calculated gradient is acceptable.

Statistical analysis carried out using calculators or calculations using spreadsheets are acceptable provided that the student selects the data to be processed and chooses the method of processing. In both cases, the student must show one example in the written text. For example, the student must quote the formula used by or entered into a calculator and define the terms used, or the student must write the formula used in a spreadsheet if it is not a standard part of the program's menu of functions (for example, mean, standard deviation).

2. Data logging in an open-ended investigation

Data-logging software can enhance data collection and transform the sort of investigations possible. In this case fully automated data-logging software is appropriate with regard to assessment **if** it is used to enable a broader, complex investigation to be undertaken where students can develop a range of responses involving independent decision-making. For example, a task could be set to investigate factors affecting cooling through evaporation. The students' work could be assessed for design and DCP as follows.

Design: aspect 1

To satisfy aspect 1 of design, the student may decide to determine if there is a relationship between the mole composition and the temperature drop in propanone/ethanol mixtures and then identify the relevant variables.

Design: aspect 2

The student could design a procedure in which data-logging temperature probes are used to obtain directly cooling curves for each mixture. Aspect 2 would be satisfied if the student has correctly planned to vary mixture composition (independent) and controls the amount of mixture tested and other relevant control variables.

Design: aspect 3

Aspect 3 would be satisfied if sufficient mixtures of different compositions are to be tested and if the time of data collection is sufficient to allow the minimum temperature to be reached.

Data collection and processing: aspect 1

The cooling curves, which have been directly generated by the data-logging software, allow raw data regarding initial and minimum temperature of the liquid mixtures to be collected. Aspect 1 would be satisfied completely if this data has been clearly presented by the student along with units, uncertainties and qualitative raw data.

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Data collection and processing: aspect 2

In order to satisfy completely aspect 2, the student should correctly calculate the temperature drop from the cooling curve data, calculate the mole compositions of the mixtures, construct a new graph plotting this temperature drop against the calculated mole composition of the mixtures, and draw a line to determine if there is a relationship, linear or otherwise. The graph could be constructed using suitable software as long as the student makes the decisions regarding the format and annotation of the graph.

Data collection and processing: aspect 3

This aspect assesses whether uncertainties have been correctly propagated in the calculations, and whether the graph of processed data has been presented appropriately with appropriate scales, labelled axes with units, accurately plotted data points and a line that is suitably best fit.

Section B: use of ICT in non-assessed practical work

It is not necessary to use ICT in assessed investigations but, in order to carry out aim 7 in practice, students will be required to use each of the following software applications at least once during the course.

- Data logging in an experiment
- Software for graph plotting
- A spreadsheet for data processing
- A database
- Computer modelling/simulation

There are many examples of the above in the ICT resources for biology, chemistry and physics on the OCC.

Apart from sensors for data logging, all the other components involve software that is free and readily available on the Internet. As students only need to use data-logging software and sensors once in the course, class sets are not required.

The use of each of the above five ICT applications by students would be authenticated by means of entries in the students' practical scheme of work, form 4/PSOW. For example, if a student used a spreadsheet in an investigation, this should be recorded on form 4/PSOW. Any other applications of ICT can also be recorded on form 4/PSOW.

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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 "encourage an understanding of the relationships between scientific disciplines and the overarching nature of the scientific method". 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 IA, 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.

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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 is 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 the students' information and communication technology 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 ICT (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, web sites, digital video, and so on).

Aim 8—"raise awareness of the moral, ethical, social, economic and environmental implications of using science and technology".

The choice of topic should enable one or more elements of aim 8 to be incorporated into the project.

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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.

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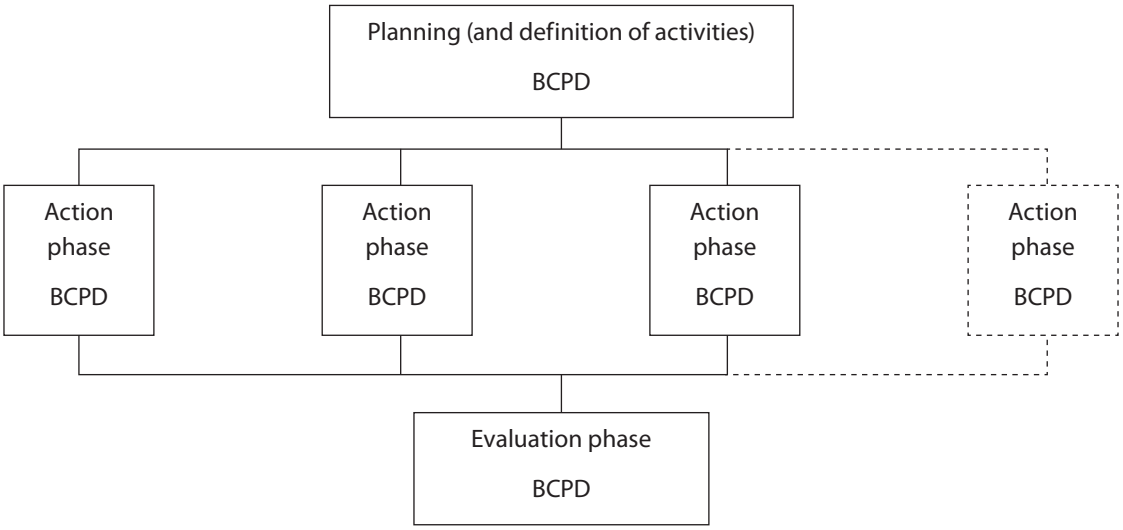
Model A: mixed subject groups and one topic

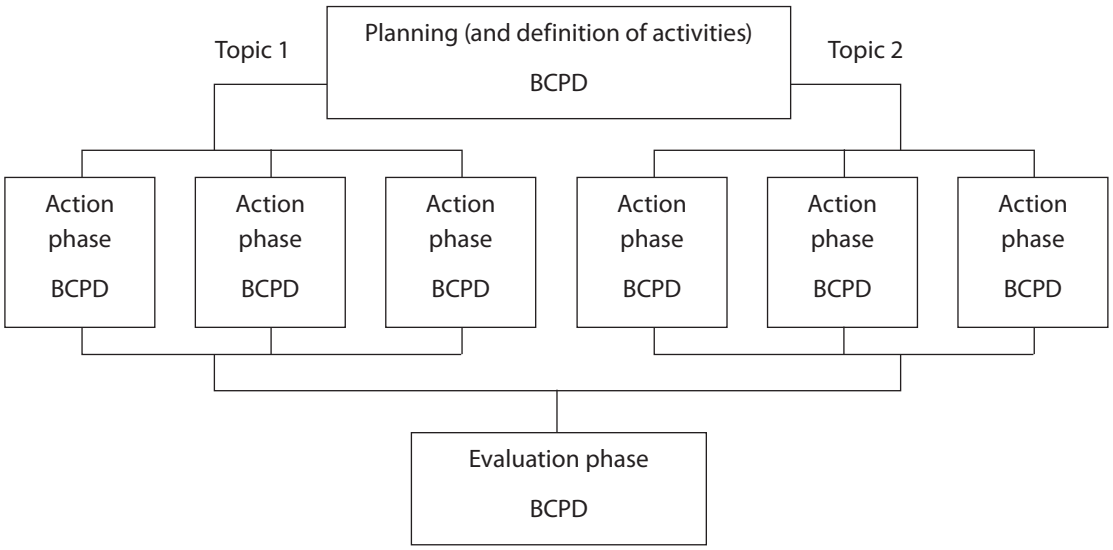
Schools may adopt mixed subject groups and choose one common topic. The number of groups will depend on the number of students. The dotted lines in the model show the addition of more groups as student numbers increase.

B—biology C—chemistry P—physics D—design technology



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 schools opting for single subject groups with one or more topics in the action phase, simply replace the mixed subject groups in model A or B with single subject groups.

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Model D: collaboration with another school

The collaborative model is open to any school. To this end, the IBO will provide an electronic collaboration board on the OCC where schools can post their project ideas and invite collaboration from another school. 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 students or schools with certificate 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 IBO 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 school work 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.

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Selecting a topic

Students may choose the topic or propose possible topics, with the teacher then deciding 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.

Assessment

The group 4 project is to be assessed for the personal skills criterion only and this will be the only place where this criterion is assessed. It is up to the school how this assessment takes place.

Note: The group 4 project is not to be used for the assessment of the other criteria.

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Personal skills (for group 4 project assessment only)

This criterion addresses objective 4.

Levels/marks	Aspect 1	Aspect 2	Aspect 3
	Self-motivation and perseverance	Working within a team	Self-reflection
Complete/2	Approaches the project with self-motivation and follows it through to completion.	Collaborates and communicates in a group situation and integrates the views of others.	Shows a thorough awareness of their own strengths and weaknesses and gives thoughtful consideration to their learning experience.
Partial/1	Completes the project but sometimes lacks self-motivation.	Exchanges some views but requires guidance to collaborate with others.	Shows limited awareness of their own strengths and weaknesses and gives some consideration to their learning experience.
Not at all/0	Lacks perseverance and motivation.	Makes little or no attempt to collaborate in a group situation.	Shows no awareness of their own strengths and weaknesses and gives no consideration to their learning experience.

The assessment can be assisted by the use of a student self-evaluation form, but the use of such a form is not a requirement.

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Nature of the subject

Chemistry is an experimental science that combines academic study with the acquisition of practical and investigational skills. It is 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.

The Diploma Programme chemistry course includes the essential principles of the subject but also, through selection of options, 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 science in higher education and those who do not.

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. Option material may be taught within the core or the additional higher level (AHL) material if desired.

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Syllabus overview

The syllabus for the Diploma Programme chemistry course is divided into three parts: the core, the AHL material and the options. The *Chemistry data booklet* is an integral part of the syllabus and should be used in conjunction with the syllabus. Students should use the data booklet during the course, and they should be issued with clean copies of it for the paper 2 and paper 3 examinations.

		Teaching hours
Core		**80**
Topic 1:	Quantitative chemistry	12.5
Topic 2:	Atomic structure	4
Topic 3:	Periodicity	6
Topic 4:	Bonding	12.5
Topic 5:	Energetics	8
Topic 6:	Kinetics	5
Topic 7:	Equilibrium	5
Topic 8:	Acids and bases	6
Topic 9:	Oxidation and reduction	7
Topic 10:	Organic chemistry	12
Topic 11:	Measurement and data processing	2
AHL		**55**
Topic 12:	Atomic structure	3
Topic 13:	Periodicity	4
Topic 14:	Bonding	5
Topic 15:	Energetics	8
Topic 16:	Kinetics	6
Topic 17:	Equilibrium	4
Topic 18:	Acids and bases	10
Topic 19:	Oxidation and reduction	5
Topic 20:	Organic chemistry	10

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		Teaching hours

Options

Options SL and HL

Option A:	Modern analytical chemistry	15/22
Option B:	Human biochemistry	15/22
Option C:	Chemistry in industry and technology	15/22
Option D:	Medicines and drugs	15/22
Option E:	Environmental chemistry	15/22
Option F:	Food chemistry	15/22
Option G:	Further organic chemistry	15/22

Students at SL are required to study any **two** options from A–G.
The duration of each option is 15 hours.

Students at HL are required to study any **two** options from A–G.
The duration of each option is 22 hours.

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Syllabus outline

		Teaching hours
Core		**80**
Topic 1: Quantitative chemistry		**12.5**
1.1	The mole concept and Avogadro's constant	2
1.2	Formulas	3
1.3	Chemical equations	1
1.4	Mass and gaseous volume relationships in chemical reactions	4.5
1.5	Solutions	2
Topic 2: Atomic structure		**4**
2.1	The atom	1
2.2	The mass spectrometer	1
2.3	Electron arrangement	2
Topic 3: Periodicity		**6**
3.1	The periodic table	1
3.2	Physical properties	2
3.3	Chemical properties	3
Topic 4: Bonding		**12.5**
4.1	Ionic bonding	2
4.2	Covalent bonding	6
4.3	Intermolecular forces	2
4.4	Metallic bonding	0.5
4.5	Physical properties	2
Topic 5: Energetics		**8**
5.1	Exothermic and endothermic reactions	1
5.2	Calculation of enthalpy changes	3
5.3	Hess's law	2
5.4	Bond enthalpies	2
Topic 6: Kinetics		**5**
6.1	Rates of reaction	2
6.2	Collision theory	3
Topic 7: Equilibrium		**5**
7.1	Dynamic equilibrium	1
7.2	The position of equilibrium	4

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		Teaching hours
Topic 8: Acids and bases		**6**
8.1	Theories of acids and bases	2
8.2	Properties of acids and bases	1
8.3	Strong and weak acids and bases	2
8.4	The pH scale	1
Topic 9: Oxidation and reduction		**7**
9.1	Introduction to oxidation and reduction	2
9.2	Redox equations	1
9.3	Reactivity	1
9.4	Voltaic cells	1
9.5	Electrolytic cells	2
Topic 10: Organic chemistry		**12**
10.1	Introduction	4
10.2	Alkanes	2
10.3	Alkenes	2
10.4	Alcohols	1
10.5	Halogenoalkanes	2
10.6	Reaction pathways	1
Topic 11: Measurement and data processing		**2**
11.1	Uncertainty and error in measurement	1
11.2	Uncertainties in calculated results	0.5
11.3	Graphical techniques	0.5
AHL		**55**
Topic 12: Atomic structure		**3**
12.1	Electron configuration	3
Topic 13: Periodicity		**4**
13.1	Trends across period 3	2
13.2	First-row d-block elements	2
Topic 14: Bonding		**5**
14.1	Shapes of molecules and ions	1
14.2	Hybridization	2
14.3	Delocalization of electrons	2
Topic 15: Energetics		**8**
15.1	Standard enthalpy changes of reaction	1.5
15.2	Born–Haber cycle	2.5
15.3	Entropy	1.5
15.4	Spontaneity	2.5
Topic 16: Kinetics		**6**
16.1	Rate expression	3
16.2	Reaction mechanism	1
16.3	Activation energy	2

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		Teaching hours
Topic 17: Equilibrium		**4**
17.1	Liquid–vapour equilibrium	2
17.2	The equilibrium law	2
Topic 18: Acids and bases		**10**
18.1	Calculations involving acids and bases	4
18.2	Buffer solutions	2
18.3	Salt hydrolysis	1
18.4	Acid–base titrations	2
18.5	Indicators	1
Topic 19: Oxidation and reduction		**5**
19.1	Standard electrode potentials	3
19.2	Electrolysis	2
Topic 20: Organic chemistry		**10**
20.1	Introduction	1
20.2	Nucleophilic substitution reactions	2
20.3	Elimination reactions	1
20.4	Condensation reactions	2
20.5	Reaction pathways	1
20.6	Stereoisomerism	3

Options SL and HL

Students at SL study the core of these options and students at HL study the whole option (that is, the core and the extension material).

Option A: Modern analytical chemistry		**15/22**
Core (SL and HL)		**15**
A1	Analytical techniques	1
A2	Principles of spectroscopy	2
A3	Infrared (IR) spectroscopy	3
A4	Mass spectrometry	2
A5	Nuclear magnetic resonance (NMR) spectroscopy	2
A6	Atomic absorption (AA) spectroscopy	3
A7	Chromatography	2
Extension (HL only)		**7**
A8	Visible and ultraviolet (UV-Vis) spectroscopy	3
A9	Nuclear magnetic resonance (NMR) spectroscopy	2
A10	Chromatography	2
Option B: Human biochemistry		**15/22**
Core (SL and HL)		**15**
B1	Energy	0.5
B2	Proteins	3
B3	Carbohydrates	3
B4	Lipids	3.5

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		Teaching hours
B5	Micronutrients and macronutrients	2
B6	Hormones	3
Extension (HL only)		**7**
B7	Enzymes	3
B8	Nucleic acids	3
B9	Respiration	1
Option C: Chemistry in industry and technology		**15/22**
Core (SL and HL)		**15**
C1	Iron, steel and aluminium	3.5
C2	The oil industry	2
C3	Addition polymers	2
C4	Catalysts	1.5
C5	Fuel cells and rechargeable batteries	2
C6	Liquid crystals	2
C7	Nanotechnology	2
Extension (HL only)		**7**
C8	Condensation polymers	1
C9	Mechanisms in the organic chemicals industry	1
C10	Silicon and photovoltaic cells	1
C11	Liquid crystals	2
C12	The chlor-alkali industry	2
Option D: Medicines and drugs		**15/22**
Core (SL and HL)		**15**
D1	Pharmaceutical products	2
D2	Antacids	1
D3	Analgesics	3
D4	Depressants	3
D5	Stimulants	2.5
D6	Antibacterials	2
D7	Antivirals	1.5
Extension (HL only)		**7**
D8	Drug action	2.5
D9	Drug design	2.5
D10	Mind-altering drugs	2
Option E: Environmental chemistry		**15/22**
Core (SL and HL)		**15**
E1	Air pollution	2
E2	Acid deposition	1.5
E3	Greenhouse effect	1.5
E4	Ozone depletion	1.5
E5	Dissolved oxygen in water	1.5
E6	Water treatment	2.5
E7	Soil	2.5
E8	Waste	2

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		Teaching hours
Extension (HL only)		**7**
E9	Ozone depletion	1
E10	Smog	2
E11	Acid deposition	1
E12	Water and soil	3

Option F: Food chemistry 15/22

Core (SL and HL)		**15**
F1	Food groups	2
F2	Fats and oils	3
F3	Shelf life	4
F4	Colour	3
F5	Genetically modified foods	1
F6	Texture	2
Extension (HL only)		**7**
F7	Oxidative rancidity (auto-oxidation)	1
F8	Antioxidants	1
F9	Stereochemistry in food	2
F10	Chemical structure and colour	3

Option G: Further organic chemistry 15/22

Core (SL and HL)		**15**
G1	Electrophilic addition reactions	3
G2	Nucleophilic addition reactions	2
G3	Elimination reactions	1
G4	Addition–elimination reactions	1
G5	Arenes	2.5
G6	Organometallic chemistry	2.5
G7	Reaction pathways	1
G8	Acid–base reactions	2
Extension (HL only)		**7**
G9	Addition–elimination reactions	2
G10	Electrophilic substitution reactions	4
G11	Reaction pathways	1

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Syllabus details—Core

Topic 1: Quantitative chemistry (12.5 hours)

1.1 The mole concept and Avogadro's constant

2 hours

TOK: Assigning numbers to the masses of the chemical elements allowed chemistry to develop into a physical science and use mathematics to express relationships between reactants and products.

	Assessment statement	Obj	Teacher's notes
1.1.1	Apply the mole concept to substances.	2	The mole concept applies to all kinds of particles: atoms, molecules, ions, electrons, formula units, and so on. The amount of substance is measured in moles (mol). The approximate value of Avogadro's constant (L), 6.02×10^{23} mol^{-1}, should be known. **TOK:** Chemistry deals with enormous differences in scale. The magnitude of Avogadro's constant is beyond the scale of our everyday experience.
1.1.2	Determine the number of particles and the amount of substance (in moles).	3	Convert between the amount of substance (in moles) and the number of atoms, molecules, ions, electrons and formula units.

1.2 Formulas

3 hours

	Assessment statement	Obj	Teacher's notes
1.2.1	Define the terms *relative atomic mass* (A_r) and *relative molecular mass* (M_r).	1	
1.2.2	Calculate the mass of one mole of a species from its formula.	2	The term molar mass (in g mol^{-1}) will be used.
1.2.3	Solve problems involving the relationship between the amount of substance in moles, mass and molar mass.	3	
1.2.4	Distinguish between the terms *empirical formula* and *molecular formula.*	2	
1.2.5	Determine the empirical formula from the percentage composition or from other experimental data.	3	**Aim 7:** Virtual experiments can be used to demonstrate this.
1.2.6	Determine the molecular formula when given both the empirical formula and experimental data.	3	

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1.3 Chemical equations

1 hour

	Assessment statement	Obj	Teacher's notes
1.3.1	Deduce chemical equations when all reactants and products are given.	3	Students should be aware of the difference between coefficients and subscripts.
1.3.2	Identify the mole ratio of any two species in a chemical equation.	2	
1.3.3	Apply the state symbols (s), (l), (g) and (aq).	2	**TOK:** When are these symbols necessary in aiding understanding and when are they redundant?

1.4 Mass and gaseous volume relationships in chemical reactions

4.5 hours

	Assessment statement	Obj	Teacher's notes
1.4.1	Calculate theoretical yields from chemical equations.	2	Given a chemical equation and the mass or amount (in moles) of one species, calculate the mass or amount of another species.
1.4.2	Determine the limiting reactant and the reactant in excess when quantities of reacting substances are given.	3	**Aim 7:** Virtual experiments can be used here.
1.4.3	Solve problems involving theoretical, experimental and percentage yield.	3	
1.4.4	Apply Avogadro's law to calculate reacting volumes of gases.	2	
1.4.5	Apply the concept of molar volume at standard temperature and pressure in calculations.	2	The molar volume of an ideal gas under standard conditions is 2.24×10^{-2} m^3 mol^{-1} (22.4 dm^3 mol^{-1}).
1.4.6	Solve problems involving the relationship between temperature, pressure and volume for a fixed mass of an ideal gas.	3	**Aim 7:** Simulations can be used to demonstrate this.
1.4.7	Solve problems using the ideal gas equation, $PV = nRT$	3	**TOK:** The distinction between the Celsius and Kelvin scales as an example of an artificial and natural scale could be discussed.
1.4.8	Analyse graphs relating to the ideal gas equation.	3	

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1.5 Solutions

2 hours

	Assessment statement	Obj	Teacher's notes
1.5.1	Distinguish between the terms *solute*, *solvent*, *solution* and *concentration* (g dm^{-3} and mol dm^{-3}).	2	Concentration in mol dm^{-3} is often represented by square brackets around the substance under consideration, for example, [HCl].
1.5.2	Solve problems involving concentration, amount of solute and volume of solution.	3	

Topic 2: Atomic structure (4 hours)

2.1 The atom

1 hour

TOK: What is the significance of the model of the atom in the different areas of knowledge? Are the models and theories that scientists create accurate descriptions of the natural world, or are they primarily useful interpretations for prediction, explanation and control of the natural world?

	Assessment statement	Obj	Teacher's notes
2.1.1	State the position of protons, neutrons and electrons in the atom.	1	**TOK:** None of these 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? Do we believe or know of their existence?
2.1.2	State the relative masses and relative charges of protons, neutrons and electrons.	1	The accepted values are: relative mass / relative charge proton: 1, +1 neutron: 1, 0 electron: 5×10^{-4}, –1
2.1.3	Define the terms *mass number* (*A*), *atomic number* (*Z*) and *isotopes of an element*.	1	
2.1.4	Deduce the symbol for an isotope given its mass number and atomic number.	3	The following notation should be used: $^{A}_{Z}X$, for example, $^{12}_{6}C$
2.1.5	Calculate the number of protons, neutrons and electrons in atoms and ions from the mass number, atomic number and charge.	2	
2.1.6	Compare the properties of the isotopes of an element.	3	

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	Assessment statement	Obj	Teacher's notes
2.1.7	Discuss the uses of radioisotopes	3	Examples should include ^{14}C in radiocarbon dating, ^{60}Co in radiotherapy, and ^{131}I and ^{125}I as medical tracers. **Aim 8:** Students should be aware of the dangers to living things of radioisotopes but also justify their usefulness with the examples above.

2.2 The mass spectrometer

1 hour

	Assessment statement	Obj	Teacher's notes
2.2.1	Describe and explain the operation of a mass spectrometer.	3	A simple diagram of a single beam mass spectrometer is required. The following stages of operation should be considered: vaporization, ionization, acceleration, deflection and detection. **Aim 7:** Simulations can be used to illustrate the operation of a mass spectrometer.
2.2.2	Describe how the mass spectrometer may be used to determine relative atomic mass using the ^{12}C scale.	2	
2.2.3	Calculate non-integer relative atomic masses and abundance of isotopes from given data.	2	

2.3 Electron arrangement

2 hours

	Assessment statement	Obj	Teacher's notes
2.3.1	Describe the electromagnetic spectrum.	2	Students should be able to identify the ultraviolet, visible and infrared regions, and to describe the variation in wavelength, frequency and energy across the spectrum. **TOK:** Infrared and ultraviolet spectroscopy are dependent on technology for their existence. What are the knowledge implications of this?
2.3.2	Distinguish between a *continuous spectrum* and a *line spectrum*.	2	
2.3.3	Explain how the lines in the emission spectrum of hydrogen are related to electron energy levels.	3	Students should be able to draw an energy level diagram, show transitions between different energy levels and recognize that the lines in a line spectrum are directly related to these differences. An understanding of convergence is expected. Series should be considered in the ultraviolet, visible and infrared regions of the spectrum. Calculations, knowledge of quantum numbers and historical references will not be assessed. **Aim 7:** Interactive simulations modelling the behaviour of electrons in the hydrogen atom can be used.

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	Assessment statement	Obj	Teacher's notes
2.3.4	Deduce the electron arrangement for atoms and ions up to $Z = 20$.	3	For example, 2.8.7 or 2,8,7 for $Z = 17$. **TOK:** In drawing an atom, we have an image of an invisible world. Which ways of knowing allow us access to the microscopic world?

Topic 3: Periodicity (6 hours)

TOK: The early discoverers of the elements allowed chemistry to make great steps with limited apparatus, often derived from the pseudoscience of alchemy. Lavoisier's work with oxygen, which overturned the phlogiston theory of heat, could be discussed as an example of a paradigm shift.

Int: The discovery of the elements and the arrangement of them is a story that exemplifies how scientific progress is made across national boundaries by the sharing of information.

3.1 The periodic table

1 hour

	Assessment statement	Obj	Teacher's notes
3.1.1	Describe the arrangement of elements in the periodic table in order of increasing atomic number.	2	Names and symbols of the elements are given in the *Chemistry data booklet*. The history of the periodic table will not be assessed. **TOK:** The predictive power of Mendeleev's periodic table could be emphasized. He is an example of a "scientist" as a "risk taker".
3.1.2	Distinguish between the terms *group* and *period*.	2	The numbering system for groups in the periodic table is shown in the *Chemistry data booklet*. Students should also be aware of the position of the transition elements in the periodic table.
3.1.3	Apply the relationship between the electron arrangement of elements and their position in the periodic table up to $Z = 20$.	2	
3.1.4	Apply the relationship between the number of electrons in the highest occupied energy level for an element and its position in the periodic table.	2	

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3.2 Physical properties

2 hours

	Assessment statement	Obj	Teacher's notes
3.2.1	Define the terms *first ionization energy* and *electronegativity*.	1	
3.2.2	Describe and explain the trends in atomic radii, ionic radii, first ionization energies, electronegativities and melting points for the alkali metals (Li → Cs) and the halogens (F → I).	3	Data for all these properties is listed in the *Chemistry data booklet*. Explanations for the first four trends should be given in terms of the balance between the attraction of the nucleus for the electrons and the repulsion between electrons. Explanations based on effective nuclear charge are not required.
3.2.3	Describe and explain the trends in atomic radii, ionic radii, first ionization energies and electronegativities for elements across period 3.	3	**Aim 7:** Databases and simulations can be used here.
3.2.4	Compare the relative electronegativity values of two or more elements based on their positions in the periodic table.	3	

3.3 Chemical properties

3 hours

	Assessment statement	Obj	Teacher's notes
3.3.1	Discuss the similarities and differences in the chemical properties of elements in the same group.	3	The following reactions should be covered. • Alkali metals (Li, Na and K) with water • Alkali metals (Li, Na and K) with halogens (Cl_2, Br_2 and I_2) • Halogens (Cl_2, Br_2 and I_2) with halide ions (Cl^-, Br^- and I^-)
3.3.2	Discuss the changes in nature, from ionic to covalent and from basic to acidic, of the oxides across period 3.	3	Equations are required for the reactions of Na_2O, MgO, P_4O_{10} and SO_3 with water. **Aim 8:** Non-metal oxides are produced by many large-scale industrial processes and the combustion engine. These acidic gases cause large-scale pollution to lakes and forests, and localized pollution in cities.

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Topic 4: Bonding (12.5 hours)

4.1 Ionic bonding

2 hours

	Assessment statement	Obj	Teacher's notes
4.1.1	Describe the ionic bond as the electrostatic attraction between oppositely charged ions.	2	
4.1.2	Describe how ions can be formed as a result of electron transfer.	2	
4.1.3	Deduce which ions will be formed when elements in groups 1, 2 and 3 lose electrons.	3	
4.1.4	Deduce which ions will be formed when elements in groups 5, 6 and 7 gain electrons.	3	
4.1.5	State that transition elements can form more than one ion.	1	Include examples such as Fe^{2+} and Fe^{3+}.
4.1.6	Predict whether a compound of two elements would be ionic from the position of the elements in the periodic table or from their electronegativity values.	3	
4.1.7	State the formula of common polyatomic ions formed by non-metals in periods 2 and 3.	1	Examples include NO_3^-, OH^-, SO_4^{2-}, CO_3^{2-}, PO_4^{3-}, NH_4^+, HCO_3^-.
4.1.8	Describe the lattice structure of ionic compounds.	2	Students should be able to describe the structure of sodium chloride as an example of an ionic lattice.

4.2 Covalent bonding

6 hours

	Assessment statement	Obj	Teacher's notes
4.2.1	Describe the covalent bond as the electrostatic attraction between a pair of electrons and positively charged nuclei.	2	Single and multiple bonds should be considered. Examples should include O_2, N_2, CO_2, HCN, C_2H_4 (ethene) and C_2H_2 (ethyne).
4.2.2	Describe how the covalent bond is formed as a result of electron sharing.	2	Dative covalent bonds are required. Examples include CO, NH_4^+ and H_3O^+.

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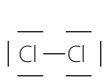
	Assessment statement	Obj	Teacher's notes
4.2.3	Deduce the Lewis (electron dot) structures of molecules and ions for up to four electron pairs on each atom.	3	A pair of electrons can be represented by dots, crosses, a combination of dots and crosses or by a line. For example, chlorine can be shown as: or or  or Note: Cl–Cl is not a Lewis structure.
4.2.4	State and explain the relationship between the number of bonds, bond length and bond strength.	3	The comparison should include the bond lengths and bond strengths of: • two carbon atoms joined by single, double and triple bonds • the carbon atom and the two oxygen atoms in the carboxyl group of a carboxylic acid.
4.2.5	Predict whether a compound of two elements would be covalent from the position of the elements in the periodic table or from their electronegativity values.	3	
4.2.6	Predict the relative polarity of bonds from electronegativity values	3	**Aim 7:** Simulations may be used here.
4.2.7	Predict the shape and bond angles for species with four, three and two negative charge centres on the central atom using the valence shell electron pair repulsion theory (VSEPR).	3	Examples should include CH_4, NH_3, H_2O, NH_4^+, H_3O^+, BF_3, C_2H_4, SO_2, C_2H_2 and CO_2. **Aim 7:** Simulations are available to study the three-dimensional structures of these and the structures in 4.2.9 and 4.2.10.
4.2.8	Predict whether or not a molecule is polar from its molecular shape and bond polarities.	3	
4.2.9	Describe and compare the structure and bonding in the three allotropes of carbon (diamond, graphite and C_{60} fullerene).	3	
4.2.10	Describe the structure of and bonding in silicon and silicon dioxide.	2	

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4.3 Intermolecular forces

2 hours

	Assessment statement	Obj	Teacher's notes
4.3.1	Describe the types of intermolecular forces (attractions between molecules that have temporary dipoles, permanent dipoles or hydrogen bonding) and explain how they arise from the structural features of molecules.	3	The term van der Waals' forces can be used to describe the interaction between non-polar molecules.
4.3.2	Describe and explain how intermolecular forces affect the boiling points of substances.	3	The presence of hydrogen bonding can be illustrated by comparing: • HF and HCl • H_2O and H_2S • NH_3 and PH_3 • CH_3OCH_3 and CH_3CH_2OH • $CH_3CH_2CH_3$, CH_3CHO and CH_3CH_2OH.

4.4 Metallic bonding

0.5 hour

	Assessment statement	Obj	Teacher's notes
4.4.1	Describe the metallic bond as the electrostatic attraction between a lattice of positive ions and delocalized electrons.	2	
4.4.2	Explain the electrical conductivity and malleability of metals.	3	**Aim 8:** Students should appreciate the economic importance of these properties and the impact that the large-scale production of iron and other metals has made on the world.

4.5 Physical properties

2 hours

	Assessment statement	Obj	Teacher's notes
4.5.1	Compare and explain the properties of substances resulting from different types of bonding.	3	Examples should include melting and boiling points, volatility, electrical conductivity and solubility in non-polar and polar solvents.

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Topic 5: Energetics (8 hours)

5.1 Exothermic and endothermic reactions

1 hour

	Assessment statement	Obj	Teacher's notes
5.1.1	Define the terms *exothermic reaction*, *endothermic reaction* and *standard enthalpy change of reaction* ($\Delta H^{\ominus}$) .	1	Standard enthalpy change is the heat energy transferred under standard conditions—pressure 101.3 kPa, temperature 298 K. Only ΔH can be measured, not H for the initial or final state of a system.
5.1.2	State that combustion and neutralization are exothermic processes.	1	
5.1.3	Apply the relationship between temperature change, enthalpy change and the classification of a reaction as endothermic or exothermic.	2	
5.1.4	Deduce, from an enthalpy level diagram, the relative stabilities of reactants and products, and the sign of the enthalpy change for the reaction.	3	

5.2 Calculation of enthalpy changes

3 hours

	Assessment statement	Obj	Teacher's notes
5.2.1	Calculate the heat energy change when the temperature of a pure substance is changed.	2	Students should be able to calculate the heat energy change for a substance given the mass, specific heat capacity and temperature change using $q = mc\Delta T$.
5.2.2	Design suitable experimental procedures for measuring the heat energy changes of reactions.	3	Students should consider reactions in aqueous solution and combustion reactions. Use of the bomb calorimeter and calibration of calorimeters will not be assessed. **Aim 7:** Data loggers and databases can be used here.
5.2.3	Calculate the enthalpy change for a reaction using experimental data on temperature changes, quantities of reactants and mass of water.	2	
5.2.4	Evaluate the results of experiments to determine enthalpy changes.	3	Students should be aware of the assumptions made and errors due to heat loss. **TOK:** What criteria do we use in judging whether discrepancies between experimental and theoretical values are due to experimental limitations or theoretical assumptions?

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5.3 Hess's law

2 hours

	Assessment statement	Obj	Teacher's notes
5.3.1	Determine the enthalpy change of a reaction that is the sum of two or three reactions with known enthalpy changes.	3	Students should be able to use simple enthalpy cycles and enthalpy level diagrams and to manipulate equations. Students will not be required to state Hess's law. **TOK:** As an example of the conservation of energy, this illustrates the unification of ideas from different areas of science.

5.4 Bond enthalpies

2 hours

	Assessment statement	Obj	Teacher's notes
5.4.1	Define the term *average bond enthalpy*.	1	
5.4.2	Explain, in terms of average bond enthalpies, why some reactions are exothermic and others are endothermic.	3	

Topic 6: Kinetics (5 hours)

6.1 Rates of reaction

2 hours

	Assessment statement	Obj	Teacher's notes
6.1.1	Define the term *rate of reaction*.	1	
6.1.2	Describe suitable experimental procedures for measuring rates of reactions.	2	**Aim 7:** Data loggers can be used to collect data and produce graphs. **TOK:** The empirical nature of the topic should be emphasized. Experimental results can support the theory but cannot prove it.
6.1.3	Analyse data from rate experiments.	3	Students should be familiar with graphs of changes in concentration, volume and mass against time.

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6.2 Collision theory

3 hours

	Assessment statement	Obj	Teacher's notes
6.2.1	Describe the kinetic theory in terms of the movement of particles whose average energy is proportional to temperature in kelvins.	2	
6.2.2	Define the term *activation energy*, E_a.	1	
6.2.3	Describe the collision theory.	2	Students should know that reaction rate depends on: • collision frequency • number of particles with $E \geq E_a$ • appropriate collision geometry or orientation.
6.2.4	Predict and explain, using the collision theory, the qualitative effects of particle size, temperature, concentration and pressure on the rate of a reaction.	3	**Aim 7:** Interactive simulations can be used to demonstrate this.
6.2.5	Sketch and explain qualitatively the Maxwell–Boltzmann energy distribution curve for a fixed amount of gas at different temperatures and its consequences for changes in reaction rate.	3	Students should be able to explain why the area under the curve is constant and does not change with temperature. **Aim 7:** Interactive simulations can be used to demonstrate this.
6.2.6	Describe the effect of a catalyst on a chemical reaction.	2	
6.2.7	Sketch and explain Maxwell–Boltzmann curves for reactions with and without catalysts.	3	

Topic 7: Equilibrium (5 hours)

7.1 Dynamic equilibrium

1 hour

	Assessment statement	Obj	Teacher's notes
7.1.1	Outline the characteristics of chemical and physical systems in a state of equilibrium.	2	**Aim 7:** Spreadsheets and simulations can be used here.

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7.2 The position of equilibrium

4 hours

	Assessment statement	Obj	Teacher's notes
7.2.1	Deduce the equilibrium constant expression (K_c) from the equation for a homogeneous reaction.	3	Consider gases, liquids and aqueous solutions.
7.2.2	Deduce the extent of a reaction from the magnitude of the equilibrium constant.	3	When $K_c >> 1$, the reaction goes almost to completion. When $K_c << 1$, the reaction hardly proceeds.
7.2.3	Apply Le Chatelier'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.	2	Students will not be required to state Le Chatelier's principle. **Aim 7:** Simulations are available that model the behaviour of equilibrium systems.
7.2.4	State and explain the effect of a catalyst on an equilibrium reaction.	3	
7.2.5	Apply the concepts of kinetics and equilibrium to industrial processes.	2	Suitable examples include the Haber and Contact processes. **Aim 8:** A case study of Fritz Haber could be included to debate the role of scientists in society.

Topic 8: Acids and bases (6 hours)

8.1 Theories of acids and bases

2 hours

	Assessment statement	Obj	Teacher's notes
8.1.1	Define *acids* and *bases* according to the Brønsted–Lowry and Lewis theories.	1	**TOK:** Discuss the value of using different theories to explain the same phenomenon. What is the relationship between depth and simplicity?
8.1.2	Deduce whether or not a species could act as a Brønsted–Lowry and/or a Lewis acid or base.	3	
8.1.3	Deduce the formula of the conjugate acid (or base) of any Brønsted–Lowry base (or acid).	3	Students should make clear the location of the proton transferred, for example, CH_3COOH/ CH_3COO^- rather than $C_2H_4O_2$/$C_2H_3O_2^-$.

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8.2 Properties of acids and bases

1 hour

	Assessment statement	Obj	Teacher's notes
8.2.1	Outline the characteristic properties of acids and bases in aqueous solution.	2	Bases that are not hydroxides, such as ammonia, soluble carbonates and hydrogencarbonates, should be included. Alkalis are bases that dissolve in water. Students should consider the effects on indicators and the reactions of acids with bases, metals and carbonates.

8.3 Strong and weak acids and bases

2 hours

	Assessment statement	Obj	Teacher's notes
8.3.1	Distinguish between *strong* and *weak* acids and bases in terms of the extent of dissociation, reaction with water and electrical conductivity.	2	**Aim 8:** Although weakly acidic solutions are relatively safe, they still cause damage over long periods of time. Students could consider the effects of acid deposition on limestone buildings and living things.
8.3.2	State whether a given acid or base is strong or weak.	1	Students should consider hydrochloric acid, nitric acid and sulfuric acid as examples of strong acids, and carboxylic acids and carbonic acid (aqueous carbon dioxide) as weak acids. Students should consider all group 1 hydroxides and barium hydroxide as strong bases, and ammonia and amines as weak bases.
8.3.3	Distinguish between *strong* and *weak* acids and bases, and determine the relative strengths of acids and bases, using experimental data.	2	

8.4 The pH scale

1 hour

	Assessment statement	Obj	Teacher's notes
8.4.1	Distinguish between aqueous solutions that are *acidic*, *neutral* or *alkaline* using the pH scale.	2	
8.4.2	Identify which of two or more aqueous solutions is more acidic or alkaline using pH values.	2	Students should be familiar with the use of a pH meter and universal indicator.
8.4.3	State that each change of one pH unit represents a 10-fold change in the hydrogen ion concentration $[H^+(aq)]$.	1	Relate integral values of pH to $[H^+(aq)]$ expressed as powers of 10. Calculation of pH from $[H^+(aq)]$ is not required. **TOK:** The distinction between artificial and natural scales could be discussed.
8.4.4	Deduce changes in $[H^+(aq)]$ when the pH of a solution changes by more than one pH unit.	3	**Aim 8:** A study of the effects of small pH changes in natural environments could be included.

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Topic 9: Oxidation and reduction (7 hours)

Aim 8: The Industrial Revolution was the consequence of the mass production of iron by a reduction process. However, iron spontaneously reverts back to an oxidized form. What price do we continue to pay in terms of energy and waste for choosing a metal so prone to oxidation and why was it chosen?

9.1 Introduction to oxidation and reduction

2 hours

	Assessment statement	Obj	Teacher's notes
9.1.1	Define *oxidation* and *reduction* in terms of electron loss and gain.	1	
9.1.2	Deduce the oxidation number of an element in a compound.	3	Oxidation numbers should be shown by a sign (+ or –) and a number, for example, +7 for Mn in $KMnO_4$. **TOK:** Are oxidation numbers "real"?
9.1.3	State the names of compounds using oxidation numbers.	1	Oxidation numbers in names of compounds are represented by Roman numerals, for example, iron(II) oxide, iron(III) oxide. **TOK:** Chemistry has developed a systematic language that has resulted in older names becoming obsolete. What has been gained and lost in this process?
9.1.4	Deduce whether an element undergoes oxidation or reduction in reactions using oxidation numbers.	3	

9.2 Redox equations

1 hour

	Assessment statement	Obj	Teacher's notes
9.2.1	Deduce simple oxidation and reduction half-equations given the species involved in a redox reaction.	3	
9.2.2	Deduce redox equations using half-equations.	3	H^+ and H_2O should be used where necessary to balance half-equations in acid solution. The balancing of equations for reactions in alkaline solution will not be assessed.
9.2.3	Define the terms *oxidizing agent* and *reducing agent*.	1	
9.2.4	Identify the oxidizing and reducing agents in redox equations.	2	

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9.3 Reactivity

1 hour

	Assessment statement	Obj	Teacher's notes
9.3.1	Deduce a reactivity series based on the chemical behaviour of a group of oxidizing and reducing agents.	3	Examples include displacement reactions of metals and halogens. Standard electrode potentials will not be assessed.
9.3.2	Deduce the feasibility of a redox reaction from a given reactivity series.	3	Students are not expected to recall a specific reactivity series.

9.4 Voltaic cells

1 hour

	Assessment statement	Obj	Teacher's notes
9.4.1	Explain how a redox reaction is used to produce electricity in a voltaic cell.	3	This should include a diagram to show how two half-cells can be connected by a salt bridge. Examples of half-cells are Mg, Zn, Fe and Cu in solutions of their ions.
9.4.2	State that oxidation occurs at the negative electrode (anode) and reduction occurs at the positive electrode (cathode).	1	

9.5 Electrolytic cells

2 hours

	Assessment statement	Obj	Teacher's notes
9.5.1	Describe, using a diagram, the essential components of an electrolytic cell.	2	The diagram should include the source of electric current and conductors, positive and negative electrodes, and the electrolyte.
9.5.2	State that oxidation occurs at the positive electrode (anode) and reduction occurs at the negative electrode (cathode).	1	
9.5.3	Describe how current is conducted in an electrolytic cell.	2	
9.5.4	Deduce the products of the electrolysis of a molten salt.	3	Half-equations showing the formation of products at each electrode will be assessed. **Aim 8:** This process (which required the discovery of electricity) has made it possible to obtain reactive metals such as aluminium from their ores. This in turn has enabled subsequent steps in engineering and technology that increase our quality of life. Unlike iron, aluminium is not prone to corrosion and is one material that is replacing iron in many of its applications.

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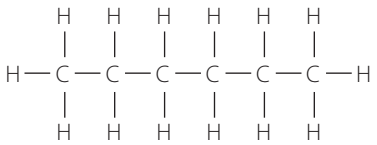
Topic 10: Organic chemistry (12 hours)

Int, aim 8: Today, we may be starting to experience the consequences of using fossil fuels as our main source of energy. There is a vast range of products that can be derived from fossil fuels as a result of carbon's rich chemistry. This raises the question "are they too valuable to burn?".

10.1 Introduction

4 hours

	Assessment statement	Obj	Teacher's notes
10.1.1	Describe the features of a homologous series.	2	Include the same general formula, neighbouring members differing by CH_2, similar chemical properties and gradation in physical properties.
10.1.2	Predict and explain the trends in boiling points of members of a homologous series.	3	
10.1.3	Distinguish between *empirical*, *molecular* and *structural* formulas.	2	A structural formula is one that shows unambiguously how the atoms are arranged together. A full structural formula (sometimes called a graphic formula or displayed formula) shows every atom and bond, for example, for hexane:  A condensed structural formula can omit bonds between atoms and can show identical groups bracketed together, for example, for hexane: $CH_3CH_2CH_2CH_2CH_2CH_3$ or $CH_3(CH_2)_4CH_3$. The use of R to represent an alkyl group and to represent the benzene ring can be used in condensed structural formulas. Although skeletal formulas are used for more complex structures in the *Chemistry data booklet*, such formulas will not be accepted in examination answers. **TOK:** The use of the different formulas illustrates the value of different models with different depths of detail.
10.1.4	Describe structural isomers as compounds with the same molecular formula but with different arrangements of atoms.	2	No distinction need be made between different types of structural isomerism, such as chain and position isomerism and functional group isomerism. Knowledge of stereoisomerism is not required in the core.
10.1.5	Deduce structural formulas for the isomers of the non-cyclic alkanes up to C_6.	3	Include both straight-chain and branched-chain isomers.
10.1.6	Apply IUPAC rules for naming the isomers of the non-cyclic alkanes up to C_6.	2	**TOK:** This could be discussed as an example of the use of the language of chemistry as a tool to classify and distinguish between different structures.

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	Assessment statement	Obj	Teacher's notes
10.1.7	Deduce structural formulas for the isomers of the straight-chain alkenes up to C_6.	3	
10.1.8	Apply IUPAC rules for naming the isomers of the straight-chain alkenes up to C_6.	2	The distinction between *cis* and *trans* isomers is not required.
10.1.9	Deduce structural formulas for compounds containing up to six carbon atoms with one of the following functional groups: alcohol, aldehyde, ketone, carboxylic acid and halide.	3	Condensed structural formulas can use OH, CHO, CO, COOH and F/Cl/Br/I.
10.1.10	Apply IUPAC rules for naming compounds containing up to six carbon atoms with one of the following functional groups: alcohol, aldehyde, ketone, carboxylic acid and halide.	2	
10.1.11	Identify the following functional groups when present in structural formulas: amino (NH_2), benzene ring (⬡) and esters (RCOOR).	2	
10.1.12	Identify primary, secondary and tertiary carbon atoms in alcohols and halogenoalkanes.	2	The terms primary, secondary and tertiary can also be applied to the molecules containing these carbon atoms.
10.1.13	Discuss the volatility and solubility in water of compounds containing the functional groups listed in 10.1.9.	3	

10.2 Alkanes

2 hours

	Assessment statement	Obj	Teacher's notes
10.2.1	Explain the low reactivity of alkanes in terms of bond enthalpies and bond polarity.	3	
10.2.2	Describe, using equations, the complete and incomplete combustion of alkanes.	2	
10.2.3	Describe, using equations, the reactions of methane and ethane with chlorine and bromine.	2	
10.2.4	Explain the reactions of methane and ethane with chlorine and bromine in terms of a free-radical mechanism.	3	Reference should be made to homolytic fission and the reaction steps of initiation, propagation and termination. The use of the half-arrow to represent the movement of a single electron is not required. The formulas of free radicals should include the radical symbol, for example, Cl• .

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10.3 Alkenes

2 hours

	Assessment statement	Obj	Teacher's notes
10.3.1	Describe, using equations, the reactions of alkenes with hydrogen and halogens.	2	
10.3.2	Describe, using equations, the reactions of symmetrical alkenes with hydrogen halides and water.	2	
10.3.3	Distinguish between *alkanes* and *alkenes* using bromine water.	2	
10.3.4	Outline the polymerization of alkenes.	2	Include the formation of poly(ethene), poly(chloroethene) and poly(propene) as examples of addition polymers. Include the identification of the repeating unit, for example, $-\left(-CH_2-CH_2-\right)_n-$ for poly(ethene).
10.3.5	Outline the economic importance of the reactions of alkenes.	2	**Aim 8:** Include the hydrogenation of vegetable oils in the manufacture of margarine, the hydration of ethene in the manufacture of ethanol, and polymerization in the manufacture of plastics.

10.4 Alcohols

1 hour

	Assessment statement	Obj	Teacher's notes
10.4.1	Describe, using equations, the complete combustion of alcohols.	2	
10.4.2	Describe, using equations, the oxidation reactions of alcohols.	2	A suitable oxidizing agent is acidified potassium dichromate(VI). Equations may be balanced using the symbol [O] to represent oxygen supplied by the oxidizing agent. Include the different conditions needed to obtain good yields of different products, that is, an aldehyde by distilling off the product as it is formed, and a carboxylic acid by heating under reflux.
10.4.3	Determine the products formed by the oxidation of primary and secondary alcohols.	3	Assume that tertiary alcohols are not oxidized by potassium dichromate(VI).

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10.5 Halogenoalkanes

2 hours

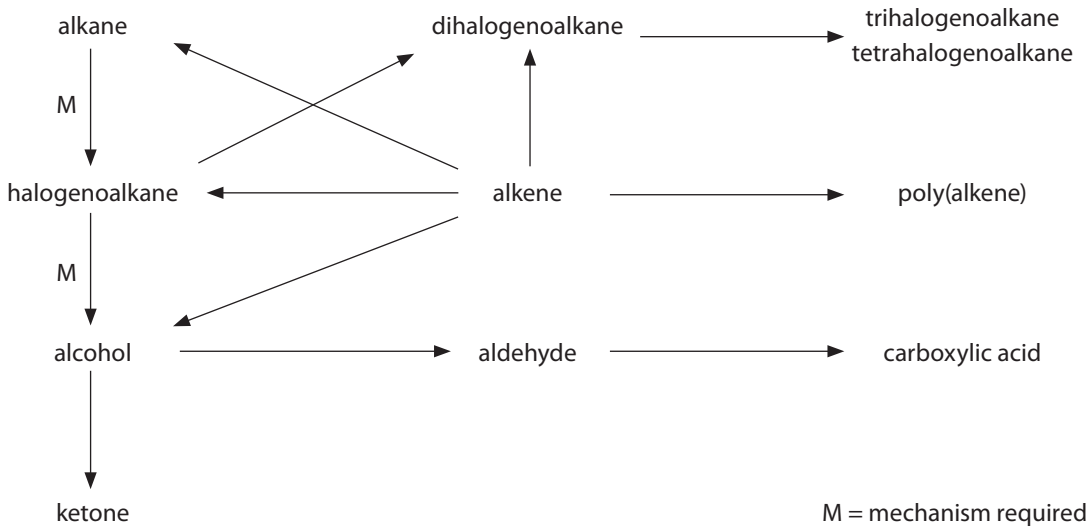
	Assessment statement	Obj	Teacher's notes
10.5.1	Describe, using equations, the substitution reactions of halogenoalkanes with sodium hydroxide.	2	**Aim 7:** Simulations are available for this.
10.5.2	Explain the substitution reactions of halogenoalkanes with sodium hydroxide in terms of S_N1 and S_N2 mechanisms.	3	Reference should be made to heterolytic fission. Curly arrows should be used to represent the movement of electron pairs. For tertiary halogenoalkanes the predominant mechanism is S_N1, and for primary halogenoalkanes it is S_N2. Both mechanisms occur for secondary halogenoalkanes.

10.6 Reaction pathways

1 hour

	Assessment statement	Obj	Teacher's notes
10.6.1	Deduce reaction pathways given the starting materials and the product.	3	Conversions with more than two stages will not be assessed. Reagents, conditions and equations should be included. For example, the conversion of but-2-ene to butanone can be done in two stages: but-2-ene can be heated with steam and a catalyst to form butan-2-ol, which can then be oxidized by heating with acidified potassium dichromate(VI) to form butanone.

The compound and reaction types in this topic are summarized in the following scheme:



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Topic 11: Measurement and data processing (2 hours)

11.1 Uncertainty and error in measurement

1 hour

	Assessment statement	Obj	Teacher's notes
11.1.1	Describe and give examples of random uncertainties and systematic errors.	2	
11.1.2	Distinguish between *precision* and *accuracy*.	2	It is possible for a measurement to have great precision yet be inaccurate (for example, if the top of a meniscus is read in a pipette or a measuring cylinder).
11.1.3	Describe how the effects of random uncertainties may be reduced.	2	Students should be aware that random uncertainties, but not systematic errors, are reduced by repeating readings.
11.1.4	State random uncertainty as an uncertainty range (±).	1	
11.1.5	State the results of calculations to the appropriate number of significant figures.	1	The number of significant figures in any answer should reflect the number of significant figures in the given data.

11.2 Uncertainties in calculated results

0.5 hour

	Assessment statement	Obj	Teacher's notes
11.2.1	State uncertainties as absolute and percentage uncertainties.	1	
11.2.2	Determine the uncertainties in results.	3	Only a simple treatment is required. For functions such as addition and subtraction, absolute uncertainties can be added. For multiplication, division and powers, percentage uncertainties can be added. If one uncertainty is much larger than others, the approximate uncertainty in the calculated result can be taken as due to that quantity alone.

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11.3 Graphical techniques

0.5 hour

TOK: Why are graphs helpful in providing powerful interpretations of reality.

	Assessment statement	Obj	Teacher's notes
11.3.1	Sketch graphs to represent dependences and interpret graph behaviour.	3	Students should be able to give a qualitative physical interpretation of a particular graph, for example, the variables are proportional or inversely proportional.
11.3.2	Construct graphs from experimental data.	3	This involves the choice of axes and scale, and the plotting of points. **Aim 7:** Software graphing packages could be used.
11.3.3	Draw best-fit lines through data points on a graph.	1	These can be curves or straight lines.
11.3.4	Determine the values of physical quantities from graphs.	3	Include measuring and interpreting the slope (gradient), and stating the units for these quantities.

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Syllabus details—AHL

Topic 12: Atomic structure (3 hours)

12.1 Electron configuration

3 hours

	Assessment statement	Obj	Teacher's notes
12.1.1	Explain how evidence from first ionization energies across periods accounts for the existence of main energy levels and sub-levels in atoms.	3	**TOK:** Which ways of knowing do we use to interpret indirect evidence? Do we believe or know of the existence of energy levels?
12.1.2	Explain how successive ionization energy data is related to the electron configuration of an atom.	3	**Aim 7:** Spreadsheets, databases and modelling software can be used here.
12.1.3	State the relative energies of s, p, d and f orbitals in a single energy level.	1	**Aim 7:** Simulations can be used here.
12.1.4	State the maximum number of orbitals in a given energy level.	1	
12.1.5	Draw the shape of an s orbital and the shapes of the p_x, p_y and p_z orbitals.	1	**TOK:** The breakdown of the classical concepts of position and momentum is another example of the limitations of everyday experience. The need for a probability picture at the atomic scale shows that human knowledge is ultimately limited.
12.1.6	Apply the Aufbau principle, Hund's rule and the Pauli exclusion principle to write electron configurations for atoms and ions up to $Z = 54$.	2	For $Z = 23$, the full electron configuration is $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^3$ and the abbreviated electron configuration is $[Ar]4s^2 3d^3$ or $[Ar]3d^3 4s^2$. Exceptions to the principle for copper and chromium should be known. Students should be familiar with the representation of the spinning electron in an orbital as an arrow in a box.

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Topic 13: Periodicity (4 hours)

13.1 Trends across period 3

2 hours

	Assessment statement	Obj	Teacher's notes
13.1.1	Explain the physical states (under standard conditions) and electrical conductivity (in the molten state) of the chlorides and oxides of the elements in period 3 in terms of their bonding and structure.	3	Include the following oxides and chlorides. • Oxides: Na_2O, MgO, Al_2O_3, SiO_2, P_4O_6 and P_4O_{10}, SO_2 and SO_3, Cl_2O and Cl_2O_7 • Chlorides: $NaCl$, $MgCl_2$, Al_2Cl_6, $SiCl_4$, PCl_3 and PCl_5, and Cl_2
13.1.2	Describe the reactions of chlorine and the chlorides referred to in 13.1.1 with water.	2	

13.2 First-row d-block elements

2 hours

	Assessment statement	Obj	Teacher's notes
13.2.1	List the characteristic properties of transition elements.	1	Examples should include variable oxidation number, complex ion formation, existence of coloured compounds and catalytic properties.
13.2.2	Explain why Sc and Zn are not considered to be transition elements.	3	
13.2.3	Explain the existence of variable oxidation number in ions of transition elements.	3	Students should know that all transition elements can show an oxidation number of +2. In addition, they should be familiar with the oxidation numbers of the following: Cr (+3, +6), Mn (+4, +7), Fe (+3) and Cu (+1).
13.2.4	Define the term *ligand*.	1	
13.2.5	Describe and explain the formation of complexes of d-block elements.	3	Include $[Fe(H_2O)_6]^{3+}$, $[Fe(CN)_6]^{3-}$, $[CuCl_4]^{2-}$ and $[Ag(NH_3)_2]^+$. Only monodentate ligands are required.
13.2.6	Explain why some complexes of d-block elements are coloured.	3	Students need only know that, in complexes, the d sub-level splits into two sets of orbitals of different energy and the electronic transitions that take place between them are responsible for their colours.
13.2.7	State examples of the catalytic action of transition elements and their compounds.	1	Examples should include: • MnO_2 in the decomposition of hydrogen peroxide • V_2O_5 in the Contact process • Fe in the Haber process and in heme • Ni in the conversion of alkenes to alkanes • Co in vitamin B_{12} • Pd and Pt in catalytic converters. The mechanisms of action will not be assessed.

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	Assessment statement	Obj	Teacher's notes
13.2.8	Outline the economic significance of catalysts in the Contact and Haber processes.	2	**Aim 8**

Topic 14: Bonding (5 hours)

14.1 Shapes of molecules and ions

1 hour

	Assessment statement	Obj	Teacher's notes
14.1.1	Predict the shape and bond angles for species with five and six negative charge centres using the VSEPR theory.	3	Examples should include PCl_5, SF_6, XeF_4 and PF_6^-. **Aim 7:** Interactive simulations are available to illustrate this.

14.2 Hybridization

2 hours

	Assessment statement	Obj	Teacher's notes
14.2.1	Describe σ and π bonds.	2	Treatment should include: • σ bonds resulting from the axial overlap of orbitals • π bonds resulting from the sideways overlap of parallel p orbitals • double bonds formed by one σ and one π bond • triple bonds formed by one σ and two π bonds.
14.2.2	Explain hybridization in terms of the mixing of atomic orbitals to form new orbitals for bonding.	3	Students should consider sp, sp^2 and sp^3 hybridization, and the shapes and orientation of these orbitals. **TOK:** Is hybridization a real process or a mathematical device?
14.2.3	Identify and explain the relationships between Lewis structures, molecular shapes and types of hybridization (sp, sp^2 and sp^3).	3	Students should consider examples from inorganic as well as organic chemistry.

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14.3 Delocalization of electrons

2 hours

	Assessment statement	Obj	Teacher's notes
14.3.1	Describe the delocalization of π electrons and explain how this can account for the structures of some species.	3	Examples should include NO_3^-, NO_2^-, CO_3^{2-}, O_3, $RCOO^-$ and benzene. **TOK:** Kekulé claimed that the inspiration for the cyclic structure of benzene came from a dream. What role do the less rational ways of knowing play in the acquisition of scientific knowledge? What distinguishes a scientific from a non-scientific hypothesis: its origins or how it is tested?

Topic 15: Energetics (8 hours)

15.1 Standard enthalpy changes of reaction

1.5 hour

	Assessment statement	Obj	Teacher's notes
15.1.1	Define and apply the terms *standard state, standard enthalpy change of formation* ($\Delta H_f^{\ominus}$) and *standard enthalpy change of combustion* ($\Delta H_c^{\ominus}$).	2	
15.1.2	Determine the enthalpy change of a reaction using standard enthalpy changes of formation and combustion.	3	

15.2 Born–Haber cycle

2.5 hours

	Assessment statement	Obj	Teacher's notes
15.2.1	Define and apply the terms *lattice enthalpy* and *electron affinity*.	2	
15.2.2	Explain how the relative sizes and the charges of ions affect the lattice enthalpies of different ionic compounds.	3	The relative value of the theoretical lattice enthalpy increases with higher ionic charge and smaller ionic radius due to increased attractive forces.
15.2.3	Construct a Born–Haber cycle for group 1 and 2 oxides and chlorides, and use it to calculate an enthalpy change.	3	
15.2.4	Discuss the difference between theoretical and experimental lattice enthalpy values of ionic compounds in terms of their covalent character.	3	A significant difference between the two values indicates covalent character.

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15.3 Entropy

1.5 hours

	Assessment statement	Obj	Teacher's notes
15.3.1	State and explain the factors that increase the entropy in a system.	3	
15.3.2	Predict whether the entropy change (ΔS) for a given reaction or process is positive or negative.	3	
15.3.3	Calculate the standard entropy change for a reaction ($\Delta S^{\ominus}$) using standard entropy values ($S^{\ominus}$).	2	

15.4 Spontaneity

2.5 hours

	Assessment statement	Obj	Teacher's notes
15.4.1	Predict whether a reaction or process will be spontaneous by using the sign of $\Delta G^{\ominus}$.	3	
15.4.2	Calculate $\Delta G^{\ominus}$ for a reaction using the equation $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$ and by using values of the standard free energy change of formation, $\Delta G_f^{\ominus}$.	2	
15.4.3	Predict the effect of a change in temperature on the spontaneity of a reaction using standard entropy and enthalpy changes and the equation $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$.	3	

Topic 16: Kinetics (6 hours)

16.1 Rate expression

3 hours

	Assessment statement	Obj	Teacher's notes
16.1.1	Distinguish between the terms *rate constant*, *overall order of reaction* and *order of reaction* with respect to a particular reactant.	2	
16.1.2	Deduce the rate expression for a reaction from experimental data.	3	**Aim 7:** Virtual experiments can be used here.
16.1.3	Solve problems involving the rate expression.	3	

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	Assessment statement	Obj	Teacher's notes
16.1.4	Sketch, identify and analyse graphical representations for zero-, first- and second-order reactions.	3	Students should be familiar with both concentration–time and rate–concentration graphs.

16.2 Reaction mechanism

1 hour

	Assessment statement	Obj	Teacher's notes
16.2.1	Explain that reactions can occur by more than one step and that the slowest step determines the rate of reaction (rate-determining step).	3	
16.2.2	Describe the relationship between reaction mechanism, order of reaction and rate-determining step.	2	Only examples with one- or two-step reactions where the mechanism is given will be assessed. **TOK:** Agreement between rate equation and a suggested mechanism only provides evidence to support a reaction mechanism. Disagreement disproves the mechanism.

16.3 Activation energy

2 hours

	Assessment statement	Obj	Teacher's notes
16.3.1	Describe qualitatively the relationship between the rate constant (k) and temperature (T).	2	
16.3.2	Determine activation energy (E_a) values from the Arrhenius equation by a graphical method.	3	The Arrhenius equation and its logarithmic form are provided in the *Chemistry data booklet*. The use of simultaneous equations will not be assessed.

Topic 17: Equilibrium (4 hours)

17.1 Liquid–vapour equilibrium

2 hours

	Assessment statement	Obj	Teacher's notes
17.1.1	Describe the equilibrium established between a liquid and its own vapour and how it is affected by temperature changes.	2	
17.1.2	Sketch graphs showing the relationship between vapour pressure and temperature and explain them in terms of the kinetic theory.	3	

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	Assessment statement	Obj	Teacher's notes
17.1.3	State and explain the relationship between enthalpy of vaporization, boiling point and intermolecular forces.	3	

17.2 The equilibrium law

2 hours

	Assessment statement	Obj	Teacher's notes
17.2.1	Solve homogeneous equilibrium problems using the expression for K_c.	3	The use of quadratic equations will not be assessed.

Topic 18: Acids and bases (10 hours)

18.1 Calculations involving acids and bases

4 hours

	Assessment statement	Obj	Teacher's notes
18.1.1	State the expression for the ionic product constant of water (K_w).	1	
18.1.2	Deduce $[H^+(aq)]$ and $[OH^-(aq)]$ for water at different temperatures given K_w values.	3	
18.1.3	Solve problems involving $[H^+(aq)]$, $[OH^-(aq)]$, pH and pOH.	3	
18.1.4	State the equation for the reaction of any weak acid or weak base with water, and hence deduce the expressions for K_a and K_b.	1	Only examples involving the transfer of one proton will be assessed.
18.1.5	Solve problems involving solutions of weak acids and bases using the expressions: $K_a \times K_b = K_w$ $pK_a + pK_b = pK_w$ $pH + pOH = pK_w$.	3	Students should state when approximations are used in equilibrium calculations. The use of quadratic equations will not be assessed.
18.1.6	Identify the relative strengths of acids and bases using values of K_a, K_b, pK_a and pK_b.	2	

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18.2 Buffer solutions

2 hours

	Assessment statement	Obj	Teacher's notes
18.2.1	Describe the composition of a buffer solution and explain its action.	3	
18.2.2	Solve problems involving the composition and pH of a specified buffer system.	3	Only examples involving the transfer of one proton will be assessed. Examples should include ammonia solution/ammonium chloride and ethanoic acid/ sodium ethanoate. Students should state when approximations are used in equilibrium calculations. The use of quadratic equations will not be assessed. **Aim 7:** Virtual experiments can be used to demonstrate this.

18.3 Salt hydrolysis

1 hour

	Assessment statement	Obj	Teacher's notes
18.3.1	Deduce whether salts form acidic, alkaline or neutral aqueous solutions.	3	Examples should include salts formed from the four possible combinations of strong and weak acids and bases. The effect of the charge density of the cations in groups 1, 2 and 3 and d-block elements should also be considered. For example, $[Fe(H_2O)_6]^{3+}(aq) \longrightarrow [Fe(OH)(H_2O)_5]^{2+}(aq) + H^+(aq)$

18.4 Acid–base titrations

2 hours

	Assessment statement	Obj	Teacher's notes
18.4.1	Sketch the general shapes of graphs of pH against volume for titrations involving strong and weak acids and bases, and explain their important features.	3	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. **Aim 7:** Data logging, databases, spreadsheets and simulations are all possible here.

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18.5 Indicators

1 hour

	Assessment statement	Obj	Teacher's notes
18.5.1	Describe qualitatively the action of an acid–base indicator.	2	Use $\underset{\text{colour A}}{HIn(aq)} \rightleftharpoons \underset{\text{colour B}}{H^+(aq)} + In^-(aq)$.
18.5.2	State and explain how the pH range of an acid–base indicator relates to its pK_a value.	3	
18.5.3	Identify an appropriate indicator for a titration, given the equivalence point of the titration and the pH range of the indicator.	2	Examples of indicators are listed in the *Chemistry data booklet*.

Topic 19: Oxidation and reduction (5 hours)

19.1 Standard electrode potentials

3 hours

	Assessment statement	Obj	Teacher's notes
19.1.1	Describe the standard hydrogen electrode.	2	
19.1.2	Define the term *standard electrode potential* ($E^{\ominus}$).	1	
19.1.3	Calculate cell potentials using standard electrode potentials.	2	
19.1.4	Predict whether a reaction will be spontaneous using standard electrode potential values.	3	

19.2 Electrolysis

2 hours

	Assessment statement	Obj	Teacher's notes
19.2.1	Predict and explain the products of electrolysis of aqueous solutions.	3	Explanations should refer to $E^{\ominus}$ values, nature of the electrode and concentration of the electrolyte. Examples include the electrolysis of water, aqueous sodium chloride and aqueous copper(II) sulfate. **Aim 7:** Virtual experiments can be used to demonstrate this.
19.2.2	Determine the relative amounts of the products formed during electrolysis.	3	The factors to be considered are charge on the ion, current and duration of electrolysis.
19.2.3	Describe the use of electrolysis in electroplating.	2	**Aim 8**

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Topic 20: Organic chemistry (10 hours)

20.1 Introduction

1 hour

	Assessment statement	Obj	Teacher's notes
20.1.1	Deduce structural formulas for compounds containing up to six carbon atoms with one of the following functional groups: amine, amide, ester and nitrile.	3	Condensed structural formulas can use NH_2, $CONH_2$, –COOC– and CN for these groups.
20.1.2	Apply IUPAC rules for naming compounds containing up to six carbon atoms with one of the following functional groups: amine, amide, ester and nitrile.	2	

20.2 Nucleophilic substitution reactions

2 hours

	Assessment statement	Obj	Teacher's notes
20.2.1	Explain why the hydroxide ion is a better nucleophile than water.	3	
20.2.2	Describe and explain how the rate of nucleophilic substitution in halogenoalkanes by the hydroxide ion depends on the identity of the halogen.	3	
20.2.3	Describe and explain how the rate of nucleophilic substitution in halogenoalkanes by the hydroxide ion depends on whether the halogenoalkane is primary, secondary or tertiary.	3	
20.2.4	Describe, using equations, the substitution reactions of halogenoalkanes with ammonia and potassium cyanide.	2	
20.2.5	Explain the reactions of primary halogenoalkanes with ammonia and potassium cyanide in terms of the S_N2 mechanism.	3	
20.2.6	Describe, using equations, the reduction of nitriles using hydrogen and a nickel catalyst.	2	

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20.3 Elimination reactions

1 hour

	Assessment statement	Obj	Teacher's notes
20.3.1	Describe, using equations, the elimination of HBr from bromoalkanes.	2	
20.3.2	Describe and explain the mechanism for the elimination of HBr from bromoalkanes.	3	

20.4 Condensation reactions

2 hours

	Assessment statement	Obj	Teacher's notes
20.4.1	Describe, using equations, the reactions of alcohols with carboxylic acids to form esters, and state the uses of esters.	2	Mechanisms will not be assessed.
20.4.2	Describe, using equations, the reactions of amines with carboxylic acids.	2	Mechanisms will not be assessed.
20.4.3	Deduce the structures of the polymers formed in the reactions of alcohols with carboxylic acids.	3	Emphasize the need for two functional groups on each monomer. Include the polyester formed from ethane-1,2-diol and benzene-1,4-dicarboxylic acid. Include the identification of the repeating unit.
20.4.4	Deduce the structures of the polymers formed in the reactions of amines with carboxylic acids.	3	Emphasize the need for two functional groups on each monomer. Include the polyamide formed from 1,6-diaminohexane and hexanedioic acid. Include the identification of the repeating unit.
20.4.5	Outline the economic importance of condensation reactions.	2	**Aim 8**

20.5 Reaction pathways

1 hour

	Assessment statement	Obj	Teacher's notes
20.5.1	Deduce reaction pathways given the starting materials and the product.	3	Conversions with more than two stages will not be assessed. Reagents, conditions and equations should be included. For example, the conversion of 1-bromopropane to 1-butylamine can be done in two stages: 1-bromopropane can be reacted with potassium cyanide to form propanenitrile, which can then be reduced by heating with hydrogen and a nickel catalyst.

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20.6 Stereoisomerism

3 hours

	Assessment statement	Obj	Teacher's notes
20.6.1	Describe stereoisomers as compounds with the same structural formula but with different arrangements of atoms in space.	2	
20.6.2	Describe and explain geometrical isomerism in non-cyclic alkenes.	3	Include the prefixes *cis*- and *trans*- and the term restricted rotation.
20.6.3	Describe and explain geometrical isomerism in C_3 and C_4 cycloalkanes.	3	Include the dichloro derivatives of cyclopropane and cyclobutane.
20.6.4	Explain the difference in the physical and chemical properties of geometrical isomers.	3	Include *cis*- and *trans*-1,2-dichloroethene as examples with different boiling points, and *cis*- and *trans*-but-2-ene-1,4-dioic acid as examples that react differently when heated.
20.6.5	Describe and explain optical isomerism in simple organic molecules.	3	Include examples such as butan-2-ol and 2-bromobutane. The term asymmetric can be used to describe a carbon atom joined to four different atoms or groups. The term chiral can be used to describe a carbon atom joined to four different atoms or groups, and also as a description of the molecule itself. Include the meanings of the terms enantiomer and racemic mixture. **TOK:** The existence of optical isomers provided indirect evidence of a tetrahedrally bonded carbon atom. This is an example of the power of reasoning in allowing us access to the molecular scale. Do we know or believe those carbon atoms are tetrahedrally coordinated? The use of conventions in representing three-dimensional molecules in two dimensions could also be discussed.
20.6.6	Outline the use of a polarimeter in distinguishing between optical isomers.	2	Include the meaning of the term plane-polarized light.
20.6.7	Compare the physical and chemical properties of enantiomers.	3	

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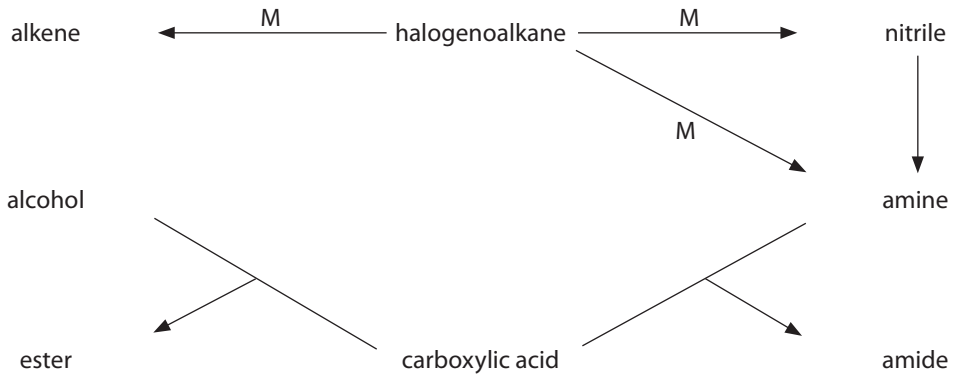
The compound and reaction types in this topic are summarized in the following scheme.



M = mechanism required

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Syllabus details—Options SL and HL

SL students study the core of these options and HL students study the whole option (the core and the extension material).

Option A: Modern analytical chemistry (15/22 hours)

Analytical chemistry techniques are widely used in today's society. When teaching this option, problem solving and the need to use the information gained from one or more techniques to solve problems should be emphasized. Students should understand the chemical principles behind each analytical technique.

This option builds on some of the key ideas in both physical and organic chemistry that were introduced in the core.

Core material: A1–A7 are core material for SL and HL (15 hours).

Extension material: A8–A10 are extension material for HL only (7 hours).

A1 Analytical techniques

1 hour

	Assessment statement	Obj	Teacher's notes
A.1.1	State the reasons for using analytical techniques.	1	Uses should include structure determination, analysis of composition of substances and to determine purity.
A.1.2	State that the structure of a compound can be determined by using information from a variety of analytical techniques singularly or in combination.	1	Students should realize that information from only one technique is usually insufficient to determine or confirm a structure.

A2 Principles of spectroscopy

2 hours

	Assessment statement	Obj	Teacher's notes
A.2.1	Describe the electromagnetic spectrum.	2	X-ray, ultraviolet (UV), visible, infrared (IR), radio and microwave should be identified. Highlight the variation in wavelength, wave number, frequency and energy across the spectrum. **TOK:** The electromagnetic spectrum is a carrier of information. The nature of the information is limited by its wavelength.

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	Assessment statement	Obj	Teacher's notes
A.2.2	Distinguish between *absorption* and *emission* spectra and how each is produced.	2	
A.2.3	Describe the atomic and molecular processes in which absorption of energy takes place.	2	The description should include vibrations, rotation and electronic transitions. **Aim 7:** Simulations of these processes are available.

A3 Infrared (IR) spectroscopy

3 hours

	Assessment statement	Obj	Teacher's notes
A.3.1	Describe the operating principles of a double-beam IR spectrometer.	2	A schematic diagram of a simple double-beam spectrometer is sufficient.
A.3.2	Describe how information from an IR spectrum can be used to identify bonds.	2	
A.3.3	Explain what occurs at a molecular level during the absorption of IR radiation by molecules.	3	H_2O, $-CH_2-$, SO_2 and CO_2 are suitable examples. Stress the change in bond polarity as the vibrations (stretching and bending) occur.
A.3.4	Analyse IR spectra of organic compounds.	3	Students will be assessed using examples containing up to three functional groups. The *Chemistry data booklet* contains a table of IR absorptions for some bonds in organic molecules. Students should realize that IR absorption data can be used to identify the bonds present, but not always the functional groups present.

A4 Mass spectrometry

2 hours

	Assessment statement	Obj	Teacher's notes
A.4.1	Determine the molecular mass of a compound from the molecular ion peak.	3	
A.4.2	Analyse fragmentation patterns in a mass spectrum to find the structure of a compound.	3	Examples of fragments should include: • $(M_r - 15)^+$ loss of CH_3 • $(M_r - 17)^+$ loss of OH • $(M_r - 29)^+$ loss of C_2H_5 or CHO • $(M_r - 31)^+$ loss of CH_3O • $(M_r - 45)^+$ loss of COOH.

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A5 Nuclear magnetic resonance (NMR) spectroscopy

2 hours

	Assessment statement	Obj	Teacher's notes
A.5.1	Deduce the structure of a compound given information from its ^{1}H NMR spectrum.	3	Students will only be assessed on their ability to deduce the number of different hydrogen (proton) environments and the relative numbers of hydrogen atoms in each environment. They should be familiar both with a word description of a spectrum and with a diagram of a spectrum, including an integration trace. The interpretation of splitting patterns will not be assessed. **Aim 7:** Data banks could be used here.
A.5.2	Outline how NMR is used in body scanners.	2	**Aim 8:** 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.

A6 Atomic absorption (AA) spectroscopy

3 hours

	Assessment statement	Obj	Teacher's notes
A.6.1	State the uses of AA spectroscopy.	1	**Aim 8:** Include uses such as the identification of metals in water, blood, soils and foods.
A.6.2	Describe the principles of atomic absorption.	2	
A.6.3	Describe the use of each of the following components of the AA spectrophotometer: fuel, atomizer, monochromatic light source, monochromatic detector and read-out.	2	
A.6.4	Determine the concentration of a solution from a calibration curve.	3	**Aim 7:** Details about the instruments used can be found on the Internet.

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A7 Chromatography

2 hours

	Assessment statement	Obj	Teacher's notes
A.7.1	State the reasons for using chromatography.	1	The qualitative and quantitative aspects of chromatography should be outlined.
A.7.2	Explain that all chromatographic techniques involve adsorption on a stationary phase and partition between a stationary phase and a mobile phase.	3	Components in a mixture have different tendencies to adsorb onto a surface or dissolve in a solvent. This provides a means of separating the components of a mixture.
A.7.3	Outline the use of paper chromatography, thin-layer chromatography (TLC) and column chromatography.	2	An outline of the operation for each technique will be assessed. This should include an understanding and calculation of R_f values where relevant. Students should be aware that, in some instances, paper chromatograms may need to be developed, for example, in the separation of sugars.

HL A8 Visible and ultraviolet (UV-Vis) spectroscopy

3 hours

	Assessment statement	Obj	Teacher's notes
A.8.1	Describe the effect of different ligands on the splitting of the d orbitals in transition metal complexes.	2	The ligands should include NH_3, H_2O and Cl^-.
A.8.2	Describe the factors that affect the colour of transition metal complexes.	2	Include the identity of the metal ion (for example, Mn^{2+} or Fe^{2+}), the oxidation number of the metal (for example, for Fe, +2 or +3) and the identity of the ligand (for example, NH_3 or H_2O). These factors will be assessed only for octahedral complexes in aqueous solution.
A.8.3	State that organic molecules containing a double bond absorb UV radiation.	1	Refer to conjugated and delocalized systems, including arenes, alkenes and chlorophyll.
A.8.4	Describe the effect of the conjugation of double bonds in organic molecules on the wavelength of the absorbed light.	2	Examples should include retinol and phenolphthalein. **Aim 8:** The application of this in sun creams could be discussed.
A.8.5	Predict whether or not a particular molecule will absorb UV or visible radiation.	3	
A.8.6	Determine the concentration of a solution from a calibration curve using the Beer–Lambert law.	3	

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HL A9 Nuclear magnetic resonance (NMR) spectroscopy

2 hours

	Assessment statement	Obj	Teacher's notes
A.9.1	Explain the use of tetramethylsilane (TMS) as the reference standard.	3	
A.9.2	Analyse ^{1}H NMR spectra.	3	Students should be able to interpret the following from ^{1}H NMR spectra: number of peaks, area under each peak, chemical shift and splitting patterns. Treatment of spin–spin coupling constants will not be assessed, but students should be familiar with singlets, doublets, triplets and quartets.

HL A10 Chromatography

2 hours

	Assessment statement	Obj	Teacher's notes
A.10.1	Describe the techniques of gas–liquid chromatography (GLC) and high-performance liquid chromatography (HPLC).	2	An outline of the operation for each technique will be assessed. This should include an understanding of R_t value and its dependence on other factors where relevant.
A.10.2	Deduce which chromatographic technique is most appropriate for separating the components in a particular mixture.	3	**Aim 8:** HPLC can identify compounds that are temperature-sensitive. Uses include: analysis of oil; alcoholic beverages; antioxidants, sugars and vitamins in foods; pharmaceuticals; polymers; biochemical and biotechnology research; and quality control of insecticides and herbicides. GLC can identify compounds that can vaporize without decomposing. Uses include: analysis of urine samples from athletes for drugs, underground mine gases and blood alcohol levels.

Option B: Human biochemistry (15/22 hours)

The aim of this option is to give students an understanding of the chemistry of important molecules found in the human body, and the need for a balanced and healthy diet. Although the role that these molecules play in the body should be appreciated, the emphasis is placed on their chemistry, and students who have not followed a course in biology will not be at a disadvantage. Students will not be required to memorize complex structures, but they will be expected to recognize functional groups and types of bonding within and between molecules. Structures of some important biological molecules are given in the *Chemistry data booklet*. Teachers are encouraged to foster students' awareness of local and global issues.

Core material: B1–B6 are core material for SL and HL (15 hours).

Extension material: B7–B9 are extension material for HL only (7 hours).

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B1 Energy

0.5 hour

	Assessment statement	Obj	Teacher's notes
B.1.1	Calculate the energy value of a food from enthalpy of combustion data.	2	

B2 Proteins

3 hours

	Assessment statement	Obj	Teacher's notes
B.2.1	Draw the general formula of 2-amino acids.	1	
B.2.2	Describe the characteristic properties of 2-amino acids	2	Properties should include isoelectric point, formation of a zwitterion and buffer action.
B.2.3	Describe the condensation reaction of 2-amino acids to form polypeptides.	2	Reactions involving up to three amino acids will be assessed.
B.2.4	Describe and explain the primary, secondary (α-helix and β-pleated sheets), tertiary and quaternary structure of proteins.	3	Include all bonds and interactions (both intramolecular and intermolecular) responsible for the protein structure.
B.2.5	Explain how proteins can be analysed by chromatography and electrophoresis.	3	
B.2.6	List the major functions of proteins in the body.	1	Include structural proteins (for example, collagen), enzymes, hormones (for example, insulin), immunoproteins (antibodies), transport proteins (for example, hemoglobin) and as an energy source.

B3 Carbohydrates

3 hours

	Assessment statement	Obj	Teacher's notes
B.3.1	Describe the structural features of monosaccharides.	2	Monosaccharides contain a carbonyl group (C=O) and at least two –OH groups, and have the empirical formula CH_2O.
B.3.2	Draw the straight-chain and ring structural formulas of glucose and fructose.	1	Students should be made aware of the structural difference between α and β isomers.
B.3.3	Describe the condensation of monosaccharides to form disaccharides and polysaccharides.	2	Examples include: • disaccharides—lactose, maltose and sucrose • polysaccharides—starch (α-glucose), glycogen (α-glucose) and cellulose (β-glucose).
B.3.4	List the major functions of carbohydrates in the human body.	1	Include energy source (glucose), energy reserves (glycogen) and precursors for other biologically important molecules.

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	Assessment statement	Obj	Teacher's notes
B.3.5	Compare the structural properties of starch and cellulose, and explain why humans can digest starch but not cellulose.	3	Both are polymers of glucose units. Starch has two forms: amylose, which is a straight-chain polymer (α-1,4 linkage), and amylopectin, which is a branched structure with both α-1,4 and α-1,6 linkages. Cellulose has a β-1,4 linkage; this can be hydrolysed by the enzyme cellulase, which is absent in most animals, including mammals.
B.3.6	State what is meant by the term dietary fibre.	1	Dietary fibre is mainly plant material that is not hydrolysed by enzymes secreted by the human digestive tract but may be digested by microflora in the gut. Examples include cellulose, hemicellulose, lignin and pectin.
B.3.7	Describe the importance of a diet high in dietary fibre.	2	**Aim 8:** Dietary fibre may be helpful in the prevention of conditions such as diverticulosis, irritable bowel syndrome, constipation, obesity, Crohn's disease, hemorrhoids and diabetes mellitus.

B4 Lipids

3.5 hours

	Assessment statement	Obj	Teacher's notes
B.4.1	Compare the composition of the three types of lipids found in the human body.	3	Examples include triglycerides (fats and oils), phospholipid (lecithin) and steroids (cholesterol).
B.4.2	Outline the difference between HDL and LDL cholesterol and outline its importance.	2	
B.4.3	Describe the difference in structure between saturated and unsaturated fatty acids.	2	Most naturally occurring fats contain a mixture of saturated, mono-unsaturated and poly-unsaturated fatty acids and are classified according to the predominant type of unsaturation present.
B.4.4	Compare the structures of the two essential fatty acids linoleic (omega–6 fatty acid) and linolenic (omega–3 fatty acid) and state their importance.	3	
B.4.5	Define the term *iodine number* and calculate the number of C=C double bonds in an unsaturated fat/oil using addition reactions.	2	The number of moles of I_2 reacting with one mole of fat/oil indicates the number of double bonds present in the fat/oil molecule.
B.4.6	Describe the condensation of glycerol and three fatty acid molecules to make a triglyceride.	2	
B.4.7	Describe the enzyme-catalysed hydrolysis of triglycerides during digestion.	2	
B.4.8	Explain the higher energy value of fats as compared to carbohydrates.	3	

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	Assessment statement	Obj	Teacher's notes
B.4.9	Describe the important roles of lipids in the body and the negative effects that they can have on health.	2	Important roles include: • energy storage • insulation and protection of organs • steroid hormones • structural component of cell membrane • omega-3 poly-unsaturated fatty acids reduce the risk of heart disease • poly-unsaturated fats may lower levels of LDL cholesterol. Negative effects include: • increased risk of heart disease from elevated levels of LDL cholesterol and *trans* fatty acids; the major source of LDL cholesterol is saturated fats, in particular lauric (C_{12}), myristic (C_{14}) and palmitic (C_{16}) acids • obesity.

B5 Micronutrients and macronutrients

2 hours

	Assessment statement	Obj	Teacher's notes
B.5.1	Outline the difference between micronutrients and macronutrients.	2	Micronutrients are substances required in very small amounts (mg or µg) and that mainly function as a co-factor of enzymes (<0.005% body weight). Examples include vitamins and trace minerals (Fe, Cu, F, Zn, I, Se, Mn, Mo, Cr, Co and B). Macronutrients are chemical substances that are required in relatively large amounts (>0.005% body weight). Examples include proteins, fats, carbohydrates and minerals (Na, Mg, K, Ca, P, S and Cl).
B.5.2	Compare the structures of retinol (vitamin A), calciferol (vitamin D) and ascorbic acid (vitamin C).	3	
B.5.3	Deduce whether a vitamin is water- or fat-soluble from its structure.	3	Examples include: • water-soluble—vitamins B and C • fat-soluble—vitamins A, D, E and K.

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	Assessment statement	Obj	Teacher's notes
B.5.4	Discuss the causes and effects of nutrient deficiencies in different countries and suggest solutions.	3	Micronutrient deficiencies include: • iron—anemia • iodine—goitre • retinol (vitamin A)—xerophthalmia, night blindness • niacin (vitamin B_3)—pellagra • thiamin (vitamin B_1)—beriberi • ascorbic acid (vitamin C)—scurvy • calciferol (vitamin D)—rickets. Macronutrient deficiencies include: • protein—marasmus and kwashiorkor. Some causes of malnutrition may be discussed here. Solutions include: • providing food rations that are composed of fresh and vitamin- and mineral-rich foods • adding nutrients missing in commonly consumed foods • genetic modification of food • providing nutritional supplements • providing selenium supplements to people eating foods grown in selenium-poor soil.

B6 Hormones

3 hours

	Assessment statement	Obj	Teacher's notes
B.6.1	Outline the production and function of hormones in the body.	2	Hormones are chemical messengers. They are secreted directly into the blood by endocrine glands. Examples include ADH, aldosterone, estrogen, progesterone and testosterone, insulin, epinephrine (adrenaline) and thyroxine.
B.6.2	Compare the structures of cholesterol and the sex hormones.	3	Stress the common steroid backbone but the difference in functional groups.
B.6.3	Describe the mode of action of oral contraceptives.	2	**Aim 8**
B.6.4	Outline the use and abuse of steroids.	2	**Aim 8**

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HL B7 Enzymes

3 hours

	Assessment statement	Obj	Teacher's notes
B.7.1	Describe the characteristics of biological catalysts (enzymes).	2	Include: enzymes are proteins; activity depends on tertiary and quaternary structure; and the specificity of enzyme action.
B.7.2	Compare inorganic catalysts and biological catalysts (enzymes).	3	
B.7.3	Describe the relationship between substrate concentration and enzyme activity.	2	
B.7.4	Determine V_{max} and the value of the Michaelis constant (K_m) by graphical means and explain its significance.	3	
B.7.5	Describe the mechanism of enzyme action, including enzyme substrate complex, active site and induced fit model.	2	
B.7.6	Compare competitive inhibition and non-competitive inhibition.	3	
B.7.7	State and explain the effects of heavy-metal ions, temperature changes and pH changes on enzyme activity.	3	

HL B8 Nucleic acids

3 hours

	Assessment statement	Obj	Teacher's notes
B.8.1	Describe the structure of nucleotides and their condensation polymers (nucleic acids or polynucleotides).	2	Nucleic acids are polymers made up of nucleotides. A nucleotide contains a phosphate group, a pentose sugar and an organic nitrogenous base. Students should recognize, but do not need to recall, the structures of the five bases: adenine (A), cytosine (C), guanine (G), thymine (T) and uracil (U). Nucleic acids are joined by covalent bonds between the phosphate of one nucleotide and the sugar of the next, resulting in a backbone with a repeating pattern of sugar–phosphate–sugar–phosphate. Nitrogenous bases are attached to the sugar of the backbone.
B.8.2	Distinguish between the structures of DNA and RNA.	2	RNA has ribose as its pentose sugar; DNA has deoxyribose. Deoxyribose lacks an oxygen atom on C2. RNA has uracil instead of thymine as its base. RNA is a single-strand nucleic acid; DNA is a double-strand nucleic acid.

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	Assessment statement	Obj	Teacher's notes
B.8.3	Explain the double helical structure of DNA.	3	The structure has two nucleic acid strands that spiral around an axis. Students should describe the hydrogen bonding between specific pairs of nucleotide bases. **TOK:** What are the implications of the discovery of the molecular basis of life in other areas of knowledge?
B.8.4	Describe the role of DNA as the repository of genetic information, and explain its role in protein synthesis.	2	DNA is the genetic material that an individual inherits from its parents. It directs mRNA synthesis (transcription) and, through mRNA, directs protein synthesis (translation) using a triplet code.
B.8.5	Outline the steps involved in DNA profiling and state its use.	2	**Aim 8:** Include forensic and paternity cases.

HL B9 Respiration

1 hour

	Assessment statement	Obj	Teacher's notes
B.9.1	Compare aerobic and anaerobic respiration of glucose in terms of oxidation/reduction and energy released.	3	In aerobic respiration, glucose is converted into pyruvate, which, in the presence of oxygen, changes to carbon dioxide and water. Overall, glucose undergoes oxidation and oxygen undergoes reduction. In anaerobic respiration, pyruvate is converted to lactate in human beings, whereas yeast converts pyruvate to ethanol and carbon dioxide. Redox equations should be used as appropriate.
B.9.2	Outline the role of copper ions in electron transport and iron ions in oxygen transport.	2	Cytochromes and hemoglobin are suitable examples.

Option C: Chemistry in industry and technology (15/22 hours)

As one of the most important roles of chemistry is to make forms of matter that have never existed before, it plays a central role in any material revolution. The Industrial Revolution of the 18th century was the result of the large-scale extraction of iron, but the material revolution continues the development of new materials with structures and properties that serve the technologies of today. The consideration of how the materials benefit society makes this option particularly relevant to aim 8. When teaching this option, the relation between the structure of materials and their properties should be emphasized.

Core material: C1–C7 are core material for SL and HL (15 hours).

Extension material: C8–C12 are extension material for HL only (7 hours).

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C1 Iron, steel and aluminium

3.5 hours

	Assessment statement	Obj	Teacher's notes
C.1.1	State the main sources of iron.	1	
C.1.2	Describe and explain the reactions that occur in the blast furnace.	3	
C.1.3	Describe and explain the conversion of iron into steel using the basic oxygen converter.	3	
C.1.4	Describe alloys as a homogeneous mixture of metals or a mixture of a metal and non-metal.	2	
C.1.5	Explain how alloying can modify the properties of metals.	3	
C.1.6	Describe the effects of heat treatment of steel.	2	Effects should include tempering, annealing and quenching.
C.1.7	Describe the properties and uses of iron and steel.	2	
C.1.8	Describe and explain the production of aluminium by electrolysis of alumina in molten cryolite.	3	Include the use of cryolite as a solvent because of the very high melting point of Al_2O_3 and the type of materials used for the construction of the cell and choice of electrodes.
C1.9	Describe the main properties and uses of aluminium and its alloys.	2	
C.1.10	Discuss the environmental impact of iron and aluminium production.	3	**Aim 8**

C2 The oil industry

2 hours

	Assessment statement	Obj	Teacher's notes
C.2.1	Compare the use of oil as an energy source and as a chemical feedstock	3	
C.2.2	Compare catalytic cracking, thermal cracking and steam cracking.	3	**Aim 8:** Students should include the environmental impact of the processes and their products.

C3 Addition polymers

2 hours

	Assessment statement	Obj	Teacher's notes
C.3.1	Describe and explain how the properties of polymers depend on their structural features.	3	Students should consider: • different amounts of branching in low- and high-density polyethene • different positions of the methyl groups in isotactic and atactic polypropene.

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	Assessment statement	Obj	Teacher's notes
C.3.2	Describe the ways of modifying the properties of addition polymers.	2	Examples include plasticizers in polyvinyl chloride and volatile hydrocarbons in the formation of expanded polystyrene.
C.3.3	Discuss the advantages and disadvantages of polymer use.	3	Include strength, density, insulation, lack of reactivity, use of natural resources, disposal and biodegradability. Use polyethene (both LDPE and HDPE), polystyrene and polyvinyl chloride plastics as examples.

C4 Catalysts

1.5 hours

	Assessment statement	Obj	Teacher's notes
C.4.1	Compare the modes of action of homogeneous and heterogeneous catalysts.	3	Relate the modes of action of catalysts to their ability to form a range of oxidation states (transition metals), their shape and the availability of active sites.
C.4.2	Outline the advantages and disadvantages of homogeneous and heterogeneous catalysts.	2	Advantages include: • homogeneous catalysts—all the catalyst is exposed to the reactants • heterogeneous catalysts—easily removed from products by filtration. Disadvantages include: • homogeneous catalysts—can be difficult to remove from the products for reuse • heterogeneous catalysts—only effective on the surface.
C.4.3	Discuss the factors in choosing a catalyst for a process.	3	Factors could include: • selectivity (produce only the desired product) • efficiency • ability to work under mild/severe conditions • environmental impact • problems caused by catalysts becoming poisoned by impurities.

C5 Fuel cells and rechargeable batteries

2 hours

	Assessment statement	Obj	Teacher's notes
C.5.1	Describe how a hydrogen–oxygen fuel cell works.	2	Include the relevant half-equations in both acidic and alkaline electrolytes.
C.5.2	Describe the workings of rechargeable batteries.	2	Include the relevant half-equations. **Aim 8:** Examples should include the lead–acid storage battery, the nickel–cadmium (NiCad) battery and the lithium-ion battery.
C.5.3	Discuss the similarities and differences between fuel cells and rechargeable batteries.	3	

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C6 Liquid crystals

2 hours

	Assessment statement	Obj	Teacher's notes
C.6.1	Describe the meaning of the term liquid crystals.	2	Liquid crystals are fluids that have physical properties (electrical, optical and elasticity) that are dependent on molecular orientation relative to some fixed axis in the material. Examples should include graphite, cellulose, the solution extruded by a spider to form silk, and DNA. Students should be aware that liquid-crystal materials may not always be in a liquid-crystal phase.
C.6.2	Distinguish between *thermotropic* and *lyotropic* liquid crystals.	2	Thermotropic liquid-crystal materials are pure substances that show liquid-crystal behaviour over a temperature range between the solid and liquid states. The biphenyl nitriles are common examples. Lyotropic liquid crystals are solutions that show the liquid-crystal state at certain concentrations. Examples should include soap and water.
C.6.3	Describe the liquid-crystal state in terms of the arrangement of the molecules and explain thermotropic behaviour.	3	Only the nematic phase will be assessed. Rod-shaped molecules are distributed randomly but, on average, point in the same direction. Increased thermal agitation disrupts this directional order until it is lost when the normal liquid phase is formed.
C.6.4	Outline the principles of the liquid-crystal display device.	2	**Aim 8:** Only a simplified treatment is required. The ability of the liquid-crystal molecules to transmit light depends on the orientation of the molecules. The orientation of the polar molecules can be controlled by the application of a small voltage across a small film of the material. The areas of the display that are light and dark can thus be controlled. Liquid-crystal displays are used in digital watches, calculators and laptops because of their small current requirements.
C.6.5	Discuss the properties needed for a substance to be used in liquid-crystal displays.	3	Properties include: • chemically stable • a liquid-crystal phase stable over a suitable range of temperatures • polar in order to change orientation when an electric field is applied • rapid switching speed.

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C7 Nanotechnology

2 hours

	Assessment statement	Obj	Teacher's notes
C.7.1	Define the term *nanotechnology*.	1	Nanotechnology should be defined as: "Nanotechnology involves research and technology development at the 1 nm - to - 100 nm range. Nanotechnology creates and uses structures that have novel properties because of their small size. Nanotechnology builds on the ability to control or manipulate at the atomic scale." (Quoted from Booker, R and Boysen, E. 2005. *Nanotechnology for dummies*, Wiley Publishing Inc, USA. P 10) **TOK:** The use of the scanning tunnelling microscope has allowed us to "see" individual atoms. Does technology blur the distinction between simulation and reality?
C.7.2	Distinguish between *physical* and *chemical* techniques in manipulating atoms to form molecules.	2	Physical techniques allow atoms to be manipulated and positioned to specific requirements. Chemical techniques position atoms in molecules using chemical reactions.
C.7.3	Describe the structure and properties of carbon nanotubes.	2	Only a simple treatment is required. The main cylinder is made only from carbon hexagons, with pentagons needed to close the structure at the ends. Single- or multiple-walled tubes, made from concentric nanotubes, can be formed. Bundles of the tubes have high tensile strength. A comparison should be made with graphite, which is soft and malleable. The same strong covalent bonding extends along the nanotube. As the behaviour of electrons depends on the length of the tube, some forms are conductors and some are semiconductors. This is a typical nanoscale (quantum) effect, and the differences between the bulk properties and the size-dependent properties on the nanoscale should be emphasized.
C.7.4	Discuss some of the implications of nanotechnology.	3	**Aim 8:** Issues could include the following. • Possible applications • Health concerns • Toxicity regulations are difficult as properties depend on the size of particle • Unknown health effects because new materials have new health risks • Concern that the human immune system will be defenceless against particles on the nanoscale • Responsibilities of the industries • Political issues, such as the need for public education, for informed debate and for public involvement in policy discussions **TOK:** Who should decide whether particular directions in research are pursued? Who should determine priorities in the funding of research?

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HL C8 Condensation polymers

1 hour

	Assessment statement	Obj	Teacher's notes
C.8.1	Distinguish between *addition* and *condensation* polymers in terms of their structures.	2	
C.8.2	Describe how condensation polymers are formed from their monomers.	2	Examples should include phenol–methanal plastics, polyurethane and polyethylene terephthalate (PET).
C.8.3	Describe and explain how the properties of polymers depend on their structural features.	3	Examples should include Kevlar and the formation of cross-links in phenol–methanal plastics.
C.8.4	Describe ways of modifying the properties of polymers.	2	Examples should include: • air in the manufacture of polyurethane foams • doping polymer such as polyethyne with I_2 to increase conductivity • blending of polyester fibres to make them dyeable and more comfortable.
C.8.5	Discuss the advantages and disadvantages of polymer use.	3	Consider strength, density, insulation, lack of reactivity, use of natural resources, disposal and biodegradability. Examples should include PET, polyurethane foams and phenol–methanal plastics.

HL C9 Mechanisms in the organic chemicals industry

1 hour

	Assessment statement	Obj	Teacher's notes
C.9.1	Describe the free-radical mechanism involved in the manufacture of low-density polyethene.	2	
C.9.2	Outline the use of Ziegler–Natta catalysts in the manufacture of high-density polyethene.	2	The ionic mechanism will not be assessed.

HL C10 Silicon and photovoltaic cells

1 hour

	Assessment statement	Obj	Teacher's notes
C.10.1	Describe the doping of silicon to produce p-type and n-type semiconductors.	2	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.
C.10.2	Describe how sunlight interacts with semiconductors.	2	

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HL C11 Liquid crystals

2 hours

	Assessment statement	Obj	Teacher's notes
C.11.1	Identify molecules that are likely to show liquid-crystal properties, and explain their liquid-crystal behaviour on a molecular level.	3	Only the biphenyl nitriles will be assessed. The nitrile group makes the molecules polar, which ensures that the intermolecular forces are strong enough to align in a common direction. The biphenyl groups make the molecules more rigid and rod-shaped. The long alkane chain ensures that the molecules cannot pack together so closely and so maintains the liquid-crystal state.
C.11.2	Describe and explain in molecular terms the workings of a twisted nematic liquid crystal.	3	Each pixel contains a liquid crystal sandwiched between two glass plates. The plates have scratches at 90° to each other. The molecules in contact with the glass line up with the scratches, and molecules form a twisted arrangement between the plates due to intermolecular bonds. Plane-polarized light is rotated with the molecules and so is rotated through 90° as it passes through the film. When the polarizers are aligned with the scratches, light will pass through the film and the pixel will appear bright. As a voltage is applied across the film, the polar molecules will align with the field and so the twisted structure is lost. Plane-polarized light is no longer rotated and so the pixel appears dark.
C.11.3	Describe the liquid-crystal properties of Kevlar, and explain its strength and its solubility in concentrated sulfuric acid.	3	Kevlar is a lyotropic liquid crystal. It has rigid rod-shaped molecules due to the linked benzene rings. The alignment of these molecules depends on the concentration of the solution. Kevlar has strong intermolecular hydrogen bonds between the chains. This gives a very ordered and strong structure. These bonds can be broken with concentrated sulfuric acid, as O and N atoms are protonated, breaking the hydrogen bonds. **Aim 7:** Molecular modelling can be used here.

HL C12 The chlor-alkali industry

2 hours

	Assessment statement	Obj	Teacher's notes
C.12.1	Discuss the production of chlorine and sodium hydroxide by the electrolysis of sodium chloride.	3	Include the mercury, diaphragm and membrane chlor-alkali electrolysis cells.
C.12.2	Outline some important uses of the products of this process.	2	
C.12.3	Discuss the environmental impact of the processes used for the electrolysis of sodium chloride.	3	**Aim 8:** Include reasons why the membrane cell is replacing both the mercury-cathode and diaphragm cells, and reservations on the use of chlorine-containing solvents due to their effect on the ozone layer.

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Option D: Medicines and drugs (15/22 hours)

The aim of this option is to give students an understanding of how medicines and drugs can influence the functioning of the body. Students should be able to recognize the fundamental structures and relevant functional groups of several classes of drugs and medicines (as listed in this option or in topic 10), and should be able to distinguish between them. Memorizing of complex formulas is not required. Throughout the option, the contribution that science has made (and continues to make) towards maintaining and improving the health and well-being of the world's population should be stressed. Aim 8 discussions are central to this option.

Core material: D1–D7 are core material for SL and HL (15 hours).

Extension material: D8–D10 are extension material for HL only (7 hours).

D1 Pharmaceutical products

2 hours

	Assessment statement	Obj	Teacher's notes
D.1.1	List the effects of medicines and drugs on the functioning of the body.	1	Generally, a medicine or drug is any chemical that does one or more of the following. • Alters the physiological state, including consciousness, activity level or coordination • Alters incoming sensory sensations • Alters mood or emotions The importance of the body's natural healing processes and the placebo effect should be stressed.
D.1.2	Outline the stages involved in the research, development and testing of new pharmaceutical products.	2	An example of what can go wrong is the Thalidomide case. The use of combinatorial chemistry will not be assessed. A discussion of specific techniques will not be assessed. **TOK:** Should scientists be held morally responsible when drugs have adverse effects?
D.1.3	Describe the different methods of administering drugs.	2	Methods should include oral, parenteral (by injection), inhalation and rectal. Injections may be intravenous, intramuscular or subcutaneous.
D.1.4	Discuss the terms therapeutic window, tolerance and side-effects.	3	

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D2 Antacids

1 hour

	Assessment statement	Obj	Teacher's notes
D.2.1	State and explain how excess acidity in the stomach can be reduced by the use of different bases.	3	Examples should include aluminium and magnesium compounds and sodium hydrogencarbonate. Students should be able to write equations for neutralization reactions and know that antacids are often combined with alginates (which produce a neutralizing layer, preventing acid in the stomach from rising into the esophagus and causing heartburn), and with anti-foaming agents (such as dimethicone).

D3 Analgesics

3 hours

	Assessment statement	Obj	Teacher's notes
D.3.1	Describe and explain the different ways that analgesics prevent pain.	3	Mild analgesics function by intercepting the pain stimulus at the source, often by interfering with the production of substances (for example, prostaglandins) that cause pain, swelling or fever. Strong analgesics work by temporarily bonding to receptor sites in the brain, preventing the transmission of pain impulses without depressing the central nervous system. **TOK:** A discussion of pain perception could be linked to the more general discussion of perception as a way of knowing in TOK.
D.3.2	Describe the use of derivatives of salicylic acid as mild analgesics, and compare the advantages and disadvantages of using aspirin and paracetamol (acetaminophen).	2	Aspirin has been found to be useful in preventing the recurrence of heart attacks and strokes. The disadvantages of aspirin include ulceration and stomach bleeding, allergic reactions and Reye's syndrome in children (a potentially fatal liver and brain disorder). Paracetamol is very safe in the correct dose but can, in rare cases, cause blood disorders and kidney damage. Overdosage can lead to serious liver damage, brain damage and even death.
D.3.3	Compare the structures of morphine, codeine and diamorphine (heroin, a semi-synthetic opiate).	3	Stress the functional group modification to the structure of morphine that results in the semi-synthetic drug diamorphine (heroin).
D.3.4	Discuss the advantages and disadvantages of using morphine and its derivatives as strong analgesics.	3	Include the social as well as physiological effects of both short- and long-term use.

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D4 Depressants

3 hours

	Assessment statement	Obj	Teacher's notes
D.4.1	Describe the effects of depressants.	2	At low doses a depressant may exert little or no effect. At moderate doses the compound may induce sedation (soothing, reduction of anxiety). At higher doses it may induce sleep. At extremely high doses it may cause death. Depressants are often described as antidepressants because they relieve depression.
D.4.2	Discuss the social and physiological effects of the use and abuse of ethanol.	3	Include effects on the family, cost to society and the short- and long-term health effects.
D.4.3	Describe and explain the techniques used for the detection of ethanol in the breath, the blood and urine.	3	Include potassium dichromate(VI) in the breathalyser, analysis of blood and urine by chromatography, and absorption of infrared radiation or use of a fuel cell in the intoximeter.
D.4.4	Describe the synergistic effects of ethanol with other drugs.	2	Examples should include increased risk of stomach bleeding with aspirin and increased risk of heavy sedation with any drug that has a sedative effect on the central nervous system.
D.4.5	Identify other commonly used depressants and describe their structures.	2	Only the uses of diazepam (Valium®), nitrazepam (Mogadon®) and fluoxetine hydrochloride (Prozac®) will be assessed.

D5 Stimulants

2.5 hours

	Assessment statement	Obj	Teacher's notes
D.5.1	List the physiological effects of stimulants.	1	
D.5.2	Compare amphetamines and epinephrine (adrenaline).	3	Amphetamines and epinephrine (adrenaline) are chemically similar in that both derive from the phenylethylamine structure. Amphetamines mimic the effects of epinephrine (adrenaline) and are known as sympathomimetic drugs.
D.5.3	Discuss the short- and long-term effects of nicotine consumption.	3	Short-term effects include increased heart rate and blood pressure and reduction in urine output, as well as stimulating effects. Long-term effects include increased risk of heart disease, coronary thrombosis and peptic ulcers. Include also the addictive properties of nicotine and the further risks associated with smoking tobacco.
D.5.4	Describe the effects of caffeine and compare its structure with that of nicotine.	3	Caffeine is a respiratory stimulant. When consumed in large amounts it can cause anxiety, irritability and sleeplessness. It is a weak diuretic. Both caffeine and nicotine contain a tertiary amine group.

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D6 Antibacterials

2 hours

	Assessment statement	Obj	Teacher's notes
D.6.1	Outline the historical development of penicillins.	2	Include the discovery by Fleming and the development by Florey and Chain. **TOK:** What part does serendipity play in scientific discoveries?
D.6.2	Explain how penicillins work and discuss the effects of modifying the side-chain.	3	Penicillins work by interfering with the chemicals that bacteria need to form normal cell walls. Modifying the side-chain results in penicillins that are more resistant to the penicillinase enzyme.
D.6.3	Discuss and explain the importance of patient compliance and the effect of penicillin overprescription.	3	**Aim 8:** Strict adherence to a recommended treatment regime is necessary for the effectiveness of anti-TB drugs (frequently several drugs are used in combination). The use of penicillins in animal feedstock also contributes to the resistance problem.

D7 Antivirals

1.5 hours

	Assessment statement	Obj	Teacher's notes
D.7.1	State how viruses differ from bacteria.	1	
D.7.2	Describe the different ways in which antiviral drugs work.	2	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.
D.7.3	Discuss the difficulties associated with solving the AIDS problem.	3	**Int:** Specific proteins on the HIV virus bind to a receptor protein on certain white blood cells (T cells). Because of the ability of the HIV viruses to mutate, and because their metabolism is linked closely with that of the cell, effective treatment with antiviral drugs is very difficult, as is vaccine development. The control and treatment of HIV is exacerbated by the high price of anti-retroviral agents and sociocultural issues.

HL D8 Drug action

2.5 hours

	Assessment statement	Obj	Teacher's notes
D.8.1	Describe the importance of geometrical isomerism in drug action.	2	Students should be aware that *cis*- and *trans*-isomerism can occur in inorganic complexes and that the two different isomers can have different pharmacological effects. Examples should include the anti-cancer drug cisplatin.

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	Assessment statement	Obj	Teacher's notes
D.8.2	Discuss the importance of chirality in drug action.	3	The two enantiomers in a racemic mixture of a drug may have very different effects, for example, Thalidomide. One enantiomer of Thalidomide alleviates morning sickness in pregnant women, while the other enantiomer causes deformities in the limbs of the fetus.
D.8.3	Explain the importance of the beta-lactam ring action of penicillin.	3	The high reactivity of the amide group within the four-membered ring structure is a result of strain. The ring opens so that the penicillin becomes covalently bonded to the enzyme that synthesizes bacterial cell walls, thus blocking its action.
D.8.4	Explain the increased potency of diamorphine (heroin) compared to morphine.	3	The polar hydroxyl groups in morphine are replaced by non-polar ester groups, facilitating transport into the non-polar environment of the central nervous system.

HL D9 Drug design

2.5 hours

	Assessment statement	Obj	Teacher's notes
D.9.1	Discuss the use of a compound library in drug design.	3	Traditionally, a large collection of related compounds are synthesized individually and evaluated for biological properties. This approach is time-consuming and expensive.
D.9.2	Explain the use of combinatorial and parallel chemistry to synthesize new drugs.	3	Combinatorial chemistry is used to synthesize a large number of different compounds and screen them for biological activity, resulting in a "combinatorial library". Alternatively, parallel synthesis can produce smaller, more focused libraries. Students should be aware of the importance of solid-phase chemistry.
D.9.3	Describe how computers are used in drug design.	2	Three-dimensional models of drugs can be created *in silico* and molecular modelling software can be used for the virtual development and evaluation of new drugs.
D.9.4	Discuss how the polarity of a molecule can be modified to increase its aqueous solubility and how this facilitates its distribution around the body.	3	Students should be aware of the ability of acidic (carboxylic acid) and basic (amine) groups to form ionic salts, for example, soluble aspirin and fluoxetine hydrochloride (Prozac®).
D.9.5	Describe the use of chiral auxiliaries to form the desired enantiomer.	2	A chiral auxiliary is used to convert a non-chiral molecule into just the desired enantiomer, thus avoiding the need to separate enantiomers from a racemic mixture. It works by attaching itself to the non-chiral molecule to create the stereochemical conditions necessary to force the reaction to follow a certain path. Once the new molecule has been formed, the auxiliary can be taken off (recycled) to leave the desired enantiomer. An example is the synthesis of Taxol, an anti-cancer drug.

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HL D10 Mind-altering drugs

2 hours

	Assessment statement	Obj	Teacher's notes
D.10.1	Describe the effects of lysergic acid diethylamide (LSD), mescaline, psilocybin and tetrahydrocannabinol (THC).	2	
D.10.2	Discuss the structural similarities and differences between LSD, mescaline and psilocybin.	3	Students should be aware of the similarities of all three drugs and compare them to the indole ring.
D.10.3	Discuss the arguments for and against the legalization of cannabis.	3	**Aim 8:** Arguments for legalization include the ability of cannabis to offer relief from certain diseases. Arguments against legalization include the possible harmful effects and the possibility of cannabis users moving on to harder drugs.

Option E: Environmental chemistry (15/22 hours)

Human activities involve intensive use of limited resources found in air, water and soil. Many of these activities produce waste products that build up in the environment to produce pollution with increasingly local and global effects. An understanding of this impact is essential within and beyond the study of chemistry. This option has many opportunities for discussing aim 8 issues and the international dimension.

Core material: E1–E8 are core material for SL and HL (15 hours).

Extension material: E9–E12 are extension material for HL only (7 hours).

E1 Air pollution

2 hours

	Assessment statement	Obj	Teacher's notes
E.1.1	Describe the main sources of carbon monoxide (CO), oxides of nitrogen (NO_x), oxides of sulfur (SO_x), particulates and volatile organic compounds (VOCs) in the atmosphere.	2	Include both natural and anthropogenic sources. Equations should be used as appropriate.
E.1.2	Evaluate current methods for the reduction of air pollution.	3	Examples include: • CO—catalytic converters • NO_x—catalytic converters, control of fuel/air ratio • SO_x—alkaline scrubbing, limestone-based fluidized beds • particulates—electrostatic precipitation • VOCs—catalytic converters.

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E2 Acid deposition

1.5 hours

	Assessment statement	Obj	Teacher's notes
E.2.1	State what is meant by the term acid deposition and outline its origins.	1	Acid deposition refers to the process by which acidic particles, gases and precipitation leave the atmosphere. Both wet deposition (acid rain, fog and snow) and dry deposition (acidic gases and particles) will be assessed. Rain is naturally acidic because of dissolved CO_2 but acid rain has a pH of less than 5.6. It is caused by oxides of sulfur and oxides of nitrogen. The equations for the burning of sulfur and nitrogen, and for the formation of H_2SO_3, H_2SO_4, HNO_2 and HNO_3, will be assessed.
E.2.2	Discuss the environmental effects of acid deposition and possible methods to counteract them.	3	

E3 Greenhouse effect

1.5 hours

	Assessment statement	Obj	Teacher's notes
E.3.1	Describe the greenhouse effect.	2	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. **TOK:** 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?
E.3.2	List the main greenhouse gases and their sources, and discuss their relative effects.	3	The greenhouse gases to be considered are CH_4, H_2O, CO_2, N_2O and chlorofluorocarbons (CFCs). Their effects depend on their abundance and their ability to absorb heat radiation.
E.3.3	Discuss the influence of increasing amounts of greenhouse gases on the atmosphere.	3	Examples include: thermal expansion of the oceans, melting of the polar ice-caps, floods, droughts, changes in precipitation and temperature, changes in the yield and distribution of commercial crops, and changes in the distribution of pests and disease-carrying organisms.

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E4 Ozone depletion

1.5 hours

	Assessment statement	Obj	Teacher's notes
E.4.1	Describe the formation and depletion of ozone in the stratosphere by natural processes.	2	Formation: $O_2 \xrightarrow{\text{UV light}} 2O\bullet$ $O_2 + O\bullet \longrightarrow O_3$ Depletion: $O_3 \xrightarrow{\text{UV light}} O_2 + O\bullet$ $O_3 + O\bullet \longrightarrow 2O_2$
E.4.2	List the ozone-depleting pollutants and their sources.	1	Examples include chlorofluorocarbons (CFCs) and oxides of nitrogen (NO_x).
E.4.3	Discuss the alternatives to CFCs in terms of their properties.	3	Alternatives include hydrocarbons, fluorocarbons and hydrofluorocarbons (HFCs). Include toxicity, flammability, the relative weakness of the C–Cl bond and the ability to absorb infrared radiation.

E5 Dissolved oxygen in water

1.5 hours

	Assessment statement	Obj	Teacher's notes
E.5.1	Outline biochemical oxygen demand (BOD) as a measure of oxygen-demanding wastes in water.	2	
E.5.2	Distinguish between *aerobic* and *anaerobic* decomposition of organic material in water.	2	Use redox equations as appropriate.
E.5.3	Describe the process of eutrophication and its effects.	2	
E.5.4	Describe the source and effects of thermal pollution in water.	2	

E6 Water treatment

2.5 hours

	Assessment statement	Obj	Teacher's notes
E.6.1	List the primary pollutants found in waste water and identify their sources.	2	Examples include heavy metals, pesticides, dioxins, polychlorinated biphenyls (PCBs), organic matter, nitrates and phosphates. **Aim 7:** Data banks and spreadsheets can be used.
E.6.2	Outline the primary, secondary and tertiary stages of waste water treatment, and state the substance that is removed during each stage.	2	For primary treatment, filtration and sedimentation should be covered. For secondary treatment, mention the use of oxygen and bacteria (for example, the activated sludge process). Include the removal of heavy metals, phosphates and nitrates by chemical or biological processes.

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	Assessment statement	Obj	Teacher's notes
E.6.3	Evaluate the process to obtain fresh water from sea water using multi-stage distillation and reverse osmosis.	3	

E7 Soil

2.5 hours

	Assessment statement	Obj	Teacher's notes
E.7.1	Discuss salinization, nutrient depletion and soil pollution as causes of soil degradation.	3	Salinization: This is the result of continually irrigating soils. Irrigation waters contain dissolved salts, which are left behind after water evaporates. In poorly drained soils, the salts are not washed away and begin to accumulate in the topsoil. Plants cannot grow in soil that is too salty. Nutrient depletion: Agriculture disrupts the normal cycling of nutrients through the soil food web when crops are harvested. This removes all the nutrients and minerals that they absorbed from the soil while growing. Practices leading to amelioration of nutrient depletion may further contribute to environmental pollution. Soil pollution: This is the consequence of the use of chemicals such as pesticides and fertilizers. These chemicals can disrupt the soil food web, reduce the soil's biodiversity and ultimately ruin the soil. The chemicals also run off the soil into surface waters and move through the soil, polluting groundwater.
E.7.2	Describe the relevance of the soil organic matter (SOM) in preventing soil degradation, and outline its physical and biological functions.	2	The term soil organic matter (SOM) is generally used to represent the organic constituents in the soil, including undecayed plant and animal tissues, their partial decomposition products and the soil biomass. It includes: • identifiable, high-molecular-mass organic materials (for example, polysaccharides and proteins) • simpler substances (for example, sugars, amino acids and other small molecules) • humic substances. The functions of SOM can be broadly classified into two groups. • Biological: provides source of nutrients (P, N, S) and so contributes to the resilience of the soil/plant system. • Physical: improves structural stability, influences water-retention properties and alters the soil thermal properties.

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	Assessment statement	Obj	Teacher's notes
E.7.3	List common organic soil pollutants and their sources.	1	Examples should include petroleum hydrocarbons, agrichemicals, volatile organic compounds (VOCs), solvents, polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), organotin compounds and semi-volatile organic compounds (SVOCs). **Aim 7:** Data banks and spreadsheets can be used here.

E8 Waste

2 hours

	Assessment statement	Obj	Teacher's notes
E.8.1	Outline and compare the various methods for waste disposal.	3	Examples include landfills and incineration.
E.8.2	Describe the recycling of metal, glass, plastic and paper products, and outline its benefits.	2	
E.8.3	Describe the characteristics and sources of different types of radioactive waste.	2	Include both low-level and high-level radioactive waste.
E.8.4	Compare the storage and disposal methods for different types of radioactive waste.	3	

HL E9 Ozone depletion

1 hour

	Assessment statement	Obj	Teacher's notes
E.9.1	Explain the dependence of O_2 and O_3 dissociation on the wavelength of light.	3	$\lambda = 242$ nm $O_2 \longrightarrow 2O\bullet$ $\lambda = 330$ nm $O_3 \longrightarrow O_2 + O\bullet$ The energy needed should be related to the bonding in O_2 and O_3.
E.9.2	Describe the mechanism in the catalysis of O_3 depletion by CFCs and NO_x.	2	For example: $CCl_2F_2 \longrightarrow CClF_2 + Cl\bullet$ $Cl\bullet + O_3 \longrightarrow ClO\bullet + O_2$ $ClO\bullet + O\bullet \longrightarrow O_2 + Cl\bullet$ and $NO + O_3 \longrightarrow NO_2 + O_2$ $NO_2 + O\bullet \longrightarrow NO + O_2$ The net effect is: $O_3 + O\bullet \longrightarrow 2O_2$
E.9.3	Outline the reasons for greater ozone depletion in polar regions.	2	Consider the seasonal variation in temperature in the upper atmosphere. Refer to surface catalysis on ice particles.

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HL E10 Smog

2 hours

	Assessment statement	Obj	Teacher's notes
E.10.1	State the source of primary pollutants and the conditions necessary for the formation of photochemical smog.	1	VOCs and NO_x, temperature inversion, windlessness and bowl-shaped cities should be discussed.
E.10.2	Outline the formation of secondary pollutants in photochemical smog.	2	Examples include NO_2, O_3, aldehydes and peroxyacylnitrates (PANs). The role of free radicals and sunlight should be emphasized. **Aim 7:** Three-dimensional and four-dimensional GIS techniques and data banks can be used.

HL E11 Acid deposition

1 hour

	Assessment statement	Obj	Teacher's notes
E.11.1	Describe the mechanism of acid deposition caused by the oxides of nitrogen and oxides of sulfur.	2	Formation of hydroxyl radicals: $H_2O + O_3 \longrightarrow 2HO\bullet + O_2$ or $H_2O + O\bullet \longrightarrow 2HO\bullet$ $HO\bullet + NO_2 \longrightarrow HNO_3$ $HO\bullet + NO \longrightarrow HNO_2$ $HO\bullet + SO_2 \longrightarrow HOSO_2\bullet$ $HOSO_2\bullet + O_2 \longrightarrow HO_2\bullet + SO_3$ $(SO_3 + H_2O \longrightarrow H_2SO_4)$
E.11.2	Explain the role of ammonia in acid deposition.	3	In the atmosphere, ammonia neutralizes the acids formed to a large extent, to form ammonium salts. Slightly acidic ammonium salts, $(NH_4)_2SO_4$ and NH_4NO_3, formed in the atmosphere sink to the ground or are washed out of the atmosphere with rain. As NH_4^+ is deposited and enters the soil, nitrification and acidification can occur. $NH_4^+ + 2O_2 \longrightarrow 2H^+ + NO_3^- + H_2O$

HL E12 Water and soil

3 hours

	Assessment statement	Obj	Teacher's notes
E.12.1	Solve problems relating to the removal of heavy-metal ions, phosphates and nitrates from water by chemical precipitation.	3	Given the equilibrium formed by a metal M and a non-metal X: $MX(s) \rightleftharpoons M^+(aq) + X^-(aq)$ The K_{eq} for this system is given by $K_{sp} = [M^+][X^-]$, and is called the solubility product constant. Students should be able to solve problems associated with this type of equilibrium, including the common ion effect.

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	Assessment statement	Obj	Teacher's notes
E.12.2	State what is meant by the term cation-exchange capacity (CEC) and outline its importance.	2	The amount of exchangeable cations in a clay is called cation-exchange capacity. Include equations as appropriate.
E.12.3	Discuss the effects of soil pH on cation-exchange capacity and availability of nutrients.	3	Examples of nutrients include Ca, Mg, Fe, Al, P, N, S, Cu and Zn. Use equations as appropriate.
E.12.4	Describe the chemical functions of soil organic matter (SOM).	2	Include the following. • Contributes to cation-exchange capacity • Enhances the ability of soil to buffer changes in pH • Binds to organic and inorganic compounds in soil • Reduces the negative environmental effects of pesticides, heavy metals and other pollutants by binding contaminants • Forms stable complexes with cations

Option F: Food chemistry (15/22 hours)

Food chemistry is a study of the composition and properties of food, the chemical changes it undergoes during handling, processing and storage, and the principles underlying the improvement of food. The aim of this option is to give students an understanding of the chemistry of important molecules in food and the contribution that chemistry has made (and continues to make) towards maintaining and improving the quality and cost of food, adequacy of food supplies and food safety. Students should be able to recognize some important structures and relevant functional groups, and to distinguish between them. It is not necessary to memorize complex formulas, as structures and examples of some food molecules are given in the *Chemistry data booklet*. Teachers are encouraged to take a contextual approach, and to foster local and global issues.

Core material: F1–F6 are core material for SL and HL (15 hours).

Extension material: F7–F10 are extension material for HL only (7 hours).

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F1 Food groups

2 hours

	Assessment statement	Obj	Teacher's notes
F.1.1	Distinguish between a *food* and a *nutrient*.	2	Food: "Any substance, whether processed, semi-processed or raw, which is intended for human consumption, and includes drink, chewing gum and any substance which has been used in the manufacture, preparation or treatment of 'food', but does not include cosmetics or tobacco or substances used only as drugs." (Codex Alimentarius (FAO/WHO) definition 2005) Nutrient: Any substance obtained from food and used by the body to provide energy, regulate growth, maintenance and repair of the body's tissues. Proteins, lipids, carbohydrates, vitamins, minerals and water are considered nutrients.
F.1.2	Describe the chemical composition of lipids (fats and oils), carbohydrates and proteins.	2	Fats and oils are triesters (triglycerides) formed from three long-chain fatty acid (carboxylic acid) molecules and one glycerol molecule. The simplest carbohydrates are monosaccharides. They contain one carbonyl group (C=O) and at least two hydroxyl (–OH) groups, and have the empirical formula CH_2O. Monosaccharides are the building blocks of disaccharides and polysaccharides. Proteins are made up of 2-amino acids.

F2 Fats and oils

3 hours

	Assessment statement	Obj	Teacher's notes
F.2.1	Describe the difference in structure between saturated and unsaturated (mono- and poly-unsaturated) fatty acids.	2	Most naturally occurring fats contain a mixture of saturated, mono-unsaturated and poly-unsaturated fatty acids and are classified according to the predominant type of unsaturation present.
F.2.2	Predict the degree of crystallization (solidification) and melting point of fats and oils from their structure, and explain the relevance of this property in the home and in industry.	3	Solid fats are more likely to be crystalline, more saturated and/or have longer fatty acid hydrocarbon chains. Mono-unsaturated (olive, canola and peanut) and poly-unsaturated fats (safflower, sunflower, corn, fish, linoleic and linolenic) are liquids, and saturated fats (palm, coconut, lard, butter and shortening) are solids at room temperature. The melting point of fatty acids increases with increasing relative molecular mass and increasing degree of saturation. Fats and oils are chosen for cooking on the basis of their melting temperature. For example, cocoa butter melts at close to body temperature, and fats chosen for cake-making melt over a wide range of temperatures. *Cis* fatty acids (the hydrogen atoms are on the same side of the carbon–carbon double bond) have lower melting points than *trans* fatty acids (the hydrogen atoms are on opposite sides of the carbon–carbon double bond).

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	Assessment statement	Obj	Teacher's notes
F.2.3	Deduce the stability of fats and oils from their structure.	3	Saturated fats are more stable than unsaturated fats. The carbon–carbon double bonds in unsaturated fats react with oxygen (auto-oxidation), hydrogen (hydrogenation), light (photo-oxidation) and enzymes/heat/water (hydrolysis). **Aim 7:** Data banks and spreadsheets can be used here.
F.2.4	Describe the process of hydrogenation of unsaturated fats.	2	The addition of hydrogen to the carbon–carbon double bond of a fatty acid in the presence of heat (140–225°C), pressure and a finely divided metal catalyst (Zn, Cu, Ni) increases the amount of saturation, which can be partial or full.
F.2.5	Discuss the advantages and disadvantages of hydrogenating fats and oils.	3	Advantages: • changes a liquid oil to a semi-solid or solid, to make the melting point of an unsaturated fat more like that of a saturated fat • decreases the rate of oxidation (stability increases with increasing saturation) • increases hardness • controls the feel and plasticity (stiffness). Disadvantages: • mono- and poly-unsaturated fats are healthier for the heart than saturated fats • in partial hydrogenation, *trans* fatty acids can form • *trans* fatty acids are hard to metabolize, accumulate in fatty tissue, are difficult to excrete from the body, increase levels of LDL (bad) cholesterol and are a low-quality energy source.

F3 Shelf life

4 hours

	Assessment statement	Obj	Teacher's notes
F.3.1	Explain the meaning of the term shelf life.	3	A food reaches its shelf life when it no longer maintains the expected quality desired by the consumer because of changes in flavour, smell, texture and appearance (colour, mass) or because of microbial spoilage.
F.3.2	Discuss the factors that affect the shelf life and quality of food.	3	Chemical factors that cause a decrease in the shelf life include: • water content—loss of nutrients, browning and rancidity; dry foods become vulnerable to microbial spoilage if they take on moisture • chemical change, for example, pH—off flavours, colour changes, browning and loss of nutrients • light—rancidity, vitamin loss and fading of natural colours • temperature—changes the rate of other forms of spoilage • contact with air.

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	Assessment statement	Obj	Teacher's notes
F.3.3	Describe the rancidity of fats.	2	Rancidity is the perception of flavours in lipids, those that our senses perceive as off because they have a disagreeable smell, taste, texture or appearance.
F.3.4	Compare the processes of hydrolytic and oxidative rancidity in lipids.	3	Hydrolytic rancidity: The breaking down of a lipid into its component fatty acids and glycerol. It takes place more rapidly in the presence of enzymes (lipase), heat and moisture. In deep frying, water present in food and high temperatures increase the rate of hydrolysis. Examples of off-flavoured fatty acids include: • butanoic, hexanoic and octanoic acid in rancid milk • palmitic, stearic and oleic acids give chocolate an oily or fatty flavour • lauric acid gives palm and coconut oil in cocoa butter substitutes a soapy flavour • butanoic acid in butter. Oxidative rancidity: The fatty acid chains are oxidized, typically by the addition of oxygen across the carbon–carbon double bond of the unsaturated fatty acid. Oily fish (such as herring and mackerel) contain a high proportion of unsaturated fatty acids and are prone to oxidative rancidity. The process can be catalysed by light (photo-oxidation) and enzymes. Details of the free-radical chain mechanism will not be assessed.

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	Assessment statement	Obj	Teacher's notes
F.3.5	Describe ways to minimize the rate of rancidity and prolong the shelf life of food.	2	Processing—examples include: • limiting lipase hydrolysis by storing dairy products at low temperatures (refrigeration) • reducing light levels during storage or storing in coloured glass • keeping moisture levels low during processing (adding salt or sugar, smoking). Packaging—examples include: • using an inert gas, which minimizes contact with oxygen, by covering food • using low-gas-permeability packaging film or hermetic sealing • minimizing the amount of air in the headspace above oil and canning. Adding additives—examples include: • sodium sulfite, sodium hydrogensulfite and citric acid to delay the onset of non-enzymic browning • sodium and potassium nitrite and nitrate for curing meats, fixing colour and inhibiting micro-organisms • sodium benzoate and benzoic acid as antimicrobial agents in fruit juices, carbonated beverages, pickles and sauerkraut • sorbic acid, propanoic acid, calcium propanoate and sodium propanoate for delaying mould and bacterial growth in breads and cheeses • ethanoic acid and benzoic acid for delaying mould and bacterial growth in pickled meats and fish products, and also adding to flavour.
F.3.6	Describe the traditional methods used by different cultures to extend the shelf life of foods.	2	**Aim 8:** Examples include fermentation, preserving, pickling, salting, drying and smoking.
F.3.7	Define the term *antioxidant*.	1	A substance that delays the onset or slows the rate of oxidation. It is used to extend the shelf life of food.
F.3.8	List examples of common naturally occurring antioxidants and their sources.	1	Naturally occurring antioxidants include: • vitamin C (ascorbic acid) in citrus fruits, green peppers, broccoli, green leafy vegetables, strawberries, raw cabbage and potatoes • vitamin E in wheat germ, nuts, seeds, whole grains, green leafy vegetables, vegetable oils like canola and soya bean (the antioxidants present in vitamin E are called tocopherols) • β-carotene in carrots, squash, broccoli, sweet potatoes, tomatoes, kale, cantaloupe melon, peaches and apricots • selenium in fish, shellfish, red meat, eggs, grains, chicken and garlic.

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	Assessment statement	Obj	Teacher's notes
F.3.9	Compare the structural features of the major synthetic antioxidants in food.	3	Examples include 2- and 3-*tert*-butyl-4-hydroxyanisole (BHA), 3,5-di-*tert*-butyl-4-hydroxytoluene (BHT), propyl gallate (PG), 2,4,5-trihydroxybutyrophenone (THBP) and *tert*-butylhydroquinone (TBHQ).
F.3.10	Discuss the advantages and disadvantages associated with natural and synthetic antioxidants.	3	Advantages: • naturally occurring vitamins C, E and carotenoids reduce the risk of cancer and heart disease by inhibiting the formation of free radicals • vitamin C is vital for the production of hormones and collagen • β-carotene can be used as an additive in margarine to give colour (yellow) and acts as a precursor for vitamin A. Disadvantages: • consumers perceive synthetic antioxidants to be less safe because they are not naturally occurring in food • natural antioxidants can add colour and an aftertaste to food, and can be less effective at slowing down the rate of rancidity than synthetic antioxidants • synthetic antioxidants are food additives and need to be regulated by policies and legislation to ensure their safe use in food • policies regarding the labelling and safe use of food additives can be difficult to implement and monitor, especially in developing countries and internationally.
F.3.11	List some antioxidants found in the traditional foods of different cultures that may have health benefits.	1	Examples include green tea, turmeric, oregano, blueberries, cranberries and dark chocolate, which have been linked to lowering levels of LDL (bad) cholesterol and blood sugar levels, reducing high blood pressure and preventing cancerous cell development.

F4 Colour

3 hours

	Assessment statement	Obj	Teacher's notes
F.4.1	Distinguish between a *dye* and a *pigment*.	2	A dye is a food-grade synthetic water-soluble colourant. A pigment is a naturally occurring colourant found in the cells of plants and animals.
F.4.2	Explain the occurrence of colour in naturally occurring pigments.	3	Foods have colour because of their ability to reflect and absorb different wavelengths of visible light.

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	Assessment statement	Obj	Teacher's notes
F.4.3	Describe the range of colours and sources of the naturally occurring pigments anthocyanins, carotenoids, chlorophyll and heme.	2	Anthocyanins: • the most widely occurring pigments in plants • responsible for the pink, red, purple and blue colours in fruits and vegetables, including cranberries, blueberries, strawberries and raspberries. Carotenoids: • the most widespread pigment in nature • large majority produced by algae • act as a precursor for vitamin A • colours range from yellow to orange to red, including bananas, carrots, tomatoes, watermelon, red/yellow peppers and saffron • red astaxanthin, when present as a complex with protein, gives the blue or green hue found in live lobsters and crabs and the pink colour of salmon. Chlorophyll: the major light-harvesting pigments found in green plants. Heme: the red pigment found in red blood cells and muscle tissue. Myoglobin is responsible for the purplish-red colour of meat.

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	Assessment statement	Obj	Teacher's notes
F.4.4	Describe the factors that affect the colour stability of anthocyanins, carotenoids, chlorophyll and heme.	2	Factors should include the effects of oxidation, temperature change, pH change and the presence of metal ions. Students should analyse absorbance spectra that demonstrate these effects. Anthocyanins: In aqueous solution, equilibrium reaction exists between the four different structural forms depending on the pH and temperature. They are most stable and most highly coloured at low pH and temperature. $\underset{\text{quinonoid (blue)}}{(A)} \rightleftharpoons \underset{\text{flavylium (red)}}{(AH^+)} \rightleftharpoons \underset{\text{carbinol base (colourless)}}{(B)} \rightleftharpoons \underset{\text{chalcone (colourless)}}{(C)}$ They form deeply coloured coordination complexes with Fe^{3+} and Al^{3+} ions, a source of which can be the metal cans to which the fruit is exposed; this causes a discoloration in canned fruit. They become less stable when exposed to heat, causing a loss of colour and browning. Carotenoids: The presence of multiple unsaturated carbon–carbon double bonds makes carotenoids susceptible to oxidation catalysed by light, metals and hydroperoxides. Oxidation results in the bleaching of colour, loss of vitamin A activity and off odours. They are stable up to 50°C and in the pH range of 2–7, and, therefore, are not degraded by most forms of processing. With heating, the naturally occurring *trans* isomer rearranges to the *cis* isomer. Chlorophyll: Reaction with heat depends on pH. In a basic solution (pH 9), chlorophyll is stable, and in an acidic solution (pH 3) it is unstable. When heated, the cell membrane of the plant deteriorates, releasing acids, which decrease the pH. This results in the magnesium atom being displaced by two hydrogen ions, resulting in the formation of olive-brown pheophytin complex. This cell degradation during heating also makes the chlorophyll more susceptible to photo-degradation. Heme: During oxidation, oxygen binds to purple-red myoglobin (Mb), and red oxymyoglobin (MbO_2) forms. In Mb and MbO_2 the heme iron is in the Fe^{2+} state. Mb and MbO_2 can be oxidized, through auto-oxidation, changing the heme iron from Fe^{2+} to Fe^{3+}. In the Fe^{3+} state, it is called metmyoglobin (MMb) and has an undesirable brown-red colour. Interconversion between the three forms occurs readily. $\underset{\text{oxymyoglobin (red, } Fe^{2+})}{(MbO_2)} \rightleftharpoons \underset{\text{myoglobin (purple-red, } Fe^{2+})}{(Mb)} \rightleftharpoons \underset{\text{metmyoglobin (brown, } Fe^{3+})}{(MMb)}$ The stability of colour and the rate of brown MMb formation from auto-oxidation can be minimized if the meat is stored in conditions free of oxygen by using packaging films with low gas permeabilities. Air is removed from the package and a storage gas (100% CO_2) is injected.

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	Assessment statement	Obj	Teacher's notes
F.4.5	Discuss the safety issues associated with the use of synthetic colourants in food.	3	The type of colourant permitted for use varies greatly among countries. Since international trade is becoming increasingly important, colour legislation is now of international concern.
F.4.6	Compare the two processes of non-enzymatic browning (Maillard reaction) and caramelization that cause the browning of food.	3	Comparisons should include the chemical composition of the foods affected, factors that increase the rate of the browning, products and examples. Maillard reaction: Chemical composition of the foods affected—condensation reaction between an amino group on an amino acid or protein and a reducing sugar (glucose or lactose). The presence of the amino acid lysine results in the most browning colour and cysteine the least colour. Foods containing lysine, for example, milk, brown readily. Examples include: • heating sugar and cream to make toffees, caramels and fudges • milk chocolate. Products include: • desirable and undesirable colours (characteristic golden-brown colour is desirable) • change in smell and flavour (caramel aroma). Caramelization: Chemical composition of the foods affected—foods with a high carbohydrate content, especially sucrose and reducing sugars, without nitrogen-containing compounds. Factors that increase the rate of the reaction are acid- or base-catalysed at pH above 9 or below 3; a temperature above 120°C that occurs during the baking and roasting of foods with a high sugar content. Examples include the browning on the top of baked egg dishes. Products include: • volatile caramel aromas • brown caramel-coloured products.

F5 Genetically modified foods

1 hour

	Assessment statement	Obj	Teacher's notes
F.5.1	Define a *genetically modified* (GM) *food*.	1	A genetically modified food is one derived or produced from a genetically modified organism. The food can be substantially different from or essentially the same as the conventional food, in terms of composition, nutrition, taste, smell, texture and functional characteristics.

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	Assessment statement	Obj	Teacher's notes
F.5.2	Discuss the benefits and concerns of using GM foods.	3	**Aim 8:** Potential benefits are as follows. • Crops: Enhanced taste and quality, reduced maturation time, increase in nutrients and yield, improved resistance to disease, pests and herbicides, enrichment of rice with vitamin A. • Animals: Increased resistance, productivity and feed efficiency, better yields of milk and eggs, improved animal health. • Environment: "Friendly" bio-herbicides and bio-insecticides, conservation of soil, water and energy, improved natural waste management. Potential concerns are as follows: • Links to increased allergies (for people involved in their processing). • The risk of changing the composition of a balanced diet by altering the natural nutritional quality of foods. **TOK:** GM foods raise issues of conflict of concepts and values. Examine the facts, language, statistics and images used in the debate over their use. Is science, or ought it to be, value-free? What implications does your answer have for the regulation of science? Who should decide whether particular directions in research are pursued? Who should determine priorities in the funding of research?

F6 Texture

2 hours

	Assessment statement	Obj	Teacher's notes
F.6.1	Describe a dispersed system in food.	2	A dispersed system is a kinetically stable mixture of one phase in another largely immiscible phase.
F.6.2	Distinguish between the following types of dispersed systems: *suspensions*, *emulsions* and *foams* in food.	2	
F.6.3	Describe the action of emulsifiers.	2	Emulsifiers: • help with the formation of emulsions and foams • act as the interface (surface) between the liquid, solid and gas phases in the dispersed system • are soluble in fat and water. To make an emulsion, oil, water, an emulsifier and mechanical energy (beating or mixing) are needed. Stabilizers prevent emulsions and foams from separating out.

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HL F7 Oxidative rancidity (auto-oxidation)

1 hour

	Assessment statement	Obj	Teacher's notes
F.7.1	Describe the steps in the free-radical chain mechanism occurring during oxidative rancidity.	2	The key intermediates are hydroperoxides (ROOH), which degrade to volatile aldehydes and ketones with strong off flavours. They undergo further oxidation and decomposition to produce even more free radicals. 1. Initiation: formation of free radicals. The E_a for the formation of the first free radicals is high and ROOH decomposition needs metal catalysis or exposure to light. $RH \longrightarrow R\bullet + H\bullet$ RH is any unsaturated fatty acid that can lose a hydrogen to form free radicals. 2. Propagation: free-radical chain reaction. The free radicals are propagators in these reactions. $R\bullet + O_2 \longrightarrow ROO\bullet$ $ROO\bullet + RH \longrightarrow R\bullet + ROOH$ 3. Termination: free radicals combine to form non-radical products. $R\bullet + R\bullet \longrightarrow RR$ $R\bullet + ROO\bullet \longrightarrow ROOR$ $ROO\bullet + ROO\bullet \longrightarrow ROOR + O_2$

HL F8 Antioxidants

1 hour

	Assessment statement	Obj	Teacher's notes
F.8.1	Explain the differences between the three main types of antioxidants.	3	1. Antioxidants (AH) inhibit the formation of free radicals in the initiation step of auto-oxidation or interrupt the propagation of the free-radical chain. Free-radical quenchers form stable and less reactive free radicals: $ROO\bullet + AH \longrightarrow ROOH + A\bullet$ Examples include BHA, BHT, TBHQ and tocopherols. 2. Chelating agents reduce the concentration of free metal ions in solution. Examples include salts of EDTA and plant extracts (rosemary, tea, ground mustard). 3. Reducing agents (electron donors) and agents that remove or reduce concentrations of oxygen. Examples include ascorbic acid (vitamin C) and carotenoids.

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HL F9 Stereochemistry in food

2 hours

	Assessment statement	Obj	Teacher's notes
F.9.1	Explain the three different conventions used for naming the different enantiomeric forms.	3	The D and L system is commonly used for carbohydrates and amino acids, while the R and S notation is commonly used for other stereoisomers. Both relate to the difference in the enantiomers' spatial configuration. For D and L isomers, glyceraldehyde is a reference molecule. The "CORN" rule is used for amino acids. The +(*d*) and –(*l*) notation labels stereoisomers according to the direction they rotate the plane of polarized light. This property does not correspond to D, L or R, S configurations.
F.9.2	Distinguish between the properties of the different enantiomeric forms of stereoisomers found in food.	2	The different enantiomeric forms vary in their tastes, odours and toxicity. They can be used to determine the authenticity of food and the extent of processing. For example, +(*d*)-carvone tastes of caraway seeds and dill and –(*l*)-carvone tastes of spearmint. Most naturally occurring amino acids are in the L form. The D amino acids taste sweet; the L amino acids are tasteless. Most naturally occurring sugars exist in the D form and are sweet. For example: • +(*d*)-limonene smells of oranges and –(*l*)-limonene smells of lemons • natural raspberry flavour is due to R-alpha-ionone; synthetic raspberry flavourings contain both the R- and S-isomers; other synthetically made foods often contain a racemic mixture of each enantiomer.

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HL F10 Chemical structure and colour

3 hours

	Assessment statement	Obj	Teacher's notes
F.10.1	Compare the similarities and differences in the structures of the natural pigments: anthocyanins, carotenoids, chlorophyll and heme.	3	Anthocyanins: Contain the characteristic $C_6C_3C_6$ flavonoid skeleton with conjugated double bonds. They differ in the number of hydroxyl and/or methoxy groups present; the types, numbers and sites of attachments of sugars to the molecule; and the types and numbers of aliphatic or aromatic acids that are attached to the sugars in the molecule. Examples include quercetin. Carotenoids: The majority are derived from a 40-carbon polyene chain, which may be terminated by cyclic end-groups and may be complemented with oxygen-containing functional groups. The hydrocarbon carotenoids are known as carotenes, while the oxygenated derivatives are known as xanthophylls. Examples include α- and β-carotene, vitamin A. Heme and chlorophyll contain a planar heterocyclic unit called a porphin whose structure contains a cyclic system of conjugated double bonds. Porphins with substituents in positions 1 to 8 are called porphyrins. Chlorophyll: This is a magnesium porphyrin complex with the original double bond between positions 7 and 8 now saturated and an R group on C3. It is found in two forms: chlorophyll a and b, which differ in the substituent R group. In chlorophyll a, R is a CH_3 group and in chlorophyll b, R is a CHO group. Heme: Myoglobin is the primary pigment in muscle tissue and hemoglobin is the pigment in blood. Myoglobin is a complex of globin (a protein) and heme (porphryin ring containing a central iron atom).
F.10.2	Explain why anthocyanins, carotenoids, chlorophyll and heme form coloured compounds while many other organic molecules are colourless.	3	The nature of chromophores, conjugation effects and characteristic absorptions are required. Students should understand how the wavelength of energy absorbed relates to the colour the food appears.
F.10.3	Deduce whether anthocyanins and carotenoids are water- or fat-soluble from their structures.	3	Anthocyanins are water-soluble and carotenoids are fat-soluble.

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Option G: Further organic chemistry (15/22 hours)

TOK: The relationship between a reaction mechanism and the experimental evidence to support it could be discussed. See 16.2.2.

Core material: G1–G8 are core material for SL and HL (15 hours).

Extension material: G9–G11 are extension material for HL only (7 hours).

G1 Electrophilic addition reactions

3 hours

	Assessment statement	Obj	Teacher's notes
G.1.1	Describe and explain the electrophilic addition mechanisms of the reactions of alkenes with halogens and hydrogen halides.	3	Include the application of Markovnikov's rule to predict the major product in the reactions of unsymmetrical alkenes with unsymmetrical reagents.
G.1.2	Predict and explain the formation of the major product in terms of the relative stabilities of carbocations.	3	

G2 Nucleophilic addition reactions

2 hours

	Assessment statement	Obj	Teacher's notes
G.2.1	Describe, using equations, the addition of hydrogen cyanide to aldehydes and ketones.	2	
G.2.2	Describe and explain the mechanism for the addition of hydrogen cyanide to aldehydes and ketones.	3	
G.2.3	Describe, using equations, the hydrolysis of cyanohydrins to form carboxylic acids.	2	

G3 Elimination reactions

1 hour

	Assessment statement	Obj	Teacher's notes
G.3.1	Describe, using equations, the dehydration reactions of alcohols with phosphoric acid to form alkenes.	2	
G.3.2	Describe and explain the mechanism for the elimination of water from alcohols.	3	Use H^+ to represent the acid catalyst.

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G4 Addition–elimination reactions

1 hour

	Assessment statement	Obj	Teacher's notes
G.4.1	Describe, using equations, the reactions of 2,4-dinitrophenylhydrazine with aldehydes and ketones.	2	Mechanisms will not be assessed.

G5 Arenes

2.5 hours

	Assessment statement	Obj	Teacher's notes
G.5.1	Describe and explain the structure of benzene using physical and chemical evidence.	3	**TOK:** See 14.3.1. For physical evidence, include a comparison of carbon–carbon bond lengths in alkanes, alkenes and benzene, and the number of structural isomers with the formula $C_6H_4X_2$. For chemical evidence, include a comparison of the enthalpies of hydrogenation of benzene, cyclohexene, 1,3-cyclohexadiene and 1,3,5-cyclohexatriene, and the tendency of benzene to undergo substitution rather than addition reactions.
G.5.2	Describe and explain the relative rates of hydrolysis of benzene compounds halogenated in the ring and in the side-chain.	3	Only the reactions with the OH^- ion will be assessed.

G6 Organometallic chemistry

2.5 hours

	Assessment statement	Obj	Teacher's notes
G.6.1	Outline the formation of Grignard reagents.	2	Include the reaction of halogenoalkanes with magnesium metal.
G.6.2	Describe, using equations, the reactions of Grignard reagents with water, carbon dioxide, aldehydes and ketones.	2	Emphasize the formation of organic molecules with an increased number of carbon atoms.

G7 Reaction pathways

1 hour

	Assessment statement	Obj	Teacher's notes
G.7.1	Deduce reaction pathways given the starting materials and the product.	3	Conversions with more than two stages will not be assessed. Reagents, conditions and equations should be included.

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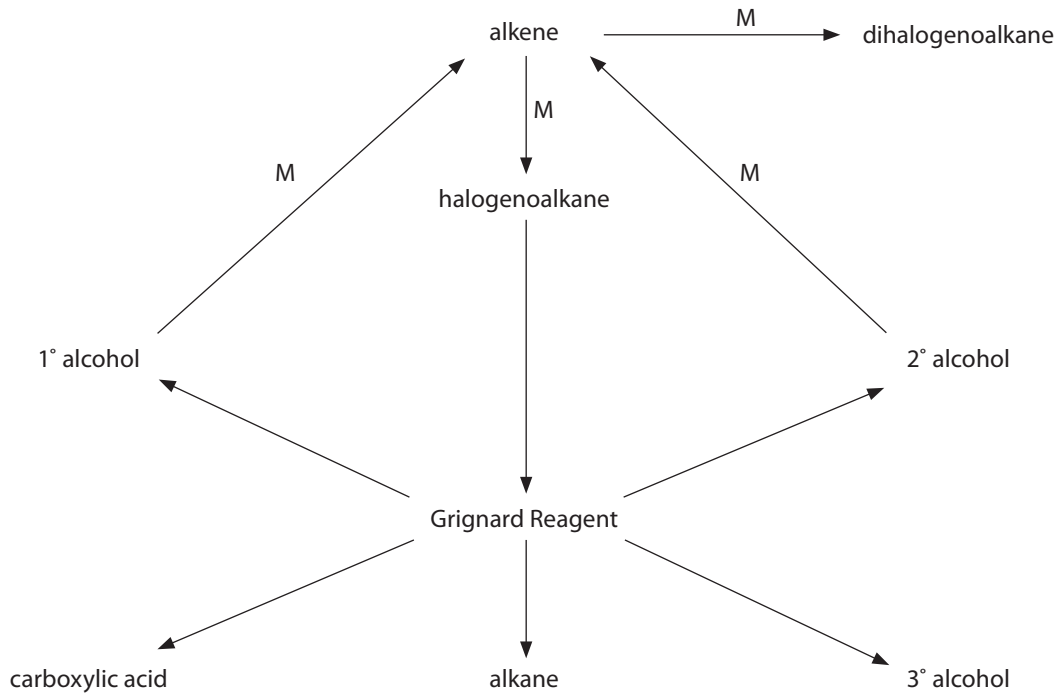
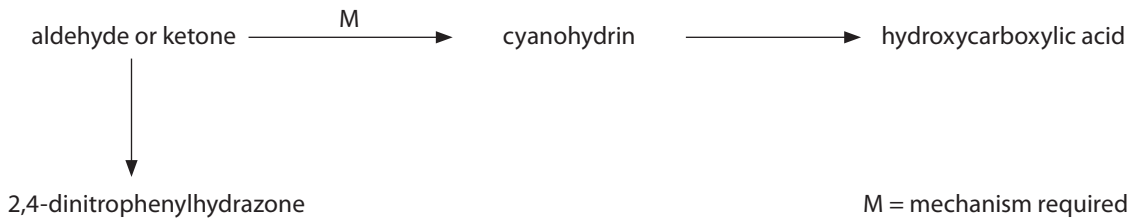
G8 Acid–base reactions

2 hours

	Assessment statement	Obj	Teacher's notes
G.8.1	Describe and explain the acidic properties of phenol and substituted phenols in terms of bonding.	3	Include a comparison of the acidities of alcohols, phenol and 2,4,6-trinitrophenol.
G.8.2	Describe and explain the acidic properties of substituted carboxylic acids in terms of bonding.	3	
G.8.3	Compare and explain the relative basicities of ammonia and amines.	3	Include primary, secondary and tertiary amines. Include the formation of salts from amines and the liberation of amines from salts using sodium hydroxide.

The compounds and reaction types in this option at SL are summarized in the following schemes.





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HL G9 Addition–elimination reactions

2 hours

	Assessment statement	Obj	Teacher's notes
G.9.1	Describe, using equations, the reactions of acid anhydrides with nucleophiles to form carboxylic acids, esters, amides and substituted amides.	2	Include the nucleophiles: water, alcohols, ammonia and amines. Aspirin and paracetamol can be made using reactions of this type.
G.9.2	Describe, using equations, the reactions of acyl chlorides with nucleophiles to form carboxylic acids, esters, amides and substituted amides.	2	Include the nucleophiles: water, alcohols, ammonia and amines.
G.9.3	Explain the reactions of acyl chlorides with nucleophiles in terms of an addition–elimination mechanism.	3	

HL G10 Electrophilic substitution reactions

4 hours

	Assessment statement	Obj	Teacher's notes
G.10.1	Describe, using equations, the nitration, chlorination, alkylation and acylation of benzene.	2	Include the use of ⬡ for the benzene ring as well as formulas such as $C_6H_5NO_2$. The introduction of more than one group into the benzene ring will not be assessed here.
G.10.2	Describe and explain the mechanisms for the nitration, chlorination, alkylation and acylation of benzene.	3	Include the formation of NO_2^+ from the reaction between concentrated nitric and sulfuric acids, and the formation of Cl^+, R^+ and RCO^+ from reactions involving aluminium chloride as a halogen carrier catalyst.
G.10.3	Describe, using equations, the nitration, chlorination, alkylation and acylation of methylbenzene.	2	
G.10.4	Describe and explain the directing effects and relative rates of reaction of different substituents on a benzene ring.	3	Include the substituents $-CH_3$, $-OH$ and $-NO_2$. Include the terms activating and deactivating. Only the introduction of one further group will be assessed, except for the formation of 2,4,6-trichlorophenol. The directing effects can be explained in terms of the charge distribution of the intermediates. The slightly increased reactivity due to the presence of $-CH_3$ can be explained in terms of its electron-releasing nature. The greatly increased reactivity due to the presence of $-OH$ can be explained in terms of its partial donation of a non-bonded electron pair. The decreased reactivity due to the presence of $-NO_2$ can be explained in terms of its electron-withdrawing nature and lack of a non-bonded electron pair.

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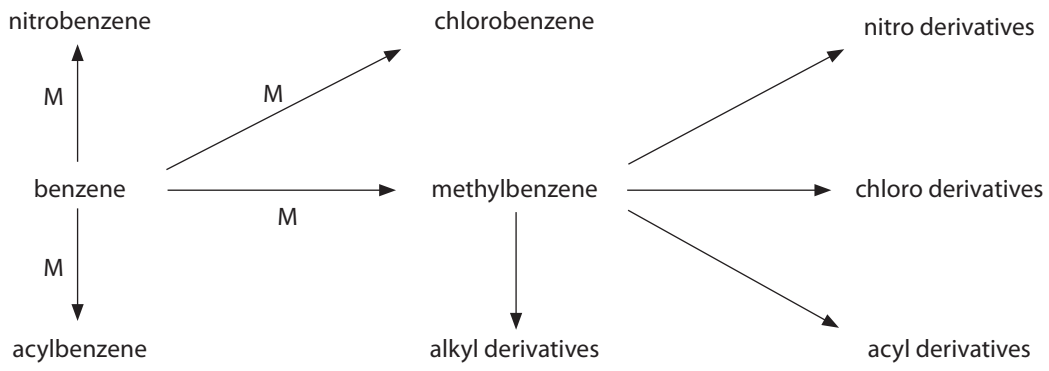
HL G11 Reaction pathways

1 hour

	Assessment statement	Obj	Teacher's notes
G.11.1	Deduce reaction pathways given the starting materials and the product.	3	Conversions with more than two stages will not be assessed. Reagents, conditions and equations should be included.

The compound and reaction types in this option at HL are summarized in the following scheme.



M = mechanism required

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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) and sketch graphs
- 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).

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