



INTERNATIONAL BACCALAUREATE ORGANIZATION

**DIPLOMA PROGRAMME**

**Chemistry**

For first examinations in 2003

*Chemistry*  
*February 2001*

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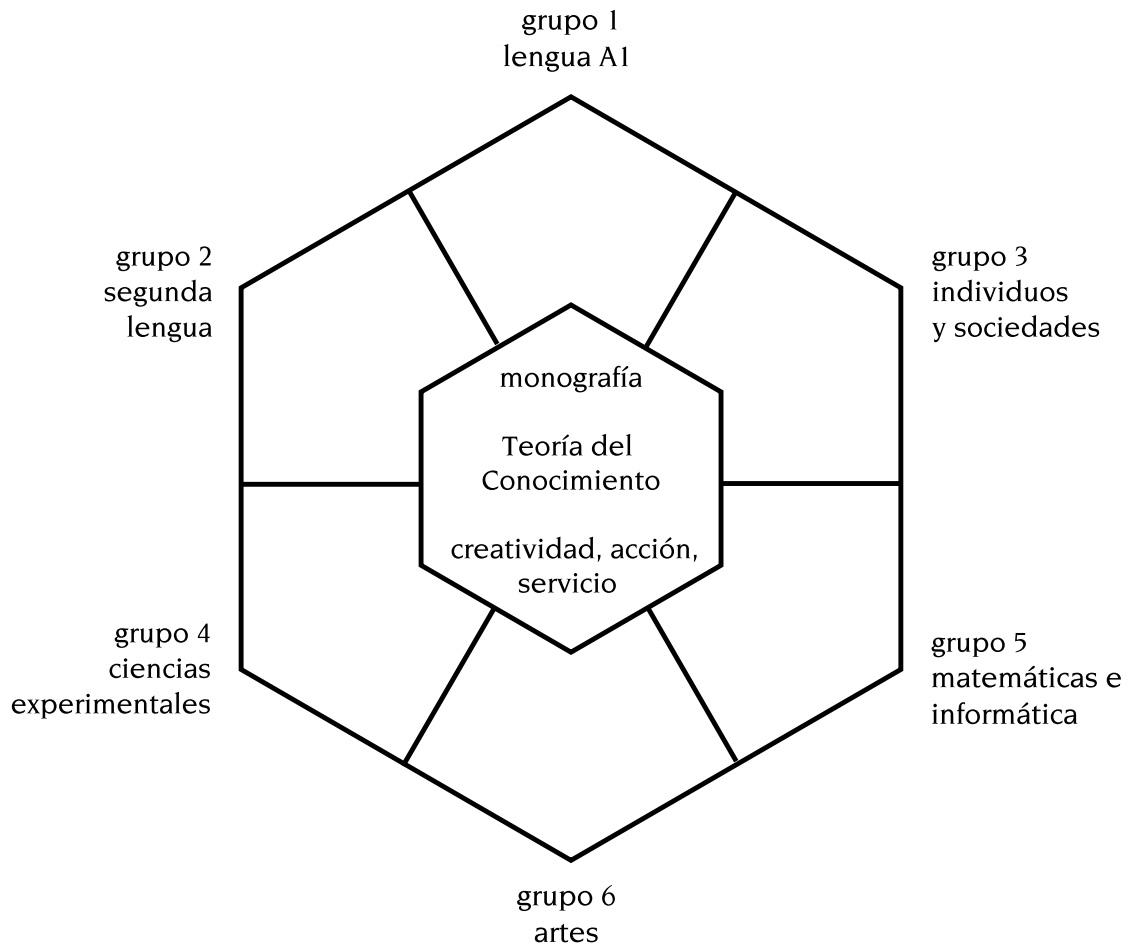
# **PART 1 – GROUP 4**

# INTRODUCTION

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The International Baccalaureate Diploma Programme is a rigorous pre-university course of studies, leading to examinations, that meets the needs of highly motivated secondary school students between the ages of 16 and 19 years. Designed as a comprehensive two-year curriculum that allows its graduates to fulfill requirements of various national education systems, the Diploma Programme model is based on the pattern of no single country but incorporates the best elements of many. The programme is available in English, French and Spanish.

The curriculum is displayed in the shape of a hexagon with six academic areas surrounding the core. Subjects are studied concurrently and students are exposed to the two great traditions of learning: the humanities and the sciences.



Diploma Programme candidates are required to select one subject from each of the six subject groups. At least three and not more than four are taken at higher level (HL), the others at standard level (SL). Higher level courses represent 240 teaching hours; standard level courses cover 150 hours. By arranging work in this fashion, students are able to explore some subjects in depth and some more broadly over the two-year period; this is a deliberate compromise between the early specialization preferred in some national systems and the breadth found in others.

Distribution requirements ensure that the science-orientated student is challenged to learn a foreign language and that the natural linguist becomes familiar with science laboratory procedures. While overall balance is maintained, flexibility in choosing higher level combinations allows the student to pursue areas of personal interest and to meet special requirements for university entrance.

Successful Diploma Programme candidates meet three requirements in addition to the six subjects. The interdisciplinary Theory of Knowledge (TOK) course is designed to develop a coherent approach to learning which transcends and unifies the academic areas and encourages appreciation of other cultural perspectives. The extended essay of some 4000 words offers the opportunity to investigate a topic of special interest and acquaints students with the independent research and writing skills expected at university. Participation in the creativity, action, service (CAS) requirement encourages students to be involved in artistic pursuits, sports and community service work.

*For first examinations in 2003*

# CURRICULUM MODEL

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A common curriculum model applies to all the Diploma Programme group 4 subjects: biology, chemistry, environmental systems, physics and design technology. (There are some differences in this model for design technology and these arise from the design project, a unique feature of this subject. A double asterisk (\*\*) indicates where these differences occur.) A core of material is studied by both higher level and standard level students in all subjects, and this is supplemented by the study of options. Higher level students also study additional higher level (AHL) material. Higher level students and SL students both study two options. There are three kinds of options: those specific to SL students, those specific to HL students and those which can be taken by both SL and HL students. Schools wishing to develop their own school-based option should contact the IBCA office in the first instance.

This curriculum model is not designed to favour the teaching of SL and HL students together. The IBO does not support the joint teaching of students at different levels as this does not provide the greatest educational benefit for either level.

Higher level students are required to spend 60 hours, and SL students 40 hours, on practical/investigative work\*\*. This includes 10 to 15 hours for the group 4 project.

## Group 4 Curriculum Model HL \*\*

<b>HL</b>	<b>Total teaching hours</b>	<b>240</b>
<b>Theory</b>		<b>180</b>
	Core	80
	Additional higher level (AHL)	55
	Options	45
<b>Internal assessment (IA)</b>		<b>60</b>
	Investigations	45–50
	Group 4 project	10–15

### Group 4 Curriculum Model SL \*\*

<b>SL</b>	<b>Total teaching hours</b>	<b>150</b>
	<b>Theory</b>	<b>110</b>
	Core	80
	Options	30
	<b>Internal assessment (IA)</b>	<b>40</b>
	Investigations	25–30
	Group 4 project	10–15

## 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 (eg Topic 6: Nucleic Acids and Proteins or Option C: Cells and Energy).

### Sub-topics

Sub-topics are numbered and the estimated teaching time required to cover the material is indicated (eg 6.1 DNA Structure (1h)). The times are for guidance only and do not include time for practical/investigative work.



## Assessment Statements (A.S.)

Assessment statements, which are numbered, are expressed in terms of the outcomes that are expected of students at the end of the course (eg 6.1.1 Outline the structure of nucleosomes). 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 page 7) according to the action verb(s) used (see page 8). The objective levels are relevant for the examinations and for balance within the syllabus, while the action verbs indicate the depth of treatment required for a given assessment statement. It is important that students are made aware of the meanings of the action verbs since these will be used in examination questions.

## Teacher's Notes

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

Topic or Option	Topic 6: Nucleic Acids and Proteins	
	A.S.	Obj
	<b>6.1 DNA Structure (1h)</b>	
	6.1.1 Outline the structure of nucleosomes. <small>Limit this to the fact that a nucleosome consists of DNA wrapped around eight histone protein molecules and held together by another histone protein.</small>	2
Sub-topic	6.1.2 State that only a small proportion of the DNA in the nucleus constitutes genes and that the majority of DNA consists of repetitive sequences. <small>The function of the repetitive sequences is not required but students should know that the presence of such sequences is used in DNA profiling (see 3.4.3).</small>	1
Assessment Statement	6.1.3 Describe the structure of DNA including the antiparallel strands, 3'-5' linkages and hydrogen bonding between purines and pyrimidines. <small>Major and minor grooves, direction of the "twist", alternative B and Z forms and details of the dimensions are not required.</small>	2
	<b>6.2 DNA Replication (1h)</b>	
	6.2.1 State that DNA replication occurs in a 5' → 3' direction. <small>The 5' end of the free DNA nucleotide is added to the 3' end of the chain of nucleotides which is already synthesized.</small>	1
Teacher's Note	6.2.2 Explain the process of DNA replication in eukaryotes including the role of enzymes (helicase, DNA polymerase III, RNA primase, DNA polymerase I and DNA ligase), Okazaki fragments and deoxynucleoside triphosphates. <small>The function of the enzymes listed should be stated in general terms only. The explanation of Okazaki fragments in relation to the direction of DNA polymerase III action is required. DNA polymerase III adds nucleotides in the 5' → 3' direction. DNA polymerase I excises the RNA primers and replaces them with DNA. Details of Meselson and Stahl's experiment are not required.</small>	3
Objective	6.2.3 State that in eukaryotic chromosomes, replication is initiated at many points.	1

# AIMS

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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 will generally involve the formation, testing and modification of hypotheses through observation and measurement, under the controlled conditions of an experiment. It is this approach, along with the falsifiability of scientific hypotheses, that distinguishes the experimental sciences 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 which will stimulate and challenge students
2. provide a body of knowledge, methods and techniques which characterize science and technology
3. enable students to apply and use a body of knowledge, methods and techniques which 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 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.

# OBJECTIVES

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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 should 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.

# ACTION VERBS

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

## Objective 1

<b>Define</b>	give the precise meaning of a word or phrase as concisely as possible
<b>Draw</b>	represent by means of pencil lines (add labels unless told not to do so)
<b>List</b>	give a sequence of names or other brief answers with no elaboration, each one clearly separated from the others
<b>Measure</b>	find a value for a quantity
<b>State</b>	give a specific name, value or other brief answer (no supporting argument or calculation is necessary)

## Objective 2

<b>Annotate</b>	add brief notes to a diagram, drawing or graph
<b>Apply</b>	use an idea, equation, principle, theory or law in a new situation
<b>Calculate</b>	find an answer using mathematical methods (show the working unless instructed not to do so)
<b>Compare</b>	give an account of similarities and differences between two (or more) items, referring to both (all) of them throughout (comparisons can be given using a table)
<b>Describe</b>	give a detailed account, including all the relevant information
<b>Distinguish</b>	give the differences between two or more different items
<b>Estimate</b>	find an approximate value for an unknown quantity, based on the information provided and scientific knowledge
<b>Identify</b>	find an answer from a number of possibilities
<b>Outline</b>	give a brief account or summary (include essential information only)

## Objective 3

<b>Analyse</b>	interpret data to reach conclusions
<b>Construct</b>	represent or develop in graphical form
<b>Deduce</b>	reach a conclusion from the information given
<b>Derive</b>	manipulate a mathematical equation to give a new equation or result
<b>Design</b>	produce a plan, object, simulation or model
<b>Determine</b>	find the only possible answer
<b>Discuss</b>	give an account including, where possible, a range of arguments, assessments of the relative importance of various factors or comparisons of alternative hypotheses
<b>Evaluate</b>	assess the implications and limitations
<b>Explain</b>	give a clear account including causes, reasons or mechanisms
<b>Predict</b>	give an expected result
<b>Solve</b>	obtain an answer using algebraic and/or numerical methods
<b>Suggest</b>	propose a hypothesis or other possible answer

# INFORMATION AND COMMUNICATION TECHNOLOGY (ICT)

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The role of computers in developing and applying scientific knowledge is well established. Scientists make measurements, handle information and model ideas. They need to process information and communicate it effectively.

## Why Use Computers in Science?

Skills in handling information are clearly important life skills. The use of ICT will enhance learning, increase awareness of the technology scientists use for processing information and prepare students better for a rapidly changing situation in the real world. Computers enable students to become more active participants in learning and research and offer a valuable resource for understanding the processes of science. Development of ICT skills will allow students to explore rich materials, access information quickly and easily and lead them into areas previously experienced only through the possession of higher order skills. The computer also allows the teacher more flexibility in both approach and presentation of materials. Creating an ICT culture in classrooms is an important endeavour for all schools.

It is for these reasons that the IBO has incorporated a new aim related to ICT for group 4—aim 7: develop and apply the students' information technology skills in the study of science.

## When Should Computers be Used?

The use of computers should complement rather than replace hands-on practical work. However computers can be used in areas where a practical approach is inappropriate or limited.

For example: sensors may be used in data-logging to obtain data over long or very short periods of time, or in experiments that otherwise would not be feasible. Simulation software may be used to illustrate concepts and models which are not readily demonstrable in laboratory experiments because they require expensive equipment or materials that are hazardous or difficult to obtain. The experiments may also involve skills not yet achieved by students or which require more time than is available.

## What Sort of Technologies are Available?

The technology for processing information includes such tools as word processors, spreadsheets, database programs, sensors and modelling programs.

## Spreadsheets

These multipurpose programs may be used for generating results tables from experimental data, data handling, sorting and searching pre-existing data, and producing graphs. Perhaps their most interesting feature is their use in calculations and mathematical modelling.

## Databases

Scientists use database programs to handle the vast amounts of data which may be generated in experiments, or to retrieve other scientists' data. The database may be on disc, CD-Rom or downloaded from the Internet. Scientists use their skills and experience to collect, organize and analyse data, look for patterns and check for errors. To appreciate the value of databases to the scientific community, students should be familiar with using a database to store, sort and graph data.

## Data-logging

Sensors and control technology can help scientists by monitoring very fast or very slow changes. Data-logging has the advantage that students can see the data recorded in real time. They can therefore focus on the trends and patterns that emerge rather than on the process of gathering the data. Sensors can also measure with more precision allowing students to have greater confidence in their results.

## Software for Modelling and Simulations

A wide range of software programs exist to model (amongst other things) photosynthesis, control of blood sugar, chemical equilibria, the cardiovascular system and wave phenomena such as interference and diffraction. Generic programs are also available which allow students to construct models of, for example, motion and gravity, heat loss or populations in an ecosystem. Some of these programs are available via the Internet.

## The Internet, CD-Roms, DVDs and Multimedia

The powerful combination of the spoken word, animation and video in these multimedia products clearly motivates and stimulates the user. Interactive multimedia has considerable potential to link different representations and ways of learning to facilitate understanding in science. It provides information that can be selected or rejected, and search facilities allow many different routes through the material which illustrate new links and patterns.

There is clearly added value in the use of interactive multimedia through visualization and differentiation. To be able to represent visually, for example, the dynamic aspects of kinetic theory or electron movements, helps students imagine the situation and aids the learning of difficult concepts. This complements more traditional teaching approaches.

## Word Processing and Graphics

Word processing is not merely a means of writing in electronic form. It can improve the quality of written work from the initial listing of ideas, their development and reworking, through to the final product. Drawing programs, scanners, digital cameras, video cameras, desktop publishing, multimedia authoring and CAD/CAM software also have their place, particularly in design technology and perhaps more widely through the group 4 project.

## Internationalism

The ease and widespread use of email should encourage the networking of teachers and students, and this replicates the networking activities of the science community. Email (and web sites) could be used to collaborate with other schools world wide, perhaps as part of the group 4 project, or in established collaborative ventures such as the Science Across the World and Globe programs.

## Ethical and Moral Dimension

This dimension of the use of ICT need not be made explicit in the group 4 subjects as students will be exposed to it through Theory of Knowledge (TOK), and it will also emerge in the day-to-day experiences of students inside and outside school. Such issues as plagiarism of extended essays, firewalls to prevent access to undesirable web sites, hacking, anti-social behaviour in local networks and on the Internet, privacy of information in databases, freedom of information and web site subscriptions may be encountered.

## How to Proceed

Because of the variability of both hardware and software between IB schools, the use of ICT will not be monitored or assessed. For this reason, there is no new objective related to ICT in group 4. However, it is vital to encourage ICT use and to stress its importance in any modern science curriculum. (One common element is the use of graphic calculators in some IB Diploma Programme mathematics courses. This allows for portable, low cost data-logging, modelling and graph plotting.) The IB community can help disseminate ideas and guidance through its workshops and the online curriculum centre.

For further information teachers should access:

- the online curriculum centre to find up-to-date and relevant resources and web site addresses, and to share experiences and resources with other IB teachers
- the web sites of national and international educational bodies promoting ICT
- the web sites of the main educational suppliers and specialized educational software and hardware suppliers, many of whom now operate internationally.



# EXTERNAL ASSESSMENT

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The external assessment consists of three written papers.

## Paper 1

Paper 1 is made up of multiple-choice questions which test knowledge of the core and additional higher level (AHL) material for higher level (HL) students and the core only for standard level (SL) students. The questions are designed to be short, one- or two-stage problems which address objectives 1 and 2 (see page 7). 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 and AHL material for HL students and the core only for SL students. 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 which will require students to analyse a given set of data. The remainder of section A is made up of short-answer questions.

In section B, students are expected to answer two questions from a choice of four at HL\*\* or one question from a choice of three at SL. 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. At HL, students will answer several short-answer questions and an extended response question in each of the two options studied. At SL, students answer several short-answer questions in each of the two options studied. A calculator is required for this paper. (In biology, students will also answer a data-based question in each of the two options studied.)

The assessment specifications at HL and SL are summarized on the next page.

There are some variations in external assessment requirements for design technology, arising from the design project. A double asterisk (\*\*) indicates where these variations occur. See the design technology guide for details.

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

## Assessment Specifications—Standard Level \*\*

Component	Overall Weighting (%)	Approximate Weighting of Objectives		Duration (hours)	Format and Syllabus Coverage
		1+2	3		
Paper 1	20	20		$\frac{3}{4}$	30 multiple-choice questions on the core
Paper 2	32	16	16	$1\frac{1}{4}$	<p><b>Section A:</b> one data-based question and several short-answer questions on the core (all compulsory)</p> <p><b>Section B:</b> one extended response question on the core (from a choice of three)</p>
Paper 3	24	12	12	1	several short-answer questions in each of the two options studied (all compulsory)

## Assessment Specifications—Higher Level \*\*

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 ( $\pm 15$ common to SL plus about five more on the core and about 20 more on the AHL)
Paper 2	36	18	18	$2\frac{1}{4}$	<p><b>Section A:</b> one data-based question and several short-answer questions on the core and the AHL (all compulsory)</p> <p><b>Section B:</b> two extended response questions on the core and AHL (from a choice of four)</p>
Paper 3	20	10	10	$1\frac{1}{4}$	several short-answer questions and one extended response question in each of the two options studied (all compulsory)

For both SL and HL, calculators are not permitted in paper 1 but are required in papers 2 and 3, where programmable graphic display calculators are allowed.

# INTERNAL ASSESSMENT

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## 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 (design technology 36%) 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 higher level and standard level is judged against assessment criteria each consisting of achievement levels 0–3.

## 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. Higher level and standard level candidates in the same subject may carry out some of the same investigations and, where more than one group of students is taught in a subject and level, common investigations are acceptable.

## 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 candidates 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.

## Choosing Investigations

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

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

Teachers should not feel that all investigations must form part of the practical scheme of work, however their scheme must meet the IB requirements. Each scheme must include at least a few complex investigations which make greater conceptual demands on the 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 to share ideas about possible investigations by joining in the discussion forums and adding resources they use onto the relevant sections of the online subject guides.

Note: Any investigation or part investigation that is to be used to assess candidates 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 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 analyse a topic or problem which can be investigated in each of the science disciplines offered by a school. 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, ie there may be several group 4 projects in the same school.

## Design Technology

In design technology, each student must carry out the design project in addition to several investigations and the group 4 project. Higher level students are required to spend 31 hours on the design project and SL students 19 hours.

## Practical Work Documentation

Details of an individual student's practical scheme of work are recorded on **form 4/PSOW** provided in the *Vade Mecum*, section 4. Electronic versions may be used as long as they include all necessary information.

In design technology, each candidate must compile a log book. This is a candidate's record of his/her development of the design project and an informal personal record of investigative activities.

## IA Time Allocation

The recommended teaching times for the IB Diploma Programme courses are 240 hours for HL and 150 hours for SL. Higher level students are required to spend 60 hours, and SL students 40 hours, on practical activities (excluding time spent writing up work). These times include 10 to 15 hours for the group 4 project.

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

The time allocated to IA activities should be spread throughout most of the course and not confined to just a few weeks at the beginning, middle or end. Only 2–3 hours of investigative work can be carried out after the deadline for submission of work to the moderator and still be counted in the total hours for the practical scheme of work.

## Guidance and Authenticity

All candidates 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 candidates 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 candidates concerning investigations, teachers should (where appropriate) guide candidates into more productive routes of enquiry rather than respond with a direct answer.

When completing an investigation outside the classroom candidates should work independently where possible. Teachers are required to ensure that work submitted is the candidate's own. If in doubt, authenticity may be checked by one or more of the following methods:

- discussion with the candidate
- asking the candidate to explain the methods used and to summarize the results
- asking the candidate to repeat the investigation.

## 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 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.

## Criteria and Aspects

There are eight assessment criteria which are used to assess the work of both higher level and standard level candidates:

- *planning (a)*—PI (a)
- *planning (b)*—PI (b)
- *data collection*—DC
- *data processing and presentation*—DPP
- *conclusion and evaluation*—CE
- *manipulative skills*—MS
- *personal skills (a)*—PS (a)
- *personal skills (b)*—PS (b)

Each candidate must be assessed at least twice on each of the eight criteria. The two marks for each of the criteria are added together to determine the final mark out of 48 for the IA component. This will then be scaled at IBCA to give a total out of 24%.

General regulations and procedures relating to IA can be found in the *Vade Mecum*.

Each of the assessment criteria can be separated into two or three **aspects** as shown on the following pages. 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)**.

## Planning (a)

ASPECTS			
LEVELS	Defining the problem or research question	Formulating a hypothesis or prediction	Selecting variables
Complete	Identifies a focused problem or research question.	Relates the hypothesis or prediction directly to the research question and explains it, quantitatively where appropriate.	Selects the relevant independent and controlled variable(s).
Partial	States the problem or research question, but it is unclear or incomplete.	States the hypothesis or prediction but does not explain it.	Selects some relevant variables.
Not at all	Does not state the problem or research question <b>or</b> repeats the general aim provided by the teacher.	Does not state a hypothesis or prediction.	Does not select any relevant variables.

## Planning (b)

ASPECTS			
LEVELS	Selecting appropriate apparatus or materials*	Designing a method for the control of variables	Designing a method for the collection of sufficient relevant data
Complete	Selects appropriate apparatus or materials.	Describes a method that allows for the control of the variables.	Describes a method that allows for the collection of sufficient relevant data.
Partial	Selects some appropriate apparatus or materials.	Describes a method that makes some attempt to control the variables.	Describes a method that allows for the collection of insufficient relevant data.
Not at all	Does not select any apparatus or materials.	Describes a method that does not allow for the control of the variables.	Describes a method that does not allow any relevant data to be collected.

\* suitable diagrams are acceptable

## Data Collection

ASPECTS		
LEVELS	Collecting and recording raw data	Organizing and presenting raw data
Complete	Records appropriate raw data (qualitative and/or quantitative), including units and uncertainties where necessary.	Presents raw data clearly, allowing for easy interpretation.
Partial	Records some appropriate raw data.	Presents raw data but does not allow for easy interpretation.
Not at all	Does not record any appropriate raw data.	Does not present raw data <b>or</b> presents it incomprehensibly.



## Data Processing and Presentation

	ASPECTS	
LEVELS	Processing raw data	Presenting processed data
Complete	Processes the raw data correctly.	Presents processed data appropriately, helping interpretation and, where relevant, takes into account errors and uncertainties.
Partial	Some raw data is processed correctly.	Presents processed data appropriately but with some errors and/or omissions.
Not at all	No processing of raw data is carried out <b>or</b> major errors are made in processing.	Presents processed data inappropriately <b>or</b> incomprehensibly.

## Conclusion and Evaluation

	ASPECTS		
LEVELS	Drawing conclusions	Evaluating procedure(s) and results	Improving the investigation
Complete	Gives a valid conclusion, based on the correct interpretation of the results, with an explanation and, where appropriate, compares results with literature values.	Evaluates procedure(s) and results including limitations, weaknesses or errors.	Identifies weaknesses and states realistic suggestions to improve the investigation.
Partial	States a conclusion that has some validity.	Evaluates procedure(s) and results but misses some obvious limitations or errors.	Suggests only simplistic improvements.
Not at all	Draws a conclusion that misinterprets the results.	The evaluation is superficial <b>or</b> irrelevant.	Suggests unrealistic improvements.

## Manipulative Skills

	ASPECTS	
LEVELS	Carrying out techniques safely	Following a variety of instructions*
Complete	Is competent and methodical in the use of the technique(s) and the equipment, and pays attention to safety issues.	Follows the instructions accurately, adapting to new circumstances (seeking assistance when required).
Partial	Requires assistance in the use of a routine technique. Works in a safe manner with occasional prompting.	Follows the instructions but requires assistance.
Not at all	Does not carry out the technique(s) <b>or</b> misuses the equipment, showing no regard for safety.	Does not follow the instructions <b>or</b> requires constant supervision.

\* Instructions may be given in a variety of forms: oral, written worksheets, diagrams, photographs, videos, flowcharts, audiotapes, models, computer programs etc.

## Personal Skills (a)

		ASPECTS		
LEVELS	Working within a team*	Recognizing the contributions of others	Exchanging and integrating ideas	
Complete	Collaborates with others, recognizing their needs, in order to complete the task.	Expects, actively seeks and acknowledges the views of others.	Exchanges ideas with others, integrating them into the task.	
Partial	Requires guidance to collaborate with others.	Acknowledges some views.	Exchanges ideas with others but requires guidance in integrating them into the task.	
Not at all	Is unsuccessful when working with others.	Disregards views of others.	Does not contribute.	

\* A team is defined as two or more people.

## Personal Skills (b)

		ASPECTS		
LEVELS	Approaching scientific investigations with self-motivation and perseverance	Working in an ethical manner	Paying attention to environmental impact	
Complete	Approaches the investigation with self-motivation and follows it through to completion.	Pays considerable attention to the authenticity of the data and information, and the approach to materials (living or non-living).	Pays considerable attention to the environmental impact of the investigation.	
Partial	Approaches the investigation with self-motivation or follows it through to completion.	Pays some attention to the authenticity of the data and information, and the approach to materials (living or non-living).	Pays some attention to the environmental impact of the investigation.	
Not at all	Lacks perseverance and motivation.	Pays little attention to the authenticity of the data and information, and the approach to materials (living or non-living).	Pays little attention to the environmental impact of the investigation.	

## Achievement Level Matrixes

For a particular criterion, a piece of work is judged to see whether the requirements of each aspect have been fulfilled completely, partially or not at all. This can then be translated into an achievement level 0, 1, 2 or 3 using the achievement level matrixes below. The lowest level of achievement is represented by 0, and 3 represents the highest level of achievement.

### Planning (a), Planning (b), Conclusion and Evaluation, Personal Skills (a), Personal Skills (b)

The matrix below refers to *planning (a)*, *planning (b)*, *conclusion and evaluation*, *personal skills (a)* and *personal skills (b)*, where each criterion has three aspects.

Level \	3			2			2			2			1		
Completely	✓	✓	✓	✓	✓		✓	✓		✓					
Partially						✓					✓	✓	✓	✓	✓
Not at all									✓						
	Aspects			Aspects			Aspects			Aspects			Aspects		
Level \	1			1			1			0			0		
Completely	✓			✓											
Partially		✓					✓	✓		✓					
Not at all			✓		✓	✓			✓		✓	✓	✓	✓	✓
	Aspects			Aspects			Aspects			Aspects			Aspects		

### Data Collection, Data Processing and Presentation, Manipulative Skills

The matrix below applies to *data collection*, *data processing and presentation*, and *manipulative skills*, where each criterion has two aspects.

Level \	3		2		1		1		0		0	
Completely	✓	✓	✓		✓							
Partially				✓			✓	✓	✓			
Not at all						✓				✓	✓	✓
	Aspects		Aspects		Aspects		Aspects		Aspects		Aspects	

## Guidance on the Criteria

### Planning (a)

It is generally not appropriate to assess *planning (a)* for most experiments or investigations found in standard textbooks, unless the experiments are modified. It is essential that students are given an open-ended problem to investigate. Although the general aim of the investigation may be provided by the teacher, students must be able to identify a focused problem or specific research question.

For example, the teacher might present the aim of the investigation generally in the form “investigate the factors that affect X”. Students should be able to recognize that certain factors will influence X and clearly define the aim of the experiment or identify a focused research question. A hypothesis or prediction should then be formulated in the light of any independent variables that have been chosen. Such a hypothesis must contain more than just an expected observation. It must include a proposed relationship between two or more variables, or at least an element of rational explanation for an expected observation, the basis of which can be investigated experimentally. A typical formulation for a hypothesis might be “if *y* is done, then *z* will occur”. Other variables that might affect the outcome should also be mentioned, even if they are not to be specifically investigated. Controlled variables should also be selected.

### Planning (b)

The student must design a realistic and appropriate method that allows for the control of variables and the collection of sufficient relevant data. The experimental set-up and measurement techniques must be described.

### Data Collection

Data collection skills are important in accurately recording observed events and are critical to scientific investigation. Data collection involves all quantitative or qualitative raw data, such as a column of results, written observations or a drawing of a specimen. Qualitative data is defined as those observed with more or less unaided senses (colour, change of state, etc) or rather crude estimates (hotter, colder, etc), whereas quantitative data implies actual measurements.

Investigations should allow students opportunities to deal with a wide range of observations and data. It is important that the practical scheme of work includes:

- the collection of qualitative and quantitative data
- various methods or techniques
- different variables (time, mass, etc)
- various conditions
- subject-specific methods of collection.

In addition:

- attention to detail should be reflected in the accuracy and precision of the data recorded
- use of data collection tables should be encouraged
- methods of collection and the measurement techniques must be appropriate to each other
- units of measurement must be relevant to the task at hand.

## Data Processing and Presentation

The practical scheme of work should provide sufficient investigations to enable a variety of methods of data processing to be used.

Students should also be exposed to the idea of error analysis. That is not to say that error analysis must be carried out for every investigation, nor should it overshadow the purpose of an investigation.

Students should show that they can take raw data, transform it and present it in a form suitable for evaluation.

Processing raw data may include:

- subjecting raw data to statistical calculations (eg producing percentages or means), with the calculations correct and accurate to the level necessary for evaluation
- converting drawings into diagrams
- converting tabulated data into a graphical form
- correctly labelling drawings
- sketching a map from measurements and observations in land form
- proceeding from a sketched idea to a working drawing (eg orthographic projection or sectional views).

The data should be presented so that the pathway to the final result can be followed. Features which should be considered when presenting data include:

- quality of layout (eg choice of format, neatness)
- choice of correct presentation (eg leave as a table, convert to a graph, convert to a flow diagram)
- use of proper scientific conventions in tables, drawings and graphs
- provision of clear, unambiguous headings for drawings, tables or graphs.

## Conclusion and Evaluation

Once the data has been processed and presented in a suitable form, the results can be interpreted, conclusions can be drawn and the method evaluated.

Students are expected to:

- analyse and explain the results of experiments and draw conclusions
- evaluate the results.

Analysis may include comparisons of different graphs or descriptions of trends shown in graphs.

Students are also expected to evaluate the procedure they adopted, specifically looking at:

- the processes
- use of equipment
- management of time.

Modifications to improve the investigation should be suggested.

## Manipulative Skills

Indications of manipulative ability are the amount of assistance required in assembling equipment, the orderliness of carrying out the procedure(s), the ability to follow the instructions accurately and adherence to safe working practices.

## Personal Skills (a)

Working in a team is when two or more students work on a task collaboratively, face-to-face, with individual accountability. Effective teamwork includes recognizing the contributions of others, which begins with each member of the team expecting every other member to contribute. The final product should be seen as something that has been achieved by all members of the team participating in the tasks involved. Encouraging the contributions of others implies not only recognizing, but also actively seeking, contributions from reluctant or less confident members of the team.

## Personal Skills (b)

Issues such as plagiarism, the integrity of data collection and data analysis, may be considered here. Sources of data should be acknowledged and data must be reported accurately, even when anomalous or when an experiment has not given rise to the results expected. Due attention to environmental impact may be demonstrated in various ways including avoidance of wastage, using proper procedures for disposal of waste, and minimizing damage to the local environment when conducting experiments.

## Assessing an Investigation

In assessing an investigation it must be noted that:

- the same standards must be applied to both HL and SL students
- level 3 does not imply faultless performance
- only whole numbers should be awarded, not fractions or decimals.

The work being assessed must be that of the student. For example in work on *planning (a)*, the student should define the problem, formulate the hypothesis and select the variables; this information should not be provided by the teacher. In work on *data collection*, the student must decide how to collect, record, organize and present the raw data. The teacher should not, for instance, specify how the data should be acquired or provide a table in which the data is recorded. This principle extends to the other criteria.

To illustrate the use of the achievement level matrixes, consider the following example. A student's work is assessed against the criterion *data processing and presentation*. The teacher feels that the first aspect, *processing raw data*, is met completely whereas the second aspect, *presenting processed data*, is only achieved partially. Using the achievement level matrix for *data processing and presentation*, this translates to a level of 2.

# THE GROUP 4 PROJECT

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## Summary of the Group 4 Project

The group 4 project allows students to appreciate the environmental, social and ethical implications of science. 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 exercise should be a collaborative experience where concepts and perceptions from across the group 4 disciplines are shared. The intention is that students analyse a topic or problem which can be investigated in each of the science disciplines offered by a school. The topic can be set in a local, national or international context.

## Project Stages

The 10–15 hours allocated to the group 4 project, which are part of the teaching time set aside for internal assessment, can be divided into four stages: planning, definition of activities, action and evaluation.

### Planning

This stage is crucial to the whole exercise and should last 2–4 hours.

- The planning stage could consist of a single session, or two or three shorter ones.
- This stage must involve all science 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 discipline 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.

### Definition of Activities

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. Contact with other schools, if a joint venture has been agreed, is an important consideration at this time.

## Action

This stage should take 6–8 hours in total 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.

- The students (as individuals, single subject groups or mixed subject groups) should investigate the topic from the perspective of the individual science disciplines.
- There should be collaboration in the action stage; findings of investigations should be shared with others working on the project. This may be difficult if the action stage takes place during normal lessons, but it is possible to use bulletin boards (either physical or electronic) to exchange information or to use times when students are together, such as lunchtimes. Enthusiastic students will no doubt share information informally.
- During this stage it is important to pay attention to safety, ethical and environmental considerations.

## Evaluation

The emphasis during this stage, for which 2–4 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 (perhaps with the aid of an overhead projector, flip charts, posters, video player, computers, etc).
- 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 student or 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.

In addition to the presentation, each student must show evidence of their participation in the project.



## Preparation

The impact the project has on the organization of the school is an important consideration. The key is the formulation of an action plan, perhaps in the form of a list of questions, to help draw up a strategy for all the activities involved. The following are suggestions for such a list (these could be adapted to suit the needs of an individual school).

- How might a topic be selected? Possibilities are a questionnaire to students, discussions with students and/or teacher selection.
- Will teachers from other non-science departments be involved?
- Will people from outside the school be used as a source of ideas for the project? If so, what is their availability?
- What communication methods are available for the coordination of activities, exchange of data and joint presentations?
- When should the project be conducted, and over what time period?
- What are the implications in terms of staff and resources?

## Strategies

### Considerations

Teachers will find that there are many factors to consider when planning the project work, besides deciding at what point to carry out the project and what the starting and completion dates should be. These factors include:

- the way the school's year is organized into terms or semesters
- the number of sciences offered
- the number of IB students
- whether or not the school wishes to collaborate with other schools either locally, nationally or internationally.

The needs of the students should be of foremost importance when weighing up the advantages and disadvantages of the various possibilities.

Ensuring that carrying out the project is a group experience (not restricted to a single science in group 4) may present organizational problems for some schools. The options may be limited because, for example, there is a small number of students, only one science is offered or other IB schools are some distance away. Teachers should take into account factors specific to their school and the general points made in this section when planning their strategies.

## Timing

The time-span for carrying out the project is not a full two years.

- The project must be finished, at the latest, 19 months after starting teaching. Therefore, allowing for the planning stages, there may only be 18 months during which the project can be carried out. In the case of those completing the course in one year, such as anticipated SL candidates, the time available is limited further.
- Before starting work on the project students should, ideally, have some experience of working in a team.
- It is very important that students have reached a point where they have a certain degree of scientific knowledge and skills, and have experience of experimental techniques, before undertaking the project

The 10–15 hours that the IBO recommends should 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 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 and provisional discussion in individual subjects could take place at the end of the first year. Students could then use the vacation 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 HL and SL

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

## General Strategies

1. Collaborate with other IB schools, including:
  - direct contact with local schools
  - post, fax, telephone, email, video conferencing.

This is particularly useful for small schools or those with a single science, and where schools have well-established contacts they wish to exploit, or new ones they wish to develop. Where schools in different countries are linked, the importance of internationalism can be reinforced.
2. Carry out the project only every two years so that first- and second-year students can work together to make a larger group, bearing in mind the restriction on timing. (This is perhaps only necessary for small schools and may be difficult in terms of timing.)
3. Encourage IB students to work with non-IB students in the school who may be following courses leading to national or other equivalent qualifications. (This may be useful for small schools or those with a single science.)
4. Encourage participation of local teachers or experts from local industries, businesses, colleges or universities. (This may be helpful to small schools or those distant from other IB schools.)
5. Collaborate with students taking group 3 subjects such as geography, psychology or economics. (This is only relevant to schools not offering the full IB Diploma Programme.)

## Selecting a Topic

In most cases all students in a single school will 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, each undertaking their own project. The students may choose the topic or propose possible topics; teachers then decide which one is the most viable based on resources, staff availability etc. Alternatively, the teachers select the topic or propose 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 below. 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 the students.
- Conduct an initial “brainstorming” session of potential topics or issues.
- Discuss, for 10 minutes, two or three topics that seem interesting.
- Select one topic by consensus.
- Examine the topic. Students in each science subject write down relevant aspects that could be studied given the local circumstances, resources etc.
- Each subject group reads out their list and a master copy is made.
- Students in each discipline 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 forms one part of a candidate's overall practical experience and does not contribute any fixed percentage to internal assessment. A school may choose:

- not to assess the project at all
- to assess the project according to the criteria for the school's local or national requirements
- to assess the project against one or more of the IB Diploma Programme internal assessment criteria.

The project may produce evidence for the full range of criteria, particularly *planning (a)* and *(b)*, and *personal skills (a)* and *(b)*.

Given the diverse nature of the activities associated with the project, it may be difficult for a single teacher to gain a fair overview of an individual student's contribution, especially in regard to *planning* and *personal skills*. It may be necessary for teachers to exchange observations and comments concerning student performance. Group, peer and self-evaluation can also contribute valuable extra information.

## Participation

The evidence of a candidate's involvement in the project, required by the IBO in a moderation sample, can take a variety of forms. It must be accompanied by a copy of the written instructions and/or a summary of the verbal instructions given in relation to the project.

For each student in the moderation sample, the evidence may be:

- a statement written by the student about his/her own individual contributions
- a copy of a self-evaluation form
- a copy of a peer-evaluation form
- an individual laboratory report or complete project report
- rough work or a record of data collected by the student
- photographs, eg of a final poster produced by the group.

## **PART 2—CHEMISTRY**

# NATURE OF THE SUBJECT

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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 higher level and standard level, 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 which suits their circumstances. Option material may be taught within the core or the additional higher level (AHL) material if desired.

# SYLLABUS OVERVIEW

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The syllabus for the Diploma Programme chemistry course is divided into three parts: the core, the additional higher level (AHL) material and the options. A syllabus overview is provided below.

## Core [80h]

Topics		Teaching hours
1	Stoichiometry	11
2	Atomic theory	4
3	Periodicity	6
4	Bonding	12
5	States of matter	5
6	Energetics	11
7	Kinetics	4
8	Equilibrium	5
9	Acids and bases	5
10	Oxidation and reduction	7
11	Organic chemistry	10

## Additional Higher Level [55h]

Topics		Teaching hours
12	Atomic theory	4
13	Periodicity	4
14	Bonding	6
15	Energetics	4
16	Kinetics	6
17	Equilibrium	4
18	Acids and bases	11
19	Oxidation and reduction	7
20	Organic chemistry	9

## Options

### Options Standard Level

A Higher physical organic chemistry

Teaching  
hours

15

### Options Standard Level/Higher Level

B Medicines and drugs

15/22

C Human biochemistry

15/22

D Environmental chemistry

15/22

E Chemical industries

15/22

F Fuels and energy

15/22

### Options Higher Level

G Modern analytical chemistry

22

H Further organic chemistry

22

Standard level candidates are required to study any **two** options from A–F.  
The duration of each option is 15 hours.

Higher level candidates are required to study any **two** options from B–H.  
The duration of each option is 22 hours.



# SYLLABUS OUTLINE

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Core [80h]		Teaching hours
<b>Topic 1</b>	<b>Stoichiometry</b>	<b>[11]</b>
	1.1 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	3
	1.5 Solutions	2
<b>Topic 2</b>	<b>Atomic theory</b>	<b>[4]</b>
	2.1 The atom	2
	2.2 Electron arrangement	2
<b>Topic 3</b>	<b>Periodicity</b>	<b>[6]</b>
	3.1 The periodic table	1
	3.2 Physical properties	2
	3.3 Chemical properties	3
<b>Topic 4</b>	<b>Bonding</b>	<b>[12]</b>
	4.1 Ionic bond	2
	4.2 Covalent bond	6
	4.3 Intermolecular forces	1.5
	4.4 Metallic bond	0.5
	4.5 Physical properties	2
<b>Topic 5</b>	<b>States of matter</b>	<b>[5]</b>
	5.1 States of matter	5
<b>Topic 6</b>	<b>Energetics</b>	<b>[11]</b>
	6.1 Exothermic and endothermic reactions	2
	6.2 Calculation of enthalpy changes	3
	6.3 Hess's law	2
	6.4 Bond enthalpies	1
	6.5 Entropy	1
	6.6 Spontaneity	2
<b>Topic 7</b>	<b>Kinetics</b>	<b>[4]</b>
	7.1 Rates of reaction	2
	7.2 Collision theory	2

<b>Core</b>		<b>Teaching hours</b>
<b>Topic 8</b>	<b>Equilibrium</b>	<b>[5]</b>
	8.1 Dynamic equilibrium	1
	8.2 The position of equilibrium	4
<b>Topic 9</b>	<b>Acids and bases</b>	<b>[5]</b>
	9.1 Properties of acids and bases	1
	9.2 Strong and weak acids and bases	1
	9.3 The pH scale	1
	9.4 Buffer solutions	1
	9.5 Acid–base titrations	1
<b>Topic 10</b>	<b>Oxidation and reduction</b>	<b>[7]</b>
	10.1 Oxidation and reduction	2
	10.2 Reactivity	2.5
	10.3 Electrolysis	2.5
<b>Topic 11</b>	<b>Organic chemistry</b>	<b>[10]</b>
	11.1 Homologous series	1
	11.2 Hydrocarbons	2
	11.3 Other functional groups	7
 <b>Additional Higher Level [55h]</b>		
<b>Topic 12</b>	<b>Atomic theory</b>	<b>[4]</b>
	12.1 The mass spectrometer	1
	12.2 Electron configuration of atoms	3
<b>Topic 13</b>	<b>Periodicity</b>	<b>[4]</b>
	13.1 Periodic trends Na → Ar (the third period)	2
	13.2 d-block elements (first row)	2
<b>Topic 14</b>	<b>Bonding</b>	<b>[6]</b>
	14.1 Shapes of molecules and ions	1
	14.2 Hybridization	2
	14.3 Delocalization of electrons	2
	14.4 Structures of allotropes of carbon	1
<b>Topic 15</b>	<b>Energetics</b>	<b>[4]</b>
	15.1 Standard enthalpy changes of reaction	1
	15.2 Lattice enthalpy	2
	15.3 Spontaneity of a reaction	1

<b>Additional Higher Level</b>		<b>Teaching hours</b>
<b>Topic 16</b>	<b>Kinetics</b>	<b>[6]</b>
16.1	Rate expression	3
16.2	Reaction mechanism	1
16.3	Activation energy	2
<b>Topic 17</b>	<b>Equilibrium</b>	<b>[4]</b>
17.1	Phase equilibrium	2
17.2	The equilibrium law	2
<b>Topic 18</b>	<b>Acids and bases</b>	<b>[11]</b>
18.1	Brønsted–Lowry acids and bases	2
18.2	Lewis theory	1
18.3	Calculations involving acids and bases	5
18.4	Salt hydrolysis	1
18.5	Acid–base titrations	1
18.6	Indicators	1
<b>Topic 19</b>	<b>Oxidation and reduction</b>	<b>[7]</b>
19.1	Redox equations	2
19.2	Standard electrode potentials	3
19.3	Electrolysis	2
<b>Topic 20</b>	<b>Organic chemistry</b>	<b>[9]</b>
20.1	Determination of structure	4
20.2	Hydrocarbons	2
20.3	Nucleophilic substitution reactions	2
20.4	Alcohols	1

Option Standard Level	Teaching hours
<b>Option A Higher physical organic chemistry</b>	<b>[15]</b>
A.1 Determination of structure	5
A.2 Rate expression	3
A.3 Reaction mechanism	1
A.4 Nucleophilic substitution reactions	2
A.5 Acids, bases and buffers	4

## Options Standard Level/Higher Level

Standard level students study the core of these options and higher level students study the whole option (ie the core and the extension material).

Option B Medicines and drugs	Teaching Hours
<b>Core (SL + HL)</b>	<b>[15]</b>
B.1 Pharmaceutical products	2
B.2 Antacids	1
B.3 Analgesics	3
B.4 Depressants	3
B.5 Stimulants	2.5
B.6 Antibacterials	2
B.7 Antivirals	1.5
<b>Extension (HL only)</b>	<b>[7]</b>
B.8 Stereochemistry in drug action and design	3
B.9 Anesthetics	2
B.10 Mind-altering drugs	2

Option C Human biochemistry	Teaching Hours
<b>Core (SL + HL)</b>	<b>[15]</b>
C.1 Diet	2
C.2 Proteins	3
C.3 Carbohydrates	2.5
C.4 Fats	2.5
C.5 Vitamins	2.5
C.6 Hormones	2.5
<b>Extension (HL only)</b>	<b>[7]</b>
C.7 Enzymes	3
C.8 Nucleic acids	2
C.9 Metal ions in biological systems	2

	Teaching Hours
<b>Option D Environmental chemistry</b>	
<b>Core (SL + HL)</b>	<b>[15]</b>
D.1 Primary air pollution	3
D.2 Ozone depletion	2
D.3 Greenhouse effect and global warming	2
D.4 Acid rain	1.5
D.5 Water suitable for drinking	3
D.6 Dissolved oxygen in water	2
D.7 Waste water treatment	1.5
<b>Extension (HL only)</b>	<b>[7]</b>
D.8 Smog	2
D.9 Ozone depletion	2
D.10 Toxic substances in water	3
<b>Option E Chemical industries</b>	
<b>Core (SL + HL)</b>	<b>[15]</b>
E.1 Initial overview	2
E.2 Principles of extraction and production of metals	2
E.3 Iron and aluminium	4
E.4 The oil industry	4
E.5 Polymers	3
<b>Extension (HL only)</b>	<b>[7]</b>
E.6 Silicon	1.5
E.7 Ellingham diagrams	1.5
E.8 Mechanisms in the organic chemicals industry	2
E.9 The chlor-alkali industry	2
<b>Option F Fuels and energy</b>	
<b>Core (SL + HL)</b>	<b>[15]</b>
F.1 Energy sources	1
F.2 Fossil fuels	4
F.3 Nuclear energy	4
F.4 Solar energy	3
F.5 Electrochemical energy	3
<b>Extension (HL only)</b>	<b>[7]</b>
F.6 Storage of energy and limits of efficiency	1
F.7 Nuclear stability	2
F.8 Radioactive decay	2
F.9 Photovoltaics	2

## Options Higher Level

Teaching  
hours

<b>Option G</b>	<b>Modern analytical chemistry</b>	<b>[22]</b>
G.1	Analytical techniques	2
G.2	Principles of spectroscopy	2
G.3	Visible and ultraviolet spectroscopy	4
G.4	Infrared spectroscopy	3
G.5	Nuclear magnetic resonance (NMR) spectroscopy	4
G.6	Mass spectrometry	3
G.7	Chromatography	4
<b>Option H</b>	<b>Further organic chemistry</b>	<b>[22]</b>
H.1	Stereoisomerism	3
H.2	Free radical substitution reactions	3
H.3	Electrophilic addition reactions	4
H.4	Electrophilic substitution reactions	4
H.5	Nucleophilic addition reactions	1
H.6	Nucleophilic substitution reactions	2
H.7	Elimination reactions	2
H.8	Addition–elimination reactions	1
H.9	Acid–base reactions	2

# SYLLABUS DETAILS

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## Topic 1: Stoichiometry

A.S.		Obj
	<b>1.1 Mole Concept and Avogadro's Constant (2h)</b>	
1.1.1	Describe the mole concept and apply it to substances.  The mole concept applies to all kinds of particles: atoms, molecules, ions, formula units etc. The amount of substance is measured in units of moles. The approximate value of Avogadro's constant ( $L$ ), $6.02 \times 10^{23} \text{ mol}^{-1}$ , should be known.	2
1.1.2	Calculate the number of particles and the amount of substance (in moles).  Convert between the amount of substance (in moles) and the number of atoms, molecules or formula units.	2
	<b>1.2 Formulas (3h)</b>	
1.2.1	Define the term <i>molar mass</i> ( $M$ ) and calculate the mass of one mole of a species.	1, 2
1.2.2	Distinguish between <i>atomic mass</i> , <i>molecular mass</i> and <i>formula mass</i> .  The term <i>molar mass</i> (in $\text{g mol}^{-1}$ ) can be used for all of these.	2
1.2.3	Define the terms <i>relative molecular mass</i> ( $M_r$ ) and <i>relative atomic mass</i> ( $A_r$ ).  The terms have no units.	1
1.2.4	State the relationship between the amount of substance (in moles) and mass, and carry out calculations involving amount of substance, mass and molar mass.	1, 2
1.2.5	Define the terms <i>empirical formula</i> and <i>molecular formula</i> .  The molecular formula is a multiple of the empirical formula.	1

<b>A.S.</b>		<b>Obj</b>
<b>1.2.6</b>	Determine the empirical formula and/or the molecular formula of a given compound.  Determine the: <ul style="list-style-type: none"> <li>• empirical formula from the percentage composition or from other suitable experimental data</li> <li>• percentage composition from the formula of a compound</li> <li>• molecular formula when given both the empirical formula and the molar mass.</li> </ul>	<b>3</b>
 <b>1.3 Chemical Equations (1 h)</b>  		
<b>1.3.1</b>	Balance chemical equations when all reactants and products are given.  Distinguish between coefficients and subscripts.	<b>2</b>
<b>1.3.2</b>	Identify the mole ratios of any two species in a balanced chemical equation.  Use balanced chemical equations to obtain information about the amounts of reactants and products.	<b>2</b>
<b>1.3.3</b>	Apply the state symbols (s), (l), (g) and (aq).  Encourage the use of state symbols in chemical equations.	<b>2</b>
 <b>1.4 Mass and Gaseous Volume Relationships in Chemical Reactions (3h)</b>  		
<b>1.4.1</b>	Calculate stoichiometric quantities and use these to determine experimental and theoretical yields.  Mass is conserved in all chemical reactions. Given a chemical equation and the mass or amount (in moles) of one species, calculate the mass or amount of another species.	<b>2, 3</b>
<b>1.4.2</b>	Determine the limiting reactant and the reactant in excess when quantities of reacting substances are given.  Given a chemical equation and the initial amounts of two or more reactants: <ul style="list-style-type: none"> <li>• identify the limiting reactant</li> <li>• calculate the theoretical yield of a product</li> <li>• calculate the amount(s) of the reactant(s) in excess remaining after the reaction is complete.</li> </ul>	<b>3</b>
<b>1.4.3</b>	Apply Avogadro's law to calculate reacting volumes of gases.	<b>2</b>



A.S.		Obj
	<b>1.5 Solutions (2h)</b>	
<b>1.5.1</b>	Define the terms <i>solute</i> , <i>solvent</i> , <i>solution</i> and <i>concentration</i> ( $\text{g dm}^{-3}$ and $\text{mol dm}^{-3}$ ). Concentration in $\text{mol dm}^{-3}$ is often represented by square brackets around the substance under consideration, eg $[\text{CH}_3\text{COOH}]$ .	<b>1</b>
<b>1.5.2</b>	Carry out calculations involving concentration, amount of solute and volume of solution.	<b>2</b>
<b>1.5.3</b>	Solve solution stoichiometry problems. Given the quantity of one species in a chemical reaction in solution (in grams, moles or in terms of concentration), determine the quantity of another species.	<b>3</b>

## Topic 2: Atomic Theory

A.S.

Obj

### 2.1 The Atom (2h)

- 2.1.1 State the relative mass and relative charge of protons, electrons and neutrons. 1

The accepted values are:

	Relative Mass	Charge
proton	1	+1
neutron	1	0
electron	$\frac{1}{1840}$	-1

- 2.1.2 State the position of protons, neutrons and electrons in the atom. 1

- 2.1.3 Define the terms *mass number (A)*, *atomic number (Z)* and *isotope*. 1

- 2.1.4 State the symbol for an isotope given its mass number and atomic number. 1

Use the notation  ${}^A_Z\text{X}$ , eg  ${}^{12}_6\text{C}$ .

- 2.1.5 Explain how the isotopes of an element differ. 3

Isotopes have the same chemical properties but different physical properties. Examples such as  ${}^1_1\text{H}$ ,  ${}^2_1\text{H}$ ,  ${}^3_1\text{H}$ ;  ${}^{12}_6\text{C}$ ,  ${}^{14}_7\text{C}$ ;  ${}^{35}_{17}\text{Cl}$  and  ${}^{37}_{17}\text{Cl}$  should be considered.

- 2.1.6 Calculate and explain non-integer atomic masses from the relative abundance of isotopes. 2, 3

- 2.1.7 Calculate the number of protons, electrons and neutrons in atoms and ions from the mass number, atomic number and charge. 2

### 2.2 Electron Arrangement (2h)

- 2.2.1 Describe and explain the difference between a continuous spectrum and a line spectrum. 2, 3

- 2.2.2 Explain how the lines in the emission spectrum of hydrogen are related to the energy levels of electrons. 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 are not required.

A.S.		Obj
2.2.3	Describe the electron arrangement of atoms in terms of main energy levels.  Students should know the maximum number of electrons that can occupy a main energy level (up to $Z = 18$ ). No knowledge of sub-levels s, p, d and f is required. The term <i>valence electrons</i> is used to describe the electrons in the highest main energy level.	2
2.2.4	Determine the electron arrangement up to $Z = 20$ .  For example, 2.8.7 or 2,8,7 for $Z = 17$ .	3

## Topic 3: Periodicity

A.S.		Obj
	<b>3.1 The Periodic Table (1h)</b>	
<b>3.1.1</b>	Describe the arrangement of elements in the periodic table in order of increasing atomic number.  Names and symbols of the elements are given in the <i>Chemistry Data Booklet</i> . The history of the periodic table is not required.	<b>2</b>
<b>3.1.2</b>	Distinguish between the terms <i>group</i> and <i>period</i> .  The numbering system for groups in the periodic table is shown in the data booklet. Students should also be aware of the position of the transition metals in the periodic table.	<b>2</b>
<b>3.1.3</b>	Deduce the relationship between the electron configuration of elements and their position in the periodic table.  Explanations are only required for the first 20 elements, although general principles can extend to the whole of the periodic table. For example, students should know or be able to predict that K is in group 1 using $Z = 19$ , but need only know that since Cs is in group 1, it has one electron in its outer shell.	<b>3</b>
	<b>3.2 Physical Properties (2h)</b>	
<b>3.2.1</b>	Describe and explain the periodic trends in atomic radii, ionic radii, ionization energies, electronegativity and melting points for the alkali metals (Li → Cs), halogens (F → I) and period 3 elements (Na → Ar).  Cross reference with topics 2, 4 and 5. Data for all these properties are listed in the 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.  Ionization energy is defined as the minimum energy required to remove one electron from an isolated gaseous atom.	<b>2, 3</b>
	<b>3.3 Chemical Properties (3h)</b>	
<b>3.3.1</b>	Discuss the similarities in chemical nature of elements in the same group.  The following reactions should be covered: <ul style="list-style-type: none"> <li>• alkali metals (Li, Na and K) with water and with halogens (Cl<sub>2</sub> and Br<sub>2</sub>)</li> <li>• halogens (Cl<sub>2</sub>, Br<sub>2</sub> and I<sub>2</sub>) with halide ions (Cl<sup>-</sup>, Br<sup>-</sup> and I<sup>-</sup>)</li> <li>• halide ions (Cl<sup>-</sup>, Br<sup>-</sup> and I<sup>-</sup>) with silver ions.</li> </ul> Reactions of the halogens with alkali and confirmation of the silver halide by reaction with ammonia solution are not required.	<b>3</b>

A.S.		Obj
<b>3.3.2</b>	Discuss the change in nature, from metallic to non-metallic, of the elements across period 3.  Use the study of the period 3 oxides to illustrate, for example, the change from basic through amphoteric to acidic oxides and their reaction with water. Halides and hydrides are not required.	<b>3</b>

## Topic 4: Bonding

A.S.		Obj
	<b>4.1 Ionic Bond (2h)</b>	
4.1.1	Describe the ionic bond as the result of electron transfer leading to attraction between oppositely charged ions.	2
4.1.2	Determine which ions will be formed when metals in groups 1, 2 and 3 lose electrons.	3
4.1.3	Determine which ions will be formed when elements in groups 6 and 7 gain electrons.	3
4.1.4	State that transition metals can form more than one ion. Restrict examples to simple ions eg $\text{Fe}^{2+}$ and $\text{Fe}^{3+}$ .	1
4.1.5	Predict whether a compound of two elements would be mainly ionic or mainly covalent from the position of the elements in the periodic table, or from their electronegativity values.	3
4.1.6	Deduce the formula and state the name of an ionic compound formed from a group 1, 2 or 3 metal and a group 5, 6 or 7 non-metal.	3, 1
	<b>4.2 Covalent Bond (6h)</b>	
4.2.1	Describe the covalent bond as the result of electron sharing. The electron pair is attracted by both nuclei leading to a bond which is directional in nature. Both single and multiple bonds should be considered. Dative covalent bonds are not required.	2
4.2.2	Draw the electron distribution of single and multiple bonds in molecules. Examples should include $\text{O}_2$ , $\text{N}_2$ , $\text{CO}_2$ , $\text{C}_2\text{H}_4$ (ethene) and $\text{C}_2\text{H}_2$ (ethyne).	1
4.2.3	State and explain the relationship between the number of bonds, bond length and bond strength. The comparison should include bond lengths and bond strengths of: <ul style="list-style-type: none"> <li>• two carbon atoms joined by single, double and triple bonds</li> <li>• the carbon atom and the two oxygen atoms in the carboxyl group of a carboxylic acid.</li> </ul>	1, 3
4.2.4	Compare the relative electronegativity values of two or more elements based on their positions in the periodic table. Precise values of electronegativity are not required.	2

A.S.		Obj
4.2.5	Identify the relative polarity of bonds based on electronegativity values. In a covalent bond, electron distribution may not be symmetrical and the electron pair may not be equally shared.	2
4.2.6	Draw and deduce Lewis (electron dot) structures of molecules and ions for up to four electron pairs on each atom. 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:	1, 3
	$\begin{array}{c} \times \times \\ \times \text{Cl} \times \times \\ \times \times \end{array} \begin{array}{c} \times \times \\ \times \text{Cl} \times \times \\ \times \times \end{array} \quad \text{or} \quad \begin{array}{c} \cdot \cdot \\ \cdot \text{Cl} \cdot \cdot \\ \cdot \cdot \end{array} \begin{array}{c} \cdot \cdot \\ \cdot \text{Cl} \cdot \cdot \\ \cdot \cdot \end{array} \quad \text{or} \quad \begin{array}{c}   \\ \text{Cl} \\   \end{array} \begin{array}{c}   \\ \text{Cl} \\   \end{array}$	
	Note: Cl – Cl is not a Lewis structure.	
4.2.7	Predict the shape and bond angles for molecules with four charge centres on the central atom. Use the valence shell electron pair repulsion (VSEPR) theory to predict the shapes and bond angles of molecules and ions having four pairs of electrons (charge centres) around the central atom. Suitable examples are NH <sub>3</sub> , H <sub>2</sub> O and alkanes (eg CH <sub>4</sub> ).	3
4.2.8	Identify the shape and bond angles for species with two and three negative charge centres. Examples should include species with non-bonding as well as bonding electron pairs, eg CO <sub>2</sub> , SO <sub>2</sub> , C <sub>2</sub> H <sub>2</sub> , C <sub>2</sub> H <sub>4</sub> , CO <sub>3</sub> <sup>2-</sup> and NO <sub>2</sub> <sup>-</sup> .	2
4.2.9	Predict molecular polarity based on bond polarity and molecular shape. The polarity of a molecule depends on its shape and on the electronegativities of its atoms, eg CO <sub>2</sub> , H <sub>2</sub> O.	3

## 4.3 Intermolecular Forces (1.5h)

4.3.1	Describe the types of intermolecular force (hydrogen bond, dipole–dipole attraction and van der Waals' forces) and explain how they arise from the structural features of molecules. All these intermolecular forces are weaker than covalent bonds. For substances of similar molar mass, hydrogen bonds are stronger than dipole–dipole attractions which are stronger than van der Waals' forces. Van der Waals' forces arise from the electrostatic attraction between temporary induced dipoles in both polar and non-polar molecules.	2, 3
4.3.2	Describe and explain how intermolecular forces affect the boiling points of substances. The hydrogen bond can be illustrated by comparing physical properties of: <ul style="list-style-type: none"> <li>• H<sub>2</sub>O and H<sub>2</sub>S</li> <li>• NH<sub>3</sub> and PH<sub>3</sub></li> <li>• C<sub>3</sub>H<sub>8</sub>, CH<sub>3</sub>CHO and C<sub>2</sub>H<sub>5</sub>OH.</li> </ul>	2, 3

A.S.		Obj
4.4.1	<p data-bbox="379 255 1289 412"><b>4.4 Metallic Bond (0.5h)</b></p> <p data-bbox="379 344 1289 412">Describe metallic bond formation and explain the physical properties of metals.</p> <p data-bbox="475 434 1289 555">Metallic bonding is explained in terms of a lattice of positive ions surrounded by delocalized valence electrons. The delocalized electrons should be related to the high electrical conductivity, malleability and ductility of metals.</p>	2, 3
4.5.1	<p data-bbox="379 600 906 654"><b>4.5 Physical Properties (2h)</b></p> <p data-bbox="379 689 1289 788">Compare and explain the following properties of substances resulting from different types of bonding: melting and boiling points, volatility, conductivity and solubility.</p> <p data-bbox="475 810 1289 931">Consider melting points, boiling points and volatility of similar substances, such as F<sub>2</sub>, Cl<sub>2</sub>, Br<sub>2</sub> and I<sub>2</sub>, and substances with different types of bonding and different intermolecular forces. Students should be aware of the effect of impurities on the melting point of a substance.</p> <p data-bbox="475 943 1289 1032">The solubilities of compounds in non-polar and polar solvents should be compared and explained. Consider also the solubilities of alcohols in water as the length of the carbon chain increases.</p>	2, 3
4.5.2	Predict the relative values of melting and boiling points, volatility, conductivity and solubility based on the different types of bonding in substances.	3



## Topic 5: States of Matter

A.S.		Obj
	<b>5.1 States of Matter (5h)</b>	
<b>5.1.1</b>	Describe and compare solids, liquids and gases as the three states of matter.  The movement of particles, the attractive forces between particles and interparticle spacing should be described. A molecular level description of what happens when evaporation, boiling, condensing, melting and freezing occur should be given. Students should understand what is meant by the term <i>diffusion</i> .	<b>2</b>
<b>5.1.2</b>	Describe kinetic theory in terms of the movement of particles whose average energy is proportional to absolute temperature.  Kinetic theory should be interpreted in terms of ideal gases consisting of point masses in random motion whose energy is proportional to absolute temperature. Students should be able to describe what happens when the temperature is changed.	<b>2</b>
<b>5.1.3</b>	Describe the Maxwell–Boltzmann energy distribution curve.	<b>2</b>
<b>5.1.4</b>	Draw and explain qualitatively Maxwell–Boltzmann energy distribution curves for different temperatures.	<b>1, 3</b>
<b>5.1.5</b>	Describe qualitatively the effects of temperature, pressure and volume changes on a fixed mass of an ideal gas.	<b>2</b>
<b>5.1.6</b>	State the ideal gas equation, $PV = nRT$ .	<b>1</b>
<b>5.1.7</b>	Apply the ideal gas equation in calculations.  Use the relationship between $P$ , $V$ , $n$ and $T$ for gases. Students should be familiar with $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ and be able to calculate molar volume.	<b>2</b>

## Topic 6: Energetics

A.S.		Obj
	<b>6.1 Exothermic and Endothermic Reactions (2h)</b>	
<b>6.1.1</b>	Define the terms <i>exothermic reaction</i> , <i>endothermic reaction</i> and <i>standard enthalpy change of reaction</i> ( $\Delta H^\ominus$ ).  Standard enthalpy change is heat transferred under standard conditions—pressure 101.3 kPa, temperature 298 K. Only $\Delta H$ can be measured, not $H$ for the initial or final state of a system.	<b>1</b>
<b>6.1.2</b>	State the relationship between temperature change, enthalpy change and whether a reaction is exothermic or endothermic.  Combustion of organic compounds are good examples of exothermic reactions.	<b>1</b>
<b>6.1.3</b>	Deduce, from an enthalpy level diagram, the relative stabilities of reactants and products and the sign of the enthalpy change for the reaction.  If the final state is more stable (lower on the enthalpy level diagram), this implies that $H_{\text{final}} < H_{\text{initial}}$ and $\Delta H$ must be negative. Energy must be released in going to a more stable state.	<b>3</b>
<b>6.1.4</b>	Describe and explain the changes which take place at the molecular level in chemical reactions.  Relate bond formation to the release of energy and bond breaking to the absorption of energy.	<b>2, 3</b>
<b>6.1.5</b>	Suggest suitable experimental procedures for measuring enthalpy changes of reactions in aqueous solution.  Explore different reactions operating at constant pressure (open containers). Use of the bomb calorimeter is not required.	<b>3</b>
	<b>6.2 Calculation of Enthalpy Changes (3h)</b>	
<b>6.2.1</b>	Calculate the heat change when the temperature of a pure substance is altered.  Students should be able to calculate the heat change for a substance given the mass, specific heat and temperature change.	<b>2</b>
<b>6.2.2</b>	Explain that enthalpy changes of reaction relate to specific quantities of either reactants or products.  Enthalpy changes are measured in joules (J) and are often quoted in $\text{kJ mol}^{-1}$ of either a reactant or a product.	<b>3</b>
<b>6.2.3</b>	Analyse experimental data for enthalpy changes of reactions in aqueous solution.	<b>3</b>

A.S.		Obj
<b>6.2.4</b>	Calculate the enthalpy change for a reaction in aqueous solution using experimental data on temperature changes, quantities of reactants and mass of solution.	<b>2</b>

Enthalpy change of an acid–base reaction could be investigated.

### 6.3 Hess's Law (2h)

<b>6.3.1</b>	Determine the enthalpy change of a reaction which is the sum of two or more reactions with known enthalpy changes.	<b>3</b>
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Use examples of simple two- and three-step processes. Students should be able to construct simple enthalpy cycles, but will not be required to state Hess's law.

### 6.4 Bond Enthalpies (1h)

<b>6.4.1</b>	Define the term <i>average bond enthalpy</i> .	<b>1</b>
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Bond enthalpies are quoted for the gaseous state and should be recognized as average values obtained from a number of similar compounds. Cross reference with 11.2.6.

<b>6.4.2</b>	Calculate the enthalpy change of a reaction using bond enthalpies.	<b>2</b>
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### 6.5 Entropy (1h)

<b>6.5.1</b>	State and explain the factors which increase the disorder (entropy) in a system.	<b>1, 3</b>
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An increase in disorder can result from the mixing of different types of particles, change of state (increased distance between particles), increased movement of particles or increased numbers of particles. An increase in the number of particles in the gaseous state usually has a greater influence than any other possible factor.

<b>6.5.2</b>	Predict whether the entropy change ( $\Delta S$ ) for a given reaction or process would be positive or negative.	<b>3</b>
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From a given equation, identify a single factor which affects the value of  $\Delta S$  and predict the sign of  $\Delta S$ .

### 6.6 Spontaneity (2h)

<b>6.6.1</b>	Define <i>standard free energy change of reaction</i> ( $\Delta G^\ominus$ ).	<b>1</b>
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<b>6.6.2</b>	State whether a reaction or process will be spontaneous by using the sign of $\Delta G^\ominus$ .	<b>1</b>
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<b>6.6.3</b>	State and predict the effect of a change in temperature on the spontaneity of a reaction, given standard entropy and enthalpy changes.	<b>1, 3</b>
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Use the equation  $\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus$ .

## Topic 7: Kinetics

A.S.		Obj
	<b>7.1 Rates of Reaction (2h)</b>	
7.1.1	<p>Define the term <i>rate of reaction</i> and describe the measurement of reaction rates.</p> <p style="padding-left: 20px;">Rate of reaction can be defined as the decrease in the concentration of reactants per unit time or the increase in the concentration of product per unit time.</p>	1, 2
7.1.2	<p>Analyse data from rate experiments.</p> <p style="padding-left: 20px;">Graphs of changes in concentration, volume or mass against time should be interpreted qualitatively.</p>	3
	<b>7.2 Collision Theory (2h)</b>	
7.2.1	<p>Describe and explain the collision theory.</p> <p style="padding-left: 20px;">Students should know that not all collisions lead to a reaction.</p>	2, 3
7.2.2	<p>Define <i>activation energy</i> (<math>E_a</math>) and explain that reactions occur when reacting species have <math>E \geq E_a</math>.</p> <p style="padding-left: 20px;">Molecules must have a minimum energy and appropriate collision geometry in order to react. A simple treatment is all that is required. Cross reference with 5.1.3 and 5.1.4.</p>	1, 3
7.2.3	<p>Predict and explain, using collision theory, the qualitative effect of particle size, temperature, concentration and catalysts on the rate of a reaction.</p> <p style="padding-left: 20px;">Increasing the temperature increases the frequency of collisions but, more importantly, the proportion of molecules with <math>E \geq E_a</math> increases.</p>	3
7.2.4	<p>Explain that reactions can occur by more than one step and that one step can determine the rate of reaction.</p> <p style="padding-left: 20px;">Few reactions involve just one step although one step in the reaction, the <i>rate determining step</i>, determines the reaction rate. Orders of reactions and rate laws are not required.</p>	3

## Topic 8: Equilibrium

A.S.

Obj

### 8.1 Dynamic Equilibrium (1h)

**8.1.1** Outline the characteristics of a system in a state of equilibrium. **2**

Many chemical reactions are reversible and never go to completion. Equilibrium can be approached from both directions. For a system in equilibrium the rate of the forward reaction equals the rate of the reverse reaction and the concentrations of all reactants and products remain constant. The system is closed and macroscopic properties remain constant.

Use phase equilibrium as an example of dynamic equilibrium involving physical changes.

### 8.2 The Position of Equilibrium (4h)

**8.2.1** State the equilibrium constant expression ( $K_c$ ) for a homogeneous reaction. **1**

Consider equilibria involving one phase, gases or species in aqueous solution. The equilibrium constant is specific to a given system and varies with temperature. No calculations are required.

**8.2.2** Deduce the extent of a reaction from the magnitude of the equilibrium constant. **3**

When  $K_c \gg 1$ , the reaction goes almost to completion.

When  $K_c \ll 1$ , the reaction hardly proceeds.

**8.2.3** Describe and predict the qualitative effects of changes of temperature, pressure and concentration on the position of equilibrium and the value of the equilibrium constant. **2, 3**

Use Le Chatelier's principle to predict the effects of these changes on the position of equilibrium. The value of the equilibrium constant ( $K_c$ ) is only affected by temperature. The position of equilibrium may change without the value of  $K_c$  changing.

**8.2.4** State and explain the effect of a catalyst on an equilibrium reaction. **1, 3**

**8.2.5** Describe and explain the application of equilibrium and kinetics concepts to the Haber process and the Contact process. **2, 3**

## Topic 9: Acids and Bases

A.S.		Obj
	<b>9.1 Properties of Acids and Bases (1h)</b>	
<b>9.1.1</b>	Outline the characteristic properties of acids and bases in aqueous solution.  The properties that must be considered are: effects on indicators and reactions of acids with bases, metals and carbonates. Bases which are not hydroxides, such as ammonia, soluble carbonates and hydrogencarbonates, should be included. Alkalis are bases that dissolve in water.	<b>2</b>
	<b>9.2 Strong and Weak Acids and Bases (1h)</b>	
	<b>Note:</b> Brønsted–Lowry definitions of acids and bases are not required for this sub-topic.	
<b>9.2.1</b>	Describe and explain the differences between strong and weak acids and bases in terms of the extent of dissociation, reaction with water and conductivity.  The term <i>ionization</i> can be used instead of <i>dissociation</i> . Solutions of equal concentration can be compared by pH and/or conductivity.	<b>2, 3</b>
<b>9.2.2</b>	State whether a given acid or base is strong or weak.  Specified strong acids are hydrochloric acid, nitric acid and sulfuric acid. Specified weak acids are ethanoic acid and carbonic acid (aqueous carbon dioxide).  Specified strong bases are all group 1 hydroxides and barium hydroxide. Specified weak bases are ammonia and ethylamine.	<b>1</b>
<b>9.2.3</b>	Describe and explain data from experiments to distinguish between strong and weak acids and bases, and to determine the relative acidities and basicities of substances.	<b>2, 3</b>
	<b>9.3 The pH Scale (1h)</b>	
<b>9.3.1</b>	Distinguish between aqueous solutions that are acidic, neutral or basic using the pH scale.	<b>2</b>
<b>9.3.2</b>	Identify which of two or more aqueous solutions is more acidic or basic, using pH values.  Measure pH using a pH meter or pH paper. Students should know that pH paper contains a mixture of indicators. The theory of pH meters is not required.	<b>2</b>

A.S.		Obj
9.3.3	State that each change of one pH unit represents a tenfold change in the hydrogen ion concentration $[H^+(aq)]$ . Relate integral values of pH to $[H^+(aq)]$ expressed as powers of ten. Calculation of pH from $[H^+(aq)]$ is not required.	1
9.3.4	Deduce changes in $[H^+(aq)]$ when the pH of a solution changes by more than one pH unit.	3
<b>9.4 Buffer Solutions (1h)</b>		
9.4.1	Describe a buffer solution in terms of its composition and behaviour. A buffer resists change in pH when a small amount of a strong acid or base is added. Suitable examples include ammonium chloride/ammonia solution and ethanoic acid/sodium ethanoate. Blood is an example of a buffer solution.	2
9.4.2	Describe ways of preparing buffer solutions.	2
<b>9.5 Acid–base Titrations (1h)</b>		
9.5.1	Draw and explain a graph showing pH against volume of titrant for titrations involving strong acids and bases.	1, 3

# Topic 10: Oxidation and Reduction

A.S.		Obj
	<b>10.1 Oxidation and Reduction (2h)</b>	
<b>10.1.1</b>	Define <i>oxidation</i> and <i>reduction</i> in terms of electron loss and gain. Introduce the concept of the half-equation.	<b>1</b>
<b>10.1.2</b>	Calculate the oxidation number of an element in a compound. Oxidation numbers should be shown by a sign (+ or -) and a number, eg +7 for Mn in $\text{KMnO}_4$ .	<b>2</b>
<b>10.1.3</b>	State and explain the relationship between oxidation numbers and the names of compounds. Oxidation numbers in names of compounds are represented by Roman numerals, eg iron(II) oxide, iron(III) oxide.	<b>1, 3</b>
<b>10.1.4</b>	Identify whether an element is oxidized or reduced in simple redox reactions, using oxidation numbers. Appropriate reactions to illustrate this can be found in topics 3 and 11. Possible examples include: iron(II) and (III), manganese(II) and (VII), chromium(III) and (VI), copper(I) and (II), oxides of sulfur and oxyacids, halogens and halide ions.	<b>2</b>
<b>10.1.5</b>	Define the terms <i>oxidizing agent</i> and <i>reducing agent</i> .	<b>1</b>
	<b>10.2 Reactivity (2.5h)</b>	
<b>10.2.1</b>	Deduce a reactivity series based upon the chemical behaviour of a group of oxidizing and reducing agents. Displacement reactions of metals and halogens (see 3.3.1) provide a good experimental illustration of reactivity. Standard electrode potentials or reduction potentials are not required.	<b>3</b>
<b>10.2.2</b>	Deduce the feasibility of a redox reaction from a given reactivity series.	<b>3</b>
<b>10.2.3</b>	Describe and explain how a redox reaction is used to produce electricity in a voltaic cell. Students should be able to draw a diagram of a simple half-cell, and show how two half-cells can be connected by a salt bridge to form a whole cell. Suitable examples of half-cells are Mg, Zn, Fe and Cu in solutions of their ions.	<b>2, 3</b>



A.S.		Obj
	<b>10.3 Electrolysis (2.5h)</b>	
<b>10.3.1</b>	Draw a diagram showing the essential components of an electrolytic cell. An electrolytic cell converts electrical energy to chemical energy. The diagram should include the source of electric current and conductors, positive and negative electrodes and the electrolyte.	<b>1</b>
<b>10.3.2</b>	Describe how current is conducted in an electrolytic cell.	<b>2</b>
<b>10.3.3</b>	Deduce the products for the electrolysis of a molten salt. Equations showing the formation of products at each electrode should be given.	<b>3</b>
<b>10.3.4</b>	Distinguish between the use of a spontaneous redox reaction to produce electricity in a voltaic cell and the use of electricity to carry out a non-spontaneous redox reaction in an electrolytic cell. Some teachers may wish to describe reactions at the electrodes in a cell in terms of reduction at the cathode and oxidation at the anode, but this is not required.	<b>2</b>
<b>10.3.5</b>	Describe and explain the use of electrolysis in electroplating. Restrict this to copper plating.	<b>2, 3</b>

# Topic 11: Organic Chemistry

A.S.		Obj
	<b>11.1 Homologous Series (1h)</b>	
11.1.1	Describe the features of a homologous series. Features include a general formula and neighbouring members differing by $\text{CH}_2$ , with similar chemical properties and with a gradation in physical properties.	2
11.1.2	Predict and explain the trends in boiling points of members of a homologous series. In a homologous series there is a gradual increase in boiling point as the number of carbon atoms increases. Cross reference with 4.3.	3
	<b>11.2 Hydrocarbons (2h)</b>	
11.2.1	Draw structural formulas for the isomers of the non-cyclic alkanes up to $\text{C}_6$ . Structural formulas should indicate clearly the bonding between atoms. For example, for pentane:	1
	$  \begin{array}{ccccccccc}  & \text{H} & & \text{H} & & \text{H} & & \text{H} & & \text{H} & & \\  &   & &   & &   & &   & &   & & \\  \text{H} & -\text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{H} \\  &   & &   & &   & &   & &   & & \\  & \text{H} & & \text{H} & & \text{H} & & \text{H} & & \text{H} & &   \end{array}  $ or $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$	
	Or $\text{CH}_3\text{---}(\text{CH}_2)_3\text{---CH}_3$ , but not $\text{C}_5\text{H}_{12}$ .	
11.2.2	State the names of alkanes up to $\text{C}_6$ . Name these using IUPAC rules. Consider both straight and branch-chained alkanes.	1
11.2.3	Explain the relative inertness of alkanes. Refer to bond enthalpies. See 6.4.	3
11.2.4	Draw structural formulas and state the names for straight-chain alkenes ( $\text{C}_n\text{H}_{2n}$ , where $n$ is between 2 and 5). Geometric ( <i>cis-trans</i> ) isomers are not required.	1
11.2.5	Describe complete and incomplete combustion of hydrocarbons. The formation of $\text{CO}$ and $\text{C}$ during incomplete combustion should be related to environmental impacts and oxidation–reduction.	2
11.2.6	State that the combustion of hydrocarbons is an exothermic process. See 6.3 and 6.4.	1

A.S.

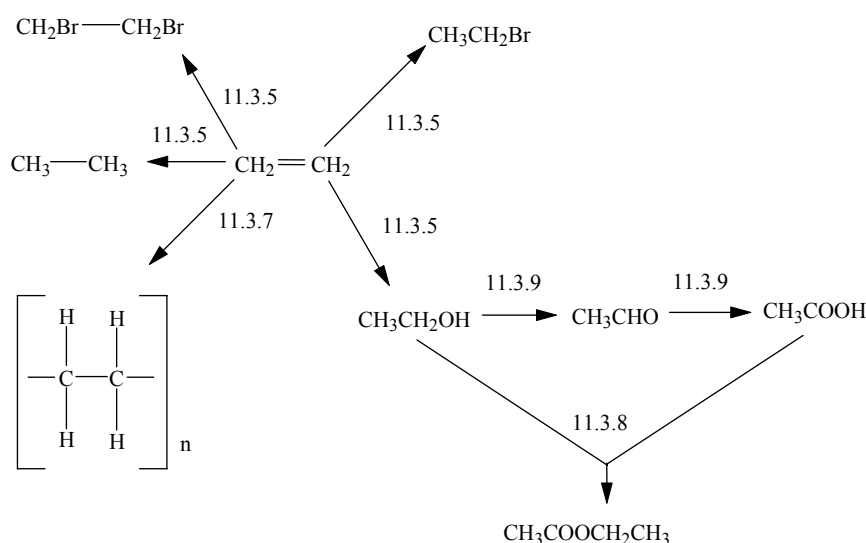
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## 11.3 Other Functional Groups (7h)

Along with alkanes and alkenes, compounds containing one or more functional groups have been chosen to introduce students to:

- interrelationships involving significant functional groups
- important reaction types such as addition, substitution, oxidation, condensation, esterification and polymerization.

This is expressed in the following scheme:

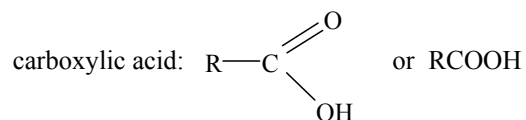
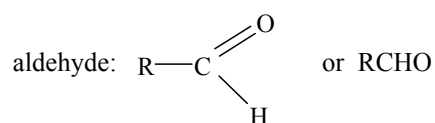


### 11.3.1

Draw and state the names of compounds containing up to five carbon atoms with one of the following functional groups: aldehyde, ketone, carboxylic acid, alcohol, amide, amine, ester and halogenoalkane.

1

Functional groups in full and condensed forms are required, eg:



### 11.3.2

Explain that functional groups can exist as isomers.

3

Examples include:

- ethanoic acid ( $\text{CH}_3\text{COOH}$ ) and methyl methanoate ( $\text{HCOOCH}_3$ )
- propanal ( $\text{CH}_3\text{CH}_2\text{CHO}$ ) and propanone ( $\text{CH}_3\text{COCH}_3$ ).

A.S.		Obj
<b>11.3.3</b>	Outline the existence of optical isomers. Restrict this to the fact that, if a carbon atom has four different substituents, the molecule exists in two enantiomeric forms that rotate the plane of polarized light in opposite directions. Students should be able to identify a chiral (asymmetric) centre.	<b>2</b>
<b>11.3.4</b>	Discuss the volatility, solubility in water and acid–base behaviour of the functional groups aldehyde, ketone, carboxylic acid, alcohol, amide, amine, ester and halogenoalkane. For example, use functional groups to explain the higher boiling point of methanol compared with methane. Cross reference with 4.3.	<b>3</b>
	<b>Note: Mechanisms are not required for 11.3.5 to 11.3.10. Conditions are also not required unless specified.</b>	
<b>11.3.5</b>	Outline the reaction of symmetrical alkenes with hydrogen, bromine, hydrogen halides and water. A double bond is relatively reactive, therefore molecules such as $\text{H}_2\text{C}=\text{CH}_2$ are important starting materials in organic synthesis.	<b>2</b>
<b>11.3.6</b>	Outline the uses of reactions of alkenes. Hydrogenation is used in the production of margarine, hydration of ethene is used in the manufacture of ethanol, and bromination can be used to distinguish between alkanes and alkenes.	<b>2</b>
<b>11.3.7</b>	Outline the polymerization of alkenes. Polyethene and polyvinyl chloride should be used as examples of addition polymers. Students should be able to draw the structures of the monomer and the repeating unit of the polymer.	<b>2</b>
<b>11.3.8</b>	Outline the condensation reaction of an alcohol with a carboxylic acid to form an ester, and state the uses of esters. Esters are used as flavouring agents, in plasticizers, as solvents and in perfumes.	<b>1, 2</b>
<b>11.3.9</b>	Describe the partial and complete oxidation of ethanol. A suitable oxidizing agent is acidified potassium dichromate(VI). Both oxidation products (ethanal and ethanoic acid) can be obtained by altering the conditions, eg ethanal by distilling off the product as it is formed, and ethanoic acid by heating under reflux.	<b>2</b>
<b>11.3.10</b>	Deduce the condensation polymers formed by amines and by carboxylic acids. Emphasize the need for two functional groups on the monomers: <ul style="list-style-type: none"> <li>• polyamides (nylons)—eg hexanedioic acid and 1,6-diaminohexane</li> <li>• polyesters—eg benzene-1,4-dicarboxylic acid and ethane-1,2-diol.</li> </ul>	<b>3</b>

A.S.

Obj

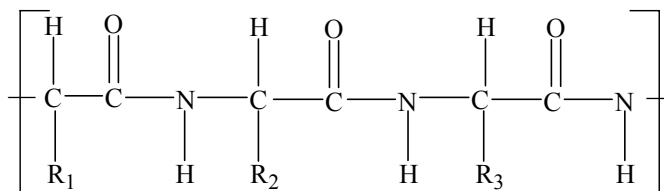
11.3.11

Outline the formation of peptides and proteins from 2-amino acids.

2

All 2-amino acids ( $\alpha$ -amino acids), except aminoethanoic acid (glycine), can show optical activity (see 11.3.3). Peptides are formed from amino acids, and two functional groups allow for the formation of macromolecules.

Students should be familiar with simple primary structures (order of amino acids) for peptides containing up to three amino acids, eg:



## Topic 12: Atomic Theory

A.S.		Obj
	<b>12.1 The Mass Spectrometer (1h)</b>	
<b>12.1.1</b>	State the principles of a mass spectrometer and outline the main stages in its operation.  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.	<b>1, 2</b>
<b>12.1.2</b>	Describe how the mass spectrometer may be used to determine relative isotopic, atomic and molecular masses using the $^{12}\text{C}$ scale.  Students should be able to calculate the relative atomic mass from the abundance of the isotopes (see 2.1.6). Interpretation of fragmentation patterns is not required.	<b>2</b>
	<b>12.2 Electron Configuration of Atoms (3h)</b>	
<b>12.2.1</b>	State and explain how evidence from first and successive ionization energies accounts for the existence of the main energy levels and sub-levels.  Interpretation of graphs of first ionization and successive ionization energies versus atomic number provides evidence for the existence of the main energy levels and sub-levels.	<b>1, 3</b>
<b>12.2.2</b>	State how orbitals are labelled.  Limit this to $n < 5$ .	<b>1</b>
<b>12.2.3</b>	State the relative energies of s, p, d and f orbitals.	<b>1</b>
<b>12.2.4</b>	State the number of orbitals at each energy level.	<b>1</b>
<b>12.2.5</b>	Draw the shape of an s orbital and the shapes of the $p_x$ , $p_y$ and $p_z$ orbitals.	<b>1</b>
<b>12.2.6</b>	State the Aufbau principle.  Reference should be made to Hund's rule.	<b>1</b>
<b>12.2.7</b>	Apply the Aufbau principle to electron configurations.  Apply the Aufbau principle for an atom up to $Z = 54$ , eg for $Z = 23$ the electronic configuration is $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^3$ or $[\text{Ar}] 4s^2 3d^3$ or $[\text{Ar}] 3d^3 4s^2$ . Exceptions to this rule are not expected.	<b>2</b>
<b>12.2.8</b>	Relate the electron configuration of an atom to its position in the periodic table.  Students should be able to label the s, p, d and f blocks of the periodic table.	<b>2</b>

## Topic 13: Periodicity

A.S.

Obj

### 13.1 Periodic Trends Na → Ar (the third period) (2h)

**13.1.1** Explain the physical properties of the chlorides and oxides of the elements in the third period (Na → Ar) in terms of their bonding and structure. **3**

Refer to the following oxides and chlorides:

- Oxides: Na<sub>2</sub>O, MgO, Al<sub>2</sub>O<sub>3</sub>, SiO<sub>2</sub>, P<sub>4</sub>O<sub>6</sub> and P<sub>4</sub>O<sub>10</sub>, SO<sub>2</sub> and SO<sub>3</sub>, Cl<sub>2</sub>O and Cl<sub>2</sub>O<sub>7</sub>.
- Chlorides: NaCl, MgCl<sub>2</sub>, Al<sub>2</sub>Cl<sub>6</sub>, SiCl<sub>4</sub>, PCl<sub>3</sub> and PCl<sub>5</sub>, and Cl<sub>2</sub> (sulfur chloride is not required).

Limit the explanation to the physical states of the compounds under standard conditions and electrical conductivity in the molten state only.

**13.1.2** Describe the chemical trends for the chlorides and oxides referred to in 13.1.1. Include relevant equations. **2**

Limit this to acid–base properties of the oxides and the reactions of the chlorides and oxides with water.

### 13.2 d-block Elements (first row) (2h)

**13.2.1** List the characteristic properties of transition elements. **1**

Restrict this to variable oxidation states, complex ion formation, coloured compounds and catalytic properties.

**13.2.2** Identify which elements are considered to be typical of the d-block elements. **2**

Sc and Zn are not typical.

**13.2.3** Describe the existence of variable oxidation states in d-block elements. **2**

The 4s and 3d sub-levels are close in energy. Students should know that all d-block elements can show an oxidation state of +2. In addition, they should be familiar with the oxidation states 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 how complexes of d-block elements are formed. **2**

Suitable examples are: [Fe(H<sub>2</sub>O)<sub>6</sub>]<sup>3+</sup>, [Fe(CN)<sub>6</sub>]<sup>3-</sup>, [CuCl<sub>4</sub>]<sup>2-</sup>, [Cu(NH<sub>3</sub>)<sub>4</sub>]<sup>2+</sup>, [Ag(NH<sub>3</sub>)<sub>2</sub>]<sup>+</sup>. 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 orbitals are split into two sets at different energy levels and the electronic transitions that take place between them are responsible for their colours.

A.S.		Obj
13.2.7	Outline the catalytic behaviour of d-block elements and their compounds. Limit this to: <ul style="list-style-type: none"><li>• <math>\text{MnO}_2</math> in the decomposition of hydrogen peroxide</li><li>• <math>\text{V}_2\text{O}_5</math> in the Contact process</li><li>• Fe in the Haber process</li><li>• Ni in the conversion of alkenes to alkanes.</li></ul> The mechanisms of action are not required.	2



## Topic 14: Bonding

A.S. Obj

### 14.1 Shapes of Molecules and Ions (1h)

14.1.1 State and predict the shape and bond angles using the VSEPR theory for 5- and 6-negative charge centres. 1, 3

The shape of the molecules/ions and bond angles if all pairs of electrons are shared, and the shape of the molecules/ions if one or more lone pairs surround the central atom, should be considered. Examples such as  $\text{PCl}_5$ ,  $\text{SF}_6$  and  $\text{XeF}_4$  can be used.

### 14.2 Hybridization (2h)

14.2.1 Describe  $\sigma$  and  $\pi$  bonds. 2

Treatment should be restricted to:

- $\sigma$  bonds—electron distribution has axial symmetry around the axis joining the two nuclei
- $\pi$  bonds resulting from the combination of parallel p orbitals
- double bonds formed by a  $\sigma$  and a  $\pi$  bond
- triple bonds formed by a  $\sigma$  and two  $\pi$  bonds.

14.2.2 State and explain the meaning of the term *hybridization*. 1, 3

Hybridization should be explained in terms of the mixing of atomic orbitals to form new orbitals for bonding. Students should consider sp, sp<sup>2</sup> and sp<sup>3</sup> hybridization, and the shapes and orientation of these orbitals.

14.2.3 Discuss the relationships between Lewis structures, molecular shapes and types of hybridization (sp, sp<sup>2</sup> and sp<sup>3</sup>). 3

Using examples from inorganic as well as organic chemistry, students should write the Lewis structure, deduce the shape of the molecule and recognize the type of hybridization.

### 14.3 Delocalization of Electrons (2h)

14.3.1 State what is meant by the delocalization of  $\pi$  electrons and explain how this can account for the structures of some substances. 1, 3

Examples such as  $\text{NO}_3^-$ ,  $\text{NO}_2^-$ ,  $\text{CO}_3^{2-}$ ,  $\text{O}_3$ ,  $\text{RCOO}^-$  and benzene can be used. (These could also be dealt with through the resonance approach.)

### 14.4 Structures of Allotropes of Carbon (1h)

14.4.1 Describe and explain the structures and properties of diamond, graphite and fullerene. 2, 3

Students should recognize the type of hybridization present in each allotrope and the delocalization of electrons in graphite and C<sub>60</sub> fullerene.

## Topic 15: Energetics

A.S.		Obj
	<b>15.1 Standard Enthalpy Changes of Reaction (1h)</b>	
15.1.1	Define and use the terms <i>standard state</i> and <i>standard enthalpy change of formation</i> ( $\Delta H_f^\ominus$ ).	1
15.1.2	Calculate the enthalpy change of a reaction using standard enthalpy changes of formation.	2
	<b>15.2 Lattice Enthalpy (2h)</b>	
15.2.1	Define the term <i>lattice enthalpy</i> . The sign of $\Delta H_{\text{lattice}}$ indicates whether the lattice is being formed or broken.	1
15.2.2	Compare the effect of both the relative sizes and the charges of ions on the lattice enthalpies of different ionic compounds. The relative value of the theoretical lattice enthalpy increases with higher ionic charge and smaller ionic radius due to increased attractive forces.	2
15.2.3	Construct a Born–Haber cycle and use it to calculate an enthalpy change.	2, 3
15.2.4	Analyse theoretical and experimental lattice enthalpy values. A significant difference between the two values indicates covalent character.	3
	<b>15.3 Spontaneity of a Reaction (1h)</b>	
15.3.1	Calculate the standard entropy change for a reaction ( $\Delta S^\ominus$ ) using values of absolute entropies.	2
15.3.2	Calculate $\Delta G^\ominus$ for a reaction using the equation $\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus$ or by using values of the standard free energy change of formation, $\Delta G_f^\ominus$ .	2

## Topic 16: Kinetics

A.S.		Obj
	<b>16.1 Rate Expression (3h)</b>	
16.1.1	Define the terms <i>rate constant</i> and <i>order of reaction</i> .	1
16.1.2	Derive the rate expression for a reaction from data. $\text{Rate} = k[\text{A}]^m[\text{B}]^n$ where $k$ = rate constant, $[\text{A}]$ = concentration of A in mol dm <sup>-3</sup> etc, $m$ and $n$ = integers, $m + n$ = overall order of the reaction.	3
16.1.3	Draw and analyse graphical representations for zero-, first- and second-order reactions.	1, 3
16.1.4	Define the term <i>half-life</i> and calculate the half-life for first-order reactions only.  The half-life should be calculated from graphs and by using the integrated form of the rate equation. The integrated rate equation for second-order reactions is not required.	1, 2
	<b>16.2 Reaction Mechanism (1h)</b>	
16.2.1	Define the terms <i>rate-determining step</i> , <i>molecularity</i> and <i>activated complex</i> .	1
16.2.2	Describe the relationship between mechanism, order, rate-determining step and activated complex.  Limit examples to one- or two-step reactions where the mechanism is known. Students should understand what an activated complex (transition state) is and how the order of a reaction relates to the mechanism.	2
	<b>16.3 Activation Energy (2h)</b>	
16.3.1	Describe qualitatively the relationship between the rate constant ( $k$ ) and temperature ( $T$ ).	2
16.3.2	Describe how the Arrhenius equation can be used to determine the activation energy and the Arrhenius constant ( $A$ ).  Arrhenius equation: $k = Ae^{(-E_a/RT)}$  $A$ relates to the geometric requirements of the collisions (see 7.2). Direct substitution using simultaneous equations and a graphical method can be used. The logarithmic form of the Arrhenius equation is:  $\ln k = -\frac{E_a}{RT} + \ln A$  Both methods should be explained, but actual calculations are not needed.	2

<b>A.S.</b>		<b>Obj</b>
<b>16.3.3</b>	Draw and explain enthalpy level diagrams for reactions with and without catalysts.	<b>1, 3</b>
<b>16.3.4</b>	Distinguish between <i>homogeneous catalysts</i> and <i>heterogeneous catalysts</i> . Homogeneous catalyst—reactants and catalyst are in the same phase. Heterogeneous catalyst—reactants and catalyst are in different phases.	<b>2</b>
<b>16.3.5</b>	Outline the use of homogeneous and heterogeneous catalysts. Examples include hydrogenation using metals (see 13.2.7) and acid-catalysed formation of esters.	<b>2</b>

## Topic 17: Equilibrium

A.S.		Obj
	<b>17.1 Phase Equilibrium (2h)</b>	
17.1.1	State and explain the equilibrium established between a liquid and its own vapour.  Liquid–vapour equilibrium is a dynamic equilibrium established when the rate of condensation equals the rate of vaporization. The vapour pressure is independent of the volume of the container, liquid or vapour.	1, 3
17.1.2	State and explain the qualitative relationship between vapour pressure and temperature.  Students should be able to show the relationship graphically and explain it in terms of kinetic theory.	1, 3
17.1.3	State and explain the relationship between enthalpy of vaporization, boiling point and intermolecular forces.  Students should be able to predict the relative strength of intermolecular forces of different liquids when given the physical properties, or vice versa. Cross reference with 4.3.	1, 3
	<b>17.2 The Equilibrium Law (2h)</b>	
17.2.1	Solve homogeneous equilibrium problems using the expression for $K_c$ .  Calculate $K_c$ given all equilibrium concentrations. Given $K_c$ and other appropriate concentrations, find an equilibrium concentration. $K_p$ and $K_{sp}$ are not required, nor is use of the quadratic expression.	3

## Topic 18: Acids and Bases

A.S.		Obj
	<b>18.1 Brønsted–Lowry Acids and Bases (2h)</b>	
18.1.1	Define acids and bases according to the Brønsted–Lowry theory.	1
18.1.2	Identify whether or not a compound could act as a Brønsted–Lowry acid or base.	2
18.1.3	Identify the conjugate acid–base pairs in a given acid–base reaction.	2
18.1.4	Determine the structure for the conjugate acid (or base) of any Brønsted–Lowry base (or acid).  The members of a conjugate acid–base pair always differ by a single proton ( $\text{H}^+$ ). Structures of conjugate acid–base pairs should always make clear the approximate location of the proton transferred, eg $\text{CH}_3\text{COOH}/\text{CH}_3\text{COO}^-$ rather than $\text{C}_2\text{H}_4\text{O}_2/\text{C}_2\text{H}_3\text{O}_2^-$ .	3
	<b>18.2 Lewis Theory (1h)</b>	
18.2.1	Define and apply the terms <i>Lewis acid</i> and <i>Lewis base</i> .  A Lewis acid–base reaction involves the formation of a new covalent bond in which both electrons are provided by one species. Such bonds are called dative covalent bonds.  The formation of complexes (see 13.2.4 and 13.2.5) is usually a Lewis acid–base reaction.	1, 2
	<b>18.3 Calculations Involving Acids and Bases (5h)</b>	
	<b>Note: A proton in water can be written as <math>\text{H}^+(\text{aq})</math> or <math>\text{H}_3\text{O}^+(\text{aq})</math>; the former is adopted here.</b>	
18.3.1	State the expression for the ionic product constant of water ( $K_w$ ).  $K_w = [\text{H}^+(\text{aq})][\text{OH}^-(\text{aq})] = 1.0 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ at 298 K, but this varies with temperature.	1
18.3.2	Deduce $[\text{H}^+(\text{aq})]$ and $[\text{OH}^-(\text{aq})]$ for water at different temperatures given $K_w$ values.	3
18.3.3	Define <i>pH</i> , <i>pOH</i> and <i>pK<sub>w</sub></i> .	1
18.3.4	Calculate $[\text{H}^+(\text{aq})]$ , $[\text{OH}^-(\text{aq})]$ , pH and pOH from specified concentrations.  The values of $[\text{H}^+(\text{aq})]$ or $[\text{OH}^-(\text{aq})]$ are directly related to the concentration of the acid or base.	2

<b>A.S.</b>		<b>Obj</b>
<b>18.3.5</b>	<p>State the equation for the reaction of any weak acid or weak base with water, and hence derive the ionization constant expression.</p> <p>In general <math>\text{HA(aq)} \rightleftharpoons \text{H}^{\text{+}}(\text{aq}) + \text{A}^{-}(\text{aq})</math>  <math>\text{B(aq)} + \text{H}_2\text{O(l)} \rightleftharpoons \text{BH}^{\text{+}}(\text{aq}) + \text{OH}^{-}(\text{aq})</math> (base hydrolysis)</p> <p>Then <math>K_{\text{a}} = \frac{[\text{H}^{\text{+}}(\text{aq})][\text{A}^{-}(\text{aq})]}{[\text{HA(aq)}]}</math> and <math>K_{\text{b}} = \frac{[\text{BH}^{\text{+}}(\text{aq})][\text{OH}^{-}(\text{aq})]}{[\text{B(aq)}]}</math></p> <p>Examples used should involve the transfer of only one proton.</p>	<b>1, 3</b>
<b>18.3.6</b>	Derive the expression $K_{\text{a}} \times K_{\text{b}} = K_{\text{w}}$ and use it to solve problems for any weak acid and its conjugate base and for any weak base and its conjugate acid.	<b>3</b>
<b>18.3.7</b>	State and explain the relationship between $K_{\text{a}}$ and $\text{p}K_{\text{a}}$ and between $K_{\text{b}}$ and $\text{p}K_{\text{b}}$ .	<b>1, 3</b>
<b>18.3.8</b>	Determine the relative strengths of acids or their conjugate bases from $K_{\text{a}}$ or $\text{p}K_{\text{a}}$ values.	<b>3</b>
<b>18.3.9</b>	<p>Apply <math>K_{\text{a}}</math> or <math>\text{p}K_{\text{a}}</math> in calculations.</p> <p>Calculations can be performed using various forms of the acid ionization constant expression (see 18.3.5). Students should state when approximations are used in equilibrium calculations. Use of the quadratic expression is not required.</p>	<b>2</b>
<b>18.3.10</b>	<p>Calculate the pH of a specified buffer system.</p> <p>Calculations will involve the transfer of only one proton. Cross reference with 9.4.</p>	<b>2</b>

## 18.4 Salt Hydrolysis (1h)

<b>18.4.1</b>	<p>State and explain whether salts form acidic, alkaline or neutral aqueous solutions.</p> <p>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, 3 and d-block elements should also be considered, eg <math>[\text{Fe}(\text{H}_2\text{O})_6]^{3+} \rightleftharpoons [\text{Fe}(\text{OH})(\text{H}_2\text{O})_5]^{2+} + \text{H}^{\text{+}}</math>.</p>	<b>1, 3</b>
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## 18.5 Acid–base Titrations (1h)

<b>18.5.1</b>	<p>Draw and explain the general shapes of graphs of pH against volume of titrant for titrations involving monoprotic acids and bases.</p> <p>All combinations should be covered: strong acid + strong base, strong acid + weak base, weak acid + strong base and weak acid + weak base.</p>	<b>1, 3</b>
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<b>A.S.</b>		<b>Obj</b>
	<b>18.6 Indicators (1h)</b>	
<b>18.6.1</b>	Describe qualitatively how an acid–base indicator works. Use $\text{HIn(aq)} \rightleftharpoons \text{H}^+(\text{aq}) + \text{In}^-(\text{aq})$ , or similar. colour A                    colour B	<b>2</b>
<b>18.6.2</b>	State and explain how the pH range of an acid–base indicator relates to its $\text{p}K_{\text{a}}$ value.	<b>1, 3</b>
<b>18.6.3</b>	Determine an appropriate indicator for a titration, given the equivalence point of the titration and $K_{\text{a}}$ (or $\text{p}K_{\text{a}}$ ) values for possible indicators.	<b>3</b>



## Topic 19: Oxidation and Reduction

A.S.		Obj
	<b>19.1 Redox Equations (2h)</b>	
19.1.1	Balance redox equations in acid solution. Half-equations and oxidation numbers may be used. $\text{H}^+(\text{aq})$ and $\text{H}_2\text{O}$ should be used where necessary to balance half-equations.	2
	<b>19.2 Standard Electrode Potentials (3h)</b>	
	<b>Note:</b> In 19.2.1 to 19.2.4 half-equations can be used to introduce redox couples, including $\text{H}^+/\text{H}_2$ and a selection of common couples from the electrochemical series. The Daniell cell provides a good illustration of the principles under consideration here.	
19.2.1	Describe the standard hydrogen electrode. Laboratory work using the standard hydrogen electrode is not required.	2
19.2.2	Define the term <i>standard electrode potential</i> and explain the measurement of standard electrode potentials to produce the electrochemical series.	1, 3
19.2.3	Define the term <i>cell potential</i> and calculate cell potentials using standard electrode potentials.	1, 3
19.2.4	Predict whether a reaction will be spontaneous using standard electrode potential ( $E^\ominus$ ) values. Students should be able to predict the direction of electron flow in an external circuit and the reaction taking place in a cell. Relate positive $E^\ominus$ values for spontaneous reactions to negative $\Delta G^\ominus$ values (see 6.6).	3
	<b>19.3 Electrolysis (2h)</b>	
19.3.1	List and explain the factors affecting the products formed in the electrolysis of aqueous solutions. Factors to be considered are position in the electrochemical series, nature of the electrode and concentration. Suitable examples for electrolysis include water, aqueous sodium chloride and aqueous copper(II) sulfate.	1, 3
19.3.2	List the factors affecting the amount of product formed during electrolysis. Factors are charge on the ion, current and duration of electrolysis.	1
19.3.3	Determine the relative amounts of the products formed during the electrolysis of aqueous solutions.	3

## Topic 20: Organic Chemistry

A.S.

Obj

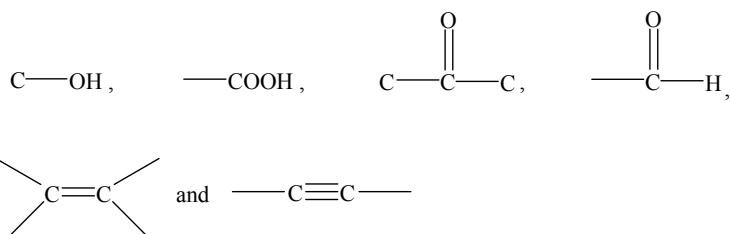
### 20.1 Determination of Structure (4h)

**20.1.1** State that the structure of a compound can be determined using information from a variety of spectroscopic and chemical techniques. **1**

Students should realize that information from only one technique is usually insufficient to determine or confirm a structure.

**20.1.2** Describe and explain how information from an infrared spectrum can be used to identify functional groups in a compound. **2, 3**

Restrict this to using infrared spectra to show the presence of the functional groups:



and to match the fingerprint region to a known spectrum.

**20.1.3** Describe and explain how information from a mass spectrum can be used to determine the structure of a compound. **2, 3**

Restrict this to using mass spectra to determine the relative molecular mass of a compound and to identify simple fragments, for example:

- $(M_r - 15)^+$  loss of  $\text{CH}_3$
- $(M_r - 29)^+$  loss of  $\text{C}_2\text{H}_5$  or  $\text{CHO}$
- $(M_r - 31)^+$  loss of  $\text{CH}_3\text{O}$
- $(M_r - 45)^+$  loss of  $\text{COOH}$ .

**20.1.4** Describe and explain how information from a  $^1\text{H}$  NMR spectrum can be used to determine the structure of a compound. **2, 3**

Restrict this to using NMR spectra to determine the number of different environments in which hydrogen is found and the number of hydrogen atoms in each environment. Splitting patterns are not required.

### 20.2 Hydrocarbons (2h)

**20.2.1** State and explain the low reactivity of alkanes in terms of the inertness of C–H and C–C bonds. **1, 3**

A.S.		Obj
20.2.2	State that alkanes can react with halogens and distinguish between <i>homolytic</i> and <i>heterolytic fission</i> . Students should be able to define and recognize a <i>free radical</i> . Mechanisms are not required.	1, 2
20.2.3	Describe and explain the structure of benzene using chemical and physical evidence. Consider the special stability of the ring system (heat of combustion or hydrogenation of C <sub>6</sub> H <sub>6</sub> in comparison to that of cyclohexene, cyclohexadiene and cyclohexatriene), as well as benzene's tendency to undergo substitution rather than addition reactions.	2, 3

## 20.3 Nucleophilic Substitution Reactions (2h)

20.3.1	Distinguish between <i>primary</i> , <i>secondary</i> and <i>tertiary halogenoalkanes</i> .	2
20.3.2	Describe and explain the S <sub>N</sub> 1 and S <sub>N</sub> 2 mechanisms in nucleophilic substitution. Students must be able to draw a stepwise mechanism. Examples of nucleophiles should include -CN, -OH and NH <sub>3</sub> for each reaction type.	2, 3
20.3.3	Describe and explain the molecularity for the S <sub>N</sub> 1 and S <sub>N</sub> 2 mechanisms. The predominant mechanism for tertiary halogenoalkanes is S <sub>N</sub> 1 and for primary halogenoalkanes it is S <sub>N</sub> 2. Both mechanisms occur for secondary halogenoalkanes.	2, 3
20.3.4	Describe how the rate of nucleophilic substitution in halogenoalkanes depends on both the identity of the halogen and whether the halogenoalkane is primary, secondary or tertiary.	2

## 20.4 Alcohols (1h)

20.4.1	Describe the dehydration reaction of alcohols to form alkenes.	2
20.4.2	Determine the products formed by the oxidation of primary, secondary and tertiary alcohols using acidified potassium dichromate(VI) solution.	3

# Options Outline

## Options Standard Level

- A Higher physical organic chemistry

## Options Standard Level/Higher Level

- B Medicines and drugs
- C Human biochemistry
- D Environmental chemistry
- E Chemical industries
- F Fuels and energy

Note: **Standard level candidates are required to study the core of each option chosen. Higher level candidates study both the core and the extension material.**

## Options Higher Level

- G Modern analytical chemistry
- H Further organic chemistry

Standard level candidates are required to study any **two** options from A–F.  
The duration of each option is 15 hours.

Higher level candidates are required to study any **two** options from B–H.  
The duration of each option is 22 hours.

## Option A: Higher Physical Organic Chemistry

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

A.S. Obj

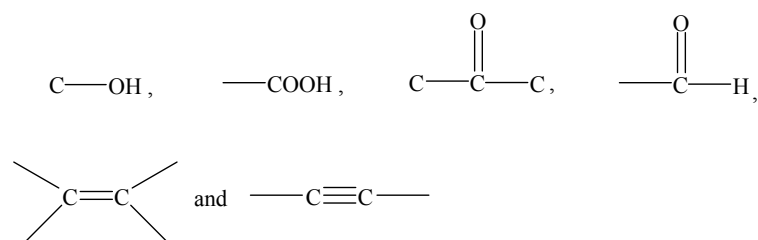
### A.1 Determination of Structure (5h)

A.1.1 State that the structure of a compound can be determined by using information from a variety of spectroscopic and chemical techniques. 1

Students should realize that information from only one technique is usually insufficient to determine or confirm a structure.

A.1.2 Describe and explain how information from an infrared spectrum can be used to identify functional groups in a compound. 2, 3

Restrict this to using infrared spectra to show the presence of the functional groups:



and to match the fingerprint region to a known spectrum.

A.1.3 Describe and explain how information from a mass spectrum can be used to determine the structure of a compound. 2, 3

Restrict this to using mass spectra to determine the relative molecular mass of a compound and to identify simple fragments, for example:

- $(M_r - 15)^+$  loss of  $\text{CH}_3$
- $(M_r - 29)^+$  loss of  $\text{C}_2\text{H}_5$  or  $\text{CHO}$
- $(M_r - 31)^+$  loss of  $\text{CH}_3\text{O}$
- $(M_r - 45)^+$  loss of  $\text{COOH}$ .

A.1.4 Describe and explain how information from a  $^1\text{H}$  NMR spectrum can be used to determine the structure of a compound. 2, 3

Restrict this to using NMR spectra to determine the number of different environments in which hydrogen is found and the number of hydrogen atoms in each environment. Splitting patterns are not required.

A.1.5 Describe and explain the structure of benzene using chemical and physical evidence. 2, 3

Consider the special stability of the ring system (heat of combustion or hydrogenation of  $\text{C}_6\text{H}_6$  in comparison to that of cyclohexene, cyclohexadiene and cyclohexatriene), as well as benzene's tendency to undergo substitution rather than addition reactions.

A.S.		Obj
	<b>A.2 Rate Expression (3h)</b>	
<b>A.2.1</b>	Define the terms <i>rate constant</i> and <i>order of reaction</i> .	<b>1</b>
<b>A.2.2</b>	Derive the rate expression for a reaction from data. $\text{Rate} = k[\text{A}]^m[\text{B}]^n$ where $k$ = rate constant, $[\text{A}]$ = concentration of A in mol dm <sup>-3</sup> etc, $m$ and $n$ = integers, $m + n$ = overall order of the reaction.	<b>3</b>
<b>A.2.3</b>	Draw and analyse graphical representations for zero-, first- and second-order reactions.	<b>1, 3</b>
<b>A.2.4</b>	Define the term <i>half-life</i> and calculate the half-life for first-order reactions only.  The half-life should be calculated from graphs and by using the integrated form of the rate equation. The integrated rate equation for second-order reactions is not required.	<b>1, 2</b>
	<b>A.3 Reaction Mechanism (1h)</b>	
<b>A.3.1</b>	Define the terms <i>rate-determining step</i> , <i>molecularity</i> and <i>activated complex</i> .	<b>1</b>
<b>A.3.2</b>	Describe the relationship between mechanism, order, rate-determining step and activated complex.  Limit examples to one- or two-step reactions where the mechanism is known. Students should understand what an activated complex (transition state) is and how the order of a reaction relates to the mechanism.	<b>2</b>
	<b>A.4 Nucleophilic Substitution Reactions (2h)</b>	
<b>A.4.1</b>	Distinguish between <i>primary</i> , <i>secondary</i> and <i>tertiary halogenoalkanes</i> .	<b>2</b>
<b>A.4.2</b>	Describe and explain the S <sub>N</sub> 1 and S <sub>N</sub> 2 mechanisms in nucleophilic substitution.  Students must be able to draw a stepwise mechanism. Examples of nucleophiles should include -CN, -OH and NH <sub>3</sub> for each reaction type.	<b>2, 3</b>
<b>A.4.3</b>	Describe and explain the molecularity for the S <sub>N</sub> 1 and S <sub>N</sub> 2 mechanisms.  The predominant mechanism for tertiary halogenoalkanes is S <sub>N</sub> 1 and for primary halogenoalkanes it is S <sub>N</sub> 2. Both mechanisms occur for secondary halogenoalkanes.	<b>2, 3</b>
<b>A.4.4</b>	Describe how the rate of nucleophilic substitution in halogenoalkanes depends on both the identity of the halogen and whether the halogenoalkane is primary, secondary or tertiary.	<b>2</b>

A.S.		Obj
	<b>A.5 Acids, Bases and Buffers (4h)</b>	
<b>A.5.1</b>	State the expression for the ionic product constant of water ( $K_w$ ). $K_w = [\text{H}^+(\text{aq})][\text{OH}^-(\text{aq})] = 1.0 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ at 298 K, but this varies with temperature.	<b>1</b>
<b>A.5.2</b>	Deduce $[\text{H}^+(\text{aq})]$ and $[\text{OH}^-(\text{aq})]$ for water at different temperatures given $K_w$ values.	<b>3</b>
<b>A.5.3</b>	Define $pH$ , $pOH$ and $pK_w$ .	<b>1</b>
<b>A.5.4</b>	Calculate $[\text{H}^+(\text{aq})]$ , $[\text{OH}^-(\text{aq})]$ , $pH$ and $pOH$ from specified concentrations. The values of $[\text{H}^+(\text{aq})]$ or $[\text{OH}^-(\text{aq})]$ are directly related to the concentration of the acid or base.	<b>2</b>
<b>A.5.5</b>	State the equation for the reaction of any weak acid or weak base with water and hence derive the ionization constant expression. In general $\text{HA}(\text{aq}) \rightleftharpoons \text{H}^+(\text{aq}) + \text{A}^-(\text{aq})$ $\text{B}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{BH}^+(\text{aq}) + \text{OH}^-(\text{aq})$ (base hydrolysis) Then $K_a = \frac{[\text{H}^+(\text{aq})][\text{A}^-(\text{aq})]}{[\text{HA}(\text{aq})]}$ and $K_b = \frac{[\text{BH}^+(\text{aq})][\text{OH}^-(\text{aq})]}{[\text{B}(\text{aq})]}$ Examples used should involve the transfer of only one proton.	<b>1, 3</b>
<b>A.5.6</b>	State and explain the relationship between $K_a$ and $pK_a$ .	<b>1, 3</b>
<b>A.5.7</b>	Determine the relative strengths of acids or their conjugate bases from $K_a$ or $pK_a$ values.	<b>3</b>
<b>A.5.8</b>	Apply $K_a$ or $pK_a$ in calculations. Calculations can be performed using various forms of the acid ionization constant expression (see A.5.5). Students should state when approximations are used in equilibrium calculations. Use of the quadratic expression is not required.	<b>2</b>
<b>A.5.9</b>	Calculate the $pH$ of a specified buffer system. Calculations will involve the transfer of only one proton. Cross reference with 9.4.	<b>2</b>

## Option B: Medicines and Drugs

The aim of this option is to give students an understanding of how drugs and medicines 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 below or in 11.3.1), and should be able to distinguish between them. Memorizing of complex formulas is not required. Throughout the option, stress the contribution that science has made (and continues to make) toward maintaining and improving the health and well-being of the world's population.

A.S.	<i>Core Material—SL and HL</i>	Obj
	<b>B.1 Pharmaceutical Products (2h)</b>	
<b>B.1.1</b>	<p>List the effects of drugs and medicines.</p> <p>Generally a drug or medicine is any chemical which does one or more of the following:</p> <ul style="list-style-type: none"> <li>• alters incoming sensory sensations</li> <li>• alters mood or emotions</li> <li>• alters physiological state, including consciousness, activity level or coordination.</li> </ul> <p>Stress the importance of the body's natural healing processes and the placebo effect.</p>	<b>1</b>
<b>B.1.2</b>	<p>Outline the stages involved in research, development and testing of new pharmaceutical products.</p> <p>Refer to the Thalidomide case as an example of what can go wrong. The use of combinatorial chemistry is not required here, but is covered in B.8.4.</p>	<b>2</b>
<b>B.1.3</b>	<p>Describe the different methods of administering drugs.</p> <p>The four main methods are oral, rectal, inhalation and parenteral (by injection). Injections may be intravenous, intramuscular or subcutaneous.</p>	<b>2</b>
<b>B.1.4</b>	<p>Discuss the terms <i>lethal dosage</i> (<math>LD_{50}</math>), <i>tolerance</i> and <i>side effects</i>.</p> <p><math>LD_{50}</math> is the lethal dose required for 50% of the population.</p> <p>A person who develops tolerance requires a larger dose of a drug in order to achieve the effect originally obtained by a smaller dose. Stress that the difference between the main effect and side effects is relative. For example, morphine is often used as a pain killer with intestinal constipation being a side effect. For a person with diarrhoea the constipation induced becomes the main effect, with the pain relief a side effect. The risk:benefit ratio should be considered.</p>	<b>3</b>



A.S. *Core Material—SL and HL* Obj

## B.2 Antacids (1h)

**B.2.1** State and explain how excess acidity in the stomach can be reduced by the use of different bases. **1, 3**

Examples should include aluminium and magnesium compounds and sodium hydrogencarbonate. Students should be able to write balanced 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).

## B.3 Analgesics (3h)

**B.3.1** Describe and explain the different ways that analgesics prevent pain. **2, 3**

Mild analgesics function by intercepting the pain stimulus at the source, often by interfering with the production of substances (eg 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.

**B.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. 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, rarely, cause blood disorders and kidney damage. Overdosage can lead to serious liver damage, brain damage and even death.

**B.3.3** Compare the structures of morphine, codeine and the semi-synthetic opiate, heroin. **2**

Stress the simple modification to the structure of morphine which results in the semi-synthetic drug, heroin.

**B.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.

## B.4 Depressants (3h)

**B.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 and at extremely high doses it may cause death. Depressants are often described as anti-depressants because they relieve depression.

<b>A.S.</b>	<i>Core Material—SL and HL</i>	<b>Obj</b>
<b>B.4.2</b>	Discuss the social and physiological effects of the use and abuse of ethanol. Include effects on the family, cost to society and the short- and long-term health effects.	<b>3</b>
<b>B.4.3</b>	Describe and explain the techniques used for the detection of ethanol in the breath and in the blood or urine. Include potassium dichromate(VI) in the breathalyser, analysis of blood or urine by chromatography and absorption of infra-red radiation in the intoximeter.	<b>2, 3</b>
<b>B.4.4</b>	Describe the synergistic effects of ethanol with other drugs. Examples 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.	<b>2</b>
<b>B.4.5</b>	List other commonly used depressants and describe their structures. Limit this to a brief mention of the use of diazepam (Valium®), nitrazepam (Mogadon®) and fluoxetine hydrochloride (Prozac®).	<b>1, 2</b>

## B.5 Stimulants (2.5h)

<b>B.5.1</b>	List the physiological effects of stimulants.	<b>1</b>
<b>B.5.2</b>	Compare amphetamines and adrenaline. Amphetamines and adrenaline are chemically similar in that both derive from the phenylethylamine structure. Amphetamines mimic the effects of adrenaline and are known as sympathomimetic drugs.	<b>2</b>
<b>B.5.3</b>	Discuss the short- and long-term effects of nicotine consumption. <ul style="list-style-type: none"> <li>• Short-term effects: increased heart rate and blood pressure and reduction in urine output, as well as stimulating effects.</li> <li>• Long-term effects: increased risk of heart disease, coronary thrombosis and peptic ulcers. Discuss also the addictive properties of nicotine and the further risks associated with smoking tobacco.</li> </ul>	<b>3</b>
<b>B.5.4</b>	Describe the effects of caffeine and compare its structure with that of nicotine. 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.	<b>2</b>

## B.6 Antibacterials (2h)

<b>B.6.1</b>	Outline the historical development of penicillins. Include the discovery by Fleming and the development by Florey and Chain.	<b>2</b>
<b>B.6.2</b>	Compare <i>broad-spectrum</i> and <i>narrow-spectrum</i> antibiotics.	<b>2</b>

<b>A.S.</b>	<i>Core Material—SL and HL</i>	<b>Obj</b>
<b>B.6.3</b>	<p>Explain how penicillins work and discuss the effects of modifying the side chain.</p> <p>Penicillins work by interfering with the chemicals that bacteria need to form normal cell walls. Modifying the side chain results in penicillins which are more resistant to the penicillinase enzyme.</p>	<b>3</b>
<b>B.6.4</b>	<p>Discuss and explain the effect overprescription of penicillins has, and the use of penicillins in animal feedstock.</p>	<b>3</b>
<b>B.7 Antivirals (1.5h)</b>		
<b>B.7.1</b>	<p>State how viruses differ from bacteria.</p>	<b>1</b>
<b>B.7.2</b>	<p>Describe the different ways in which antiviral drugs work.</p> <p>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.</p>	<b>2</b>
<b>B.7.3</b>	<p>Discuss the difficulties associated with solving the AIDS problem.</p> <p>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.</p>	<b>3</b>

A.S. *Extension Material—HL only* Obj

## B.8 Stereochemistry in Drug Action and Design (3h)

- B.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. The anti-cancer drug cisplatin is a good example.
- B.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, eg Thalidomide. One enantiomer of Thalidomide alleviates morning sickness in pregnant women, whilst the other enantiomer causes deformities in the limbs of the fetus.
- B.8.3** 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.
- B.8.4** Explain the use of combinatorial 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” (for example the “mix and split” process whereby polypeptides can be made by every combination of amino acids, using polystyrene resin beads). Stress the importance of solid phase chemistry.

## B.9 Anesthetics (2h)

- B.9.1** Compare local and general anesthetics in terms of their mode of action. **2**
- B.9.2** Compare the structures and effects of cocaine, procaine and lidocaine. **2**
- B.9.3** Discuss the advantages and disadvantages of nitrous oxide, ethoxyethane, trichloromethane, cyclopropane and halothane. **3**  
 Nitrous oxide is not very potent, trichloromethane leads to liver damage, ethoxyethane and cyclopropane are highly flammable. Halothane (2-bromo-2-chloro-1,1,1-trifluoroethane) is widely used but is potentially harmful to the ozone layer.
- B.9.4** Calculate the partial pressures of component gases in an anesthetic mixture. **2**  
 Knowledge of how to use Dalton's law of partial pressures is required. Students are not expected to state the law.

A.S.	<i>Extension Material—HL only</i>	Obj
<b>B.10 Mind-altering drugs (2h)</b>		
<b>B.10.1</b>	Describe the effects of lysergic acid diethylamide (LSD), mescaline, psilocybin and tetrahydrocannabinol (THC).	<b>2</b>
<b>B.10.2</b>	Discuss the structural similarities and differences between LSD, mescaline and psilocybin. Stress the similarity of all three drugs and compare them to the indole ring.	<b>3</b>
<b>B.10.3</b>	Discuss the arguments for and against the legalization of cannabis. Arguments for legalization include the ability of cannabis to offer relief for certain diseases. Arguments against legalization include the possible harmful effects and the possibility of cannabis users moving on to harder drugs.	<b>3</b>

## Option C: Human Biochemistry

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 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 will be expected to recognize functional groups and types of bonding within molecules. Structures of some important biological molecules are given in the data booklet.

A.S.	<i>Core Material—SL and HL</i>	Obj
	<b>C.1 Diet (2h)</b>	
C.1.1	Describe what the human body requires for a healthy diet. Students should recognize the importance of a balanced diet, including minimum requirements and the need for essential minerals.	2
C.1.2	Calculate the calorific value of a food from enthalpy of combustion data.	2
C.1.3	Discuss the benefits and concerns of using genetically modified (GM) foods. Crops and animals can be modified to provide more food, be more resistant to disease and be more tolerant to heavy metals. Concerns include the release of genetically modified organisms into the environment where they could spread and compete with the naturally occurring varieties.	3
	<b>C.2 Proteins (3h)</b>	
C.2.1	State the basic structure of 2-amino acids. There are approximately 20 common 2-amino acids ( $\alpha$ -amino acids) found in organisms. 2-amino acids have the following formula.	1
	$\begin{array}{c} \text{H} \\   \\ \text{H}_2\text{N} - \text{C} - \text{COOH} \\   \\ \text{R} \end{array}$	
C.2.2	Describe the condensation reaction of amino acids to form polypeptides.	2
C.2.3	Explain how proteins can be analysed by chromatography and electrophoresis. To use either of these techniques the peptide bonds in the proteins must first be hydrolysed to release individual amino acids. Include the use of $R_f$ values in paper chromatography. Given isoelectric points, students should be able to determine a suitable pH to achieve good separation in electrophoresis.	3

<b>A.S.</b>	<i>Core Material—SL and HL</i>	<b>Obj</b>
<b>C.2.4</b>	Describe and explain the primary, secondary, tertiary and quaternary structure of proteins.	<b>2, 3</b>
<b>C.2.5</b>	List the major functions of proteins in the body. These are structure, biological catalysts (enzymes) and energy sources.	<b>1</b>
<b>C.3 Carbohydrates (2.5h)</b>		
<b>C.3.1</b>	Describe the structural features of monosaccharides. Monosaccharides contain a carbonyl group (C=O) and at least two -OH groups, and have the empirical formula CH <sub>2</sub> O.	<b>2</b>
<b>C.3.2</b>	Describe the straight-chain formula of glucose and the structural difference between α-glucose and β-glucose.	<b>2</b>
<b>C.3.3</b>	Describe the condensation of monosaccharides to form disaccharides and polysaccharides. Limit examples to: <ul style="list-style-type: none"> <li>• disaccharides—lactose and sucrose</li> <li>• polysaccharides—starch.</li> </ul>	<b>2</b>
<b>C.3.4</b>	List the major functions of polysaccharides in the body. These are energy sources, energy reserves (eg glycogen) and precursors for other biologically important molecules.	<b>1</b>
<b>C.4 Fats (2.5h)</b>		
<b>C.4.1</b>	Describe the composition of fats and oils.	<b>2</b>
<b>C.4.2</b>	Describe the difference in structure between saturated and unsaturated fats, and explain the difference in their melting points.	<b>2, 3</b>
<b>C.4.3</b>	Calculate the number of C=C double bonds in an unsaturated fat using addition reactions. The number of C=C bonds can be determined from the number of moles of I <sub>2</sub> which add to one mole of fat.	<b>2</b>
<b>C.4.4</b>	Describe the hydrolysis of fats to form soaps and the action of soaps.	<b>2</b>
<b>C.4.5</b>	List the major functions of fats in the body. These are energy sources, insulation and cell membranes.	<b>1</b>

A.S. *Core Material—SL and HL* Obj

## C.5 Vitamins (2.5h)

C.5.1	Define the term <i>vitamin</i> .	1
C.5.2	Deduce whether a vitamin is water or fat soluble from its structure.	3
C.5.3	Describe the structures and major functions of retinol (vitamin A), calciferol (vitamin D) and ascorbic acid (vitamin C). <ul style="list-style-type: none"> <li>• Vitamin A—required for the production of rhodopsin (light-sensitive material in the rods of the retina). Deficiency can cause night blindness and xerophthalmia.</li> <li>• Vitamin D—required for the uptake of calcium from food. Deficiency can cause weak bones (rickets).</li> <li>• Vitamin C—essential in the production of collagen: the protein of connective tissue. Deficiency can cause scorbutus (scurvy).</li> </ul>	2
C.5.4	Describe the effects of food processing on the vitamin content of food. Most vitamins are unstable at higher temperatures so will be affected by prolonged cooking.	2

## C.6 Hormones (2.5h)

C.6.1	Outline the production and roles of hormones in the body. Hormones are chemical messengers produced in glands controlled by the pituitary gland, which in turn is controlled by the hypothalamus. Limit examples of production and roles to adrenalin, thyroxine, insulin and sex hormones.	2
C.6.2	Compare the structures of cholesterol and the sex hormones. Stress the common steroid backbone but the difference in functional groups (see the data booklet).	2
C.6.3	Describe the mode of action of oral contraceptives.	2
C.6.4	Outline the use and abuse of steroids.	2



A.S.	<i>Extension Material—HL only</i>	Obj
<b>C.7 Enzymes (3h)</b>		
<b>C.7.1</b>	Outline the basic characteristics of enzymes. Include: <ul style="list-style-type: none"> <li>• enzymes are proteins</li> <li>• activity depends on tertiary and quaternary structure</li> <li>• the specificity of enzyme action.</li> </ul>	<b>2</b>
<b>C.7.2</b>	Determine $V_{\max}$ and the value of the Michaelis constant ( $K_m$ ) by graphical means.	<b>3</b>
<b>C.7.3</b>	Describe the significance of $V_{\max}$ and $K_m$ .	<b>2</b>
<b>C.7.4</b>	Describe the concept of the active site in enzyme structure.	<b>2</b>
<b>C.7.5</b>	Explain competitive inhibition and non-competitive inhibition.	<b>3</b>
<b>C.7.6</b>	State and explain the effects of heavy metal ions, extremes of temperature and pH changes on enzyme activity.	<b>1, 3</b>
<b>C.7.7</b>	Describe the uses of enzymes in biotechnology. Possible examples include proteases in biological detergents, glucose isomerase converting glucose to fructose and streptokinase in breaking down blood clots.	<b>2</b>
<b>C.8 Nucleic Acids (2h)</b>		
<b>C.8.1</b>	Describe the structure of nucleotides and their condensation polymers (nucleic acids). A nucleotide contains a phosphate group, a pentose sugar group and an organic base. Students should be able to recognize, but need not recall, the structures of the five nucleotide bases: adenine, cytosine, guanine, thymine and uracil.	<b>2</b>
<b>C.8.2</b>	Describe the double helical structure of DNA. Students should be able to describe the hydrogen bonding between specific pairs of nucleotide bases.	<b>2</b>
<b>C.8.3</b>	Outline the role of DNA as the repository of genetic information, including the triplet code.	<b>2</b>
<b>C.8.4</b>	Describe the principles and uses of DNA profiling. Include forensic uses and paternity cases.	<b>2</b>

A.S.	<i>Extension Material—HL only</i>	Obj
<b>C.9 Metal Ions in Biological Systems (2h)</b>		
<b>C.9.1</b>	Explain that different metal ions fulfill different roles in the body due to their different chemical properties. Emphasize differences in charge density, redox properties and complex ion formation.	<b>3</b>
<b>C.9.2</b>	Describe the importance of the difference in Na <sup>+</sup> and K <sup>+</sup> concentrations across the cell membrane. Explain active transport using the Na <sup>+</sup> /K <sup>+</sup> pump as an example.	<b>2</b>
<b>C.9.3</b>	Outline the importance of copper ions in electron transport and iron ions in oxygen carriers. Use cytochromes and hemoglobin as examples.	<b>2</b>

## Option D: Environmental Chemistry

The effect of human activity on the environment has become increasingly global, with the effects of chemicals in air and water spanning political and natural borders. An understanding of this impact is essential within and beyond the study of chemistry.

**A.S.** *Core Material—SL and HL* **Obj**

### D.1 Primary Air Pollution (3h)

**D.1.1** Describe the sources of carbon monoxide, oxides of nitrogen and sulfur, particulates and hydrocarbons in the atmosphere. **2**

Include both natural and man-made sources. Balanced equations should be used where possible.

**D.1.2** Outline the effects of primary air pollution on health. **2**

Students should be familiar with at least one harmful effect of each of the substances in D.1.1.

**D.1.3** Discuss methods for the reduction of primary air pollution. **3**

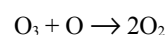
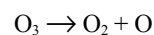
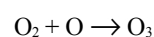
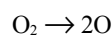
Limit this to the following methods:

- CO—catalytic converters
- NO<sub>x</sub>—catalytic converters, lean burn engines, recirculation of exhaust gases
- SO<sub>x</sub>—alkaline scrubbing, removal of sulfur-containing compounds from coal and oil, limestone-based fluidized beds
- Particulates—electrostatic precipitation
- Hydrocarbons—catalytic converters.

### D.2 Ozone Depletion (2h)

**D.2.1** Describe the formation and depletion of ozone by natural processes. **2**

Refer to the following equations.



**D.2.2** List the pollutants, and their sources, that cause the lowering of ozone concentration. **1**

Consider chlorofluorocarbons (CFCs) and nitrogen oxides.

**D.2.3** State the environmental effects of ozone depletion. **1**

Include the increased incidence of skin cancer and eye cataracts, and the suppression of plant growth.

**A.S.** *Core Material—SL and HL* **Obj**

- D.2.4** 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.

### **D.3 Greenhouse Effect and Global Warming (2h)**

- D.3.1** Describe the *greenhouse effect*. **2**  
 Greenhouse gases allow the passage of incoming solar radiation but absorb the heat radiation from the Earth, maintaining a mean global temperature. The greenhouse effect is a normal and necessary condition for life on Earth.

- D.3.2** List the main greenhouse gases and their sources, and discuss their relative effects. **1, 3**  
 The greenhouse gases to be considered are CH<sub>4</sub>, H<sub>2</sub>O, CO<sub>2</sub> and N<sub>2</sub>O, which have natural and man-made origins. Their effects depend on their abundance and their ability to absorb heat radiation.

- D.3.3** Discuss the influence of increasing amounts of greenhouse gases on global warming. **3**  
 Effects include climate change, thermal expansion of the oceans and melting of the polar ice caps.

- D.3.4** Outline the influence of particulates on the Earth's surface temperature. **2**  
 Particulates can lower the temperature by reflecting sunlight.

### **D.4 Acid Rain (1.5h)**

- D.4.1** State what is meant by *acid rain* and outline its origins. **1, 2**  
 Rain is naturally acidic because of dissolved CO<sub>2</sub>; acid rain has a pH of less than 5.6.  
 Acid rain is caused by oxides of sulfur and nitrogen. Students should know the equations for the burning of sulfur and nitrogen and for the formation of H<sub>2</sub>SO<sub>3</sub> and H<sub>2</sub>SO<sub>4</sub>.

- D.4.2** Discuss the environmental effects of acid rain and possible methods to counteract them. **3**

### **D.5 Water Suitable for Drinking (3h)**

- D.5.1** Discuss the demand for fresh water and reasons for the inadequacy of its supply. **3**  
 Only a small fraction of the Earth's water supply is fresh water. Of this fresh water, over 80% is in the form of ice caps and glaciers. Water is mainly used for agriculture and industry.

<b>A.S.</b>	<i>Core Material—SL and HL</i>	<b>Obj</b>
<b>D.5.2</b>	Compare the advantages and disadvantages of treating drinking water with chlorine and ozone. Include cost, retention time and formation of chlorinated organic compounds.	<b>2</b>
<b>D.5.3</b>	Discuss ways to obtain fresh water from sea water using distillation, reverse osmosis and ion exchange.	<b>3</b>
<b>D.5.4</b>	Discuss ways to reduce the amount of water used and to recycle water.	<b>3</b>
<b>D.6 Dissolved Oxygen in Water (2h)</b>		
<b>D.6.1</b>	Outline the importance of dissolved oxygen in water.	<b>2</b>
<b>D.6.2</b>	Outline biological oxygen demand (BOD) as a measure of oxygen-demanding wastes in water. Refer to the amount of oxygen needed to decompose waste matter over a definite period of time. No distinction between biological and biochemical oxygen demand will be made.	<b>2</b>
<b>D.6.3</b>	Distinguish between aerobic and anaerobic decomposition of organic material in water.	<b>2</b>
<b>D.6.4</b>	Describe the influence of sewage, detergents and fertilizers on the growth of aquatic plants, and the effect of their subsequent decomposition on oxygen concentration (eutrophication). The additional nitrogen and phosphorus compounds encourage growth of aquatic plants often in the form of “algal blooms” or, in coastal areas, “red tides”.	<b>2</b>
<b>D.6.5</b>	Discuss the effect of heat on dissolved oxygen and metabolism in water.	<b>3</b>
<b>D.7 Waste Water Treatment (1.5h)</b>		
<b>D.7.1</b>	Outline the primary and secondary stages of sewage treatment and state what is removed during each stage. For primary treatment filtration, flocculation and sedimentation should be covered. For secondary treatment mention the use of oxygen and bacteria (eg the activated sludge process).	<b>2</b>
<b>D.7.2</b>	Discuss the increasing use of tertiary treatment. Include removal of heavy metals and phosphates by chemical precipitation and nitrates by chemical or biological processes.	<b>3</b>

A.S. *Extension Material—HL only* **Obj**

## D.8 Smog (2h)

- D.8.1** Compare reducing and photochemical smog. **2**
- D.8.2** Describe the catalytic effect of particulates and nitrogen oxides on the oxidation of sulfur dioxide. **2**
- Particulates and SO<sub>2</sub>—heterolytic catalysis to form SO<sub>3</sub>
  - NO<sub>x</sub> + SO<sub>2</sub>—free radical catalysis to form SO<sub>3</sub>
- D.8.3** Outline the formation of secondary pollutants in photochemical smog. **2**
- Treatment should be restricted to the formation of radicals from the reaction of nitrogen oxides with sunlight and the reaction of these radicals with hydrocarbons, leading to the formation of aldehydes and peroxyacylnitrates (PANs).
- D.8.4** Discuss the formation of thermal inversions and their effects on air quality. **3**

## D.9 Ozone Depletion (2h)

- D.9.1** Explain the dependence of O<sub>2</sub> and O<sub>3</sub> dissociation on the wavelength of light. **3**
- $\lambda = 242 \text{ nm}$        $\lambda = 330 \text{ nm}$   
 $\text{O}_2 \rightarrow 2\text{O}$        $\text{O}_3 \rightarrow \text{O}_2 + \text{O}$
- The energy needed should be related to the bonding in O<sub>2</sub> and O<sub>3</sub>.
- D.9.2** Describe the steps in the catalysis of O<sub>3</sub> depletion by CFCs and NO<sub>x</sub>. **2**
- For example:
- $\text{CCl}_2\text{F}_2 \rightarrow \text{CClF}_2 + \text{Cl}$   
 $\text{Cl} + \text{O}_3 \rightarrow \text{ClO} + \text{O}_2$   
 $\text{ClO} + \text{O} \rightarrow \text{O}_2 + \text{Cl}$   
 NO<sub>x</sub> similar pathway
- D.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.
- D.9.4** Describe the properties required for sun-screening compounds. **2**
- Such compounds should contain conjugated double bonds, eg para-aminobenzoic acid (PABA), so that absorption of ultraviolet light is possible.

## D.10 Toxic Substances in Water (3h)

- D.10.1** Discuss the different approaches to expressing toxicity. **3**
- Include the advantages and disadvantages of LD<sub>50</sub> (lethal dose in 50% of the population) and maximum daily tolerance.

<b>A.S.</b>	<i>Extension Material—HL only</i>	<b>Obj</b>
<b>D.10.2</b>	State the principal toxic types of chemicals that may be found in polluted water.  Include heavy metals, pesticides, dioxins and polychlorinated biphenyls (PCBs).	<b>1</b>
<b>D.10.3</b>	Outline the sources, health and environmental effects of cadmium, mercury and lead compounds. <ul style="list-style-type: none"><li>• Cadmium—metal plating, some rechargeable batteries, pigments</li><li>• Mercury—seed dressing to prevent mould, batteries</li><li>• Lead—some kinds of paint, as tetraethyl lead in gasoline</li></ul>	<b>2</b>
<b>D.10.4</b>	Describe the sources and possible health effects of nitrates in drinking water.  Include the formation of carcinogenic nitrosamines and a possible link to the formation of nitrites leading to oxygen depletion in the body.	<b>2</b>

## Option E: Chemical Industries

Chemical industries have a major place in the world economy. The industrial revolution, which commenced in the 18th century, was also a materials revolution that started with the large-scale extraction of iron. This continues to the present day with the extraction of other metals, the production of bulk chemicals such as fertilizers, the oil and plastics industries, and the speciality chemicals industry producing medicines, enzymes, catalysts and additives. When teaching this option, emphasize chemical reactions and their relevant equations.

**A.S.** *Core Material—SL and HL* **Obj**

### E.1 Initial Overview (2h)

- |              |   |          |
|--------------|---|----------|
| <b>E.1.1</b> | Outline the abundance, occurrence and availability of sources of materials.<br>A qualitative picture only is intended. Include minerals (especially metals and their ores), petroleum and biotechnology.  | <b>2</b> |
| <b>E.1.2</b> | Identify the factors that influence the establishment of a chemical industry in a particular location.<br>Include sources of suitable raw materials, energy supply, transport to and from the site, availability of investment, skills and labour and existence of markets for the product. | <b>2</b> |
| <b>E.1.3</b> | Outline the division of the industry into both intermediates and consumer products.   | <b>2</b> |
| <b>E.1.4</b> | State the increasing importance of biotechnology in chemical manufacture.<br>Examples can be found in the manufacture of insulin and vitamins.  | <b>1</b> |

### E.2 Principles of Extraction and Production of Metals (2h)

- |              |   |          |
|--------------|---|----------|
| <b>E.2.1</b> | Outline the principles used in the physical separation of materials.  | <b>2</b> |
| <b>E.2.2</b> | Discuss the chemical principles involved in the extraction of metals from their ores.<br>Relate this to chemical reactions based on the reactivity series (see 10.2), but also include factors such as chemical conversion (iron), electrolytic conversion (aluminium) and energy requirements. | <b>3</b> |



A.S. *Core Material—SL and HL* Obj

### E.3 Iron and Aluminium (4h)

- E.3.1** State the main sources of iron. **1**  
Include iron ores and scrap (recycled) iron.
- E.3.2** Explain the reactions that occur in the blast furnace. **3**  
Include the role of coke, limestone and the formation of slag. The relevant equations should be considered.
- E.3.3** Explain the conversion of iron into steel using the basic oxygen converter. **3**
- E.3.4** Describe the properties and uses of steel as an alloy of iron. **2**  
Consider carbon steels and alloy steels (including stainless steel).
- E.3.5** Discuss the production of aluminium by electrolysis of alumina in molten cryolite. **3**  
Explain the need for cryolite as a solvent because of the very high melting point of  $\text{Al}_2\text{O}_3$ . Account for the materials used in the construction of the cell and the choice of electrodes.
- E.3.6** Describe the main properties and uses of aluminium. **2**  
Include the properties of the aluminium oxide coating and the resulting resistance to corrosion. Compare with the properties and uses of iron and steel.
- E.3.7** Discuss the environmental impact of iron and aluminium production. **3**  
Include the effects of mining the ore, siting the plant, energy costs and recycling the metals.

### E.4 The Oil Industry (4h)

- E.4.1** Outline the importance of oil as a source of chemical feedstock. **2**  
Although only about 10% of the refined products of crude oil are used as chemical feedstock, it is still the most significant source of organic chemicals. Compare the use of oil as an energy source and as a chemical feedstock.
- E.4.2** Outline the removal of sulfur from crude oil. **2**  
Refer to the need for this removal and the use of sulfur in the manufacture of sulfuric acid.
- E.4.3** Describe the fractional distillation of oil. **2**  
Compare simple distillation with fractional distillation. Students should understand that the vapour phase is always richer in the more volatile component. No calculations using Raoult's law or Dalton's law are required.
- E.4.4** Describe cracking and its products. **2**  
Include thermal cracking (both steam and catalytic) and hydrocracking.

<b>A.S.</b>	<i>Core Material—SL and HL</i>	<b>Obj</b>
<b>E.4.5</b>	Describe reforming processes and their products. Include isomerization, cyclization and aromatization. Reforming is important in some countries as a source of hydrogen for the Haber process (see 8.2.5).	<b>2</b>
<b>E.4.6</b>	State the uses of refinery products as feedstock for the organic chemical industry. Refinery products are used as raw materials in the manufacture of solvents, plastics, pesticides, food additives, pharmaceuticals, detergents, cosmetics and dyes.	<b>12</b>
 <b>E.5 Polymers (3h)</b>  		
Cross reference with 11.3.		
<b>E.5.1</b>	Describe how the properties of polymers depend on their structural features. Include the: <ul style="list-style-type: none"> <li>• different amounts of branching in low- and high-density polyethene</li> <li>• different positions of the methyl groups in isotactic and atactic polypropene</li> <li>• formation of cross-links in phenol-methanal plastics (compare thermoplastics and thermosets).</li> </ul>	<b>2</b>
<b>E.5.2</b>	Describe ways of modifying the properties of polymers. Include the use of: <ul style="list-style-type: none"> <li>• plasticizers in polyvinyl chloride</li> <li>• volatile hydrocarbons in the formation of expanded polystyrene</li> <li>• air in the manufacture of polyurethane foams.</li> </ul>	<b>2</b>
<b>E.5.3</b>	Discuss the advantages and disadvantages of polymer use. Consider strength, density, insulation, lack of reactivity, use of natural resources, disposal and biodegradability. Use polyethene, polyurethane foams, polyvinyl chloride and phenol-methanal plastics as examples.	<b>3</b>

A.S.	<i>Extension Material—HL only</i>	Obj
<b>E.6 Silicon (1.5h)</b>		
<b>E.6.1</b>	Describe the extraction and purification of silicon. Include zone refining.	<b>2</b>
<b>E.6.2</b>	Compare the electrical conductivity of a semiconductor with that of metals and non-metals. Relate this to the ionization energies of semiconductors compared to metals and non-metals.	<b>2</b>
<b>E.6.3</b>	Explain the doping of silicon to produce n-type and p-type semiconductors. In p-type semiconductors, electron holes in the crystal are created by introducing a small percentage of a group 3 element (eg In, Ga). In n-type semiconductors inclusion of a group 5 element (eg As) provides extra electrons.	<b>3</b>
<b>E.7 Ellingham Diagrams (1.5h)</b>		
<b>E.7.1</b>	Analyse Ellingham diagrams to predict the feasibility of reducing metal oxides. Refer also to the Ellingham diagram in the data booklet.	<b>3</b>
<b>E.8 Mechanisms in the Organic Chemicals Industry (2h)</b>		
<b>E.8.1</b>	Compare and discuss the mechanisms of thermal and catalytic cracking. Thermal cracking involves a free-radical mechanism whereas catalytic cracking has an anionic mechanism.	<b>2, 3</b>
<b>E.8.2</b>	Describe the mechanism involved in the manufacture of low-density polyethene. This is a free-radical mechanism.	<b>2</b>
<b>E.8.3</b>	Outline the use of Ziegler–Natta catalysts in the manufacture of high-density polyethene. The mechanism is ionic but details are not required.	<b>2</b>
<b>E.9 The Chlor-alkali Industry (2h)</b>		
<b>E.9.1</b>	Discuss the production of chlorine by the electrolysis of sodium chloride. Explain why an electrolytic process is required and why the diaphragm cell is preferable to the mercury cathode cell.	<b>3</b>

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<b>A.S.</b>	<i>Extension Material—HL only</i>	<b>Obj</b>
<b>E.9.2</b>	Outline the importance of the products of this process. The process produces sodium hydroxide with chlorine and hydrogen as by-products.	<b>2</b>
<b>E.9.3</b>	Discuss the environmental impact of this process. Include reasons why the diaphragm cell has replaced the mercury-cathode cell in many parts of the world, and that knowledge of the effect on the ozone layer has led to reservations about the use of chlorine-containing solvents.	<b>3</b>

## Option F: Fuels and Energy

The development of human society has been directly related to the ability to use and manipulate fuels for energy production. This option considers the chemical principles and environmental issues associated with the use of fossil fuels, and nuclear and solar energy.

A.S.	<i>Core Material—SL and HL</i>	Obj
	<b>F.1 Energy Sources (1h)</b>	
<b>F.1.1</b>	State desirable characteristics of energy sources. These include energy released at reasonable rates (neither too fast nor too slow) and minimal pollution.	<b>1</b>
<b>F.1.2</b>	Outline current and potential energy sources. Consider fossil fuels, nuclear (fission and fusion), electrochemical cells, solar energy and alternative sources (eg wind, tidal, geothermal).	<b>2</b>
	<b>F.2 Fossil Fuels (4h)</b>	
<b>F.2.1</b>	Describe the formation and characteristics of coal, oil and natural gas.	<b>2</b>
<b>F.2.2</b>	Determine and compare the enthalpies of combustion of coal, oil and natural gas. Calculations could be made using enthalpies of formation or from experimental data. Cross reference with 15.1.	<b>3, 2</b>
<b>F.2.3</b>	Outline the composition and characteristics of the crude oil fractions used for fuel. Students should have general, rather than specific, knowledge about the types of compounds found in each fraction, the boiling point range and the uses of the fractions.	<b>2</b>
<b>F.2.4</b>	Describe how the components of a hydrocarbon fuel relate to its octane rating. Octane rating is a measure of the ability of a fuel to resist “knocking” when burnt in a standard test engine. A fuel is rated relative to heptane (rating of 0) and 2,2,4-trimethylpentane (rating of 100). The role of lead additives in fuels and the role of aromatic compounds in unleaded fuels should be mentioned.	<b>2</b>
<b>F.2.5</b>	Explain the processes of coal gasification and liquification. Gasification produces synthesis gas and liquification produces liquid hydrocarbons. Relevant equations should be used. Advantages include the elimination of SO <sub>2</sub> pollution and the ease of transportation. The main disadvantage is the energy cost of the processes.	<b>3</b>

<b>A.S.</b>	<i>Core Material—SL and HL</i>	<b>Obj</b>
<b>F.2.6</b>	Describe how the burning of fossil fuels produces pollutants. The primary pollutants are CO, CO <sub>2</sub> , SO <sub>2</sub> , NO <sub>x</sub> , particulates (fly ash) and hydrocarbons.	<b>2</b>
<b>F.2.7</b>	Discuss the advantages and disadvantages of the different fossil fuels. Consider the cost of production and availability (reserves) as well as pollution.	<b>3</b>
<b>F.3 Nuclear Energy (4h)</b>		
<b>F.3.1</b>	Distinguish between nuclear reactions and chemical reactions. Emphasize that in nuclear reactions nuclei are converted to other nuclei, while in chemical reactions only valence electrons are involved and atoms do not change into other atoms.	<b>2</b>
<b>F.3.2</b>	Write balanced nuclear equations. Both the atomic number and mass number must be balanced.	<b>2</b>
<b>F.3.3</b>	Describe the nature of $\alpha$ , $\beta$ and $\gamma$ radiation. Compare the charge, mass, penetrating power and behaviour in an electric field.	<b>2</b>
<b>F.3.4</b>	State the concept of half-life. Half-life is independent of the amount of a radioactive sample.	<b>1</b>
<b>F.3.5</b>	Apply the concept of half-life in calculations. Restrict this to whole numbers of half-lives.	<b>2</b>
<b>F.3.6</b>	Compare nuclear fission and nuclear fusion.	<b>2</b>
<b>F.3.7</b>	Explain the functions of the main components of a nuclear power plant. Include the fuel, moderator, control rods, coolant and shielding. The materials used for the different components should be considered.	<b>3</b>
<b>F.3.8</b>	Discuss the differences between conventional power generation and nuclear reactors.	<b>3</b>
<b>F.3.9</b>	Discuss the concerns about safety in nuclear power plants. Consider the effects of: <ul style="list-style-type: none"> <li>• escape of radioactive materials at various stages</li> <li>• radioactive contamination of ordinary materials</li> <li>• escape of sodium from a breeder reactor</li> <li>• loss of control of a nuclear reaction</li> <li>• nuclear waste.</li> </ul>	<b>3</b>

A.S. *Core Material—SL and HL* Obj

## F.4 Solar Energy (3h)

- F.4.1** State how solar energy can be converted to other forms of energy. **1**  
Include chemical energy (biomass), thermal energy (passive and active methods) and electricity generation (direct and indirect methods).
- F.4.2** Describe the role of photosynthesis in converting solar energy to other forms of energy. **2**  
Products of photosynthesis are used for food, primary fuels and conversion to other fuels, eg ethanol. The equation for photosynthesis is required.
- F.4.3** Discuss how biomass can be converted to energy. **3**  
Include:  
  - direct combustion
  - combustion of waste materials from other processes
  - production of biogas
  - production and use of ethanol.Mention the advantages and disadvantages of each method. The equation for the formation of ethanol from glucose is required.
- F.4.4** Outline the principles of using solar energy for space heating. **2**  
Examples should include storage of heat by water and rocks.
- F.4.5** Discuss the methods for converting solar energy into electricity. **3**  
Include parabolic mirrors and photovoltaic cells. Consider the advantages and disadvantages of each method.

## F5 Electrochemical Energy (3h)

- F.5.1** Explain the workings of lead–acid storage batteries and dry cell (zinc–carbon and alkaline) batteries. **3**  
Include the relevant half-equations.
- F.5.2** Identify the factors that affect the voltage and power available from a battery. **2**  
Voltage depends primarily on the nature of the materials used while power depends on their quantity.
- F.5.3** Explain how a hydrogen–oxygen fuel cell works. **3**  
Include the relevant half-equations.

A.S. *Extension Material—HL only* Obj

## F.6 Storage of Energy and Limits of Efficiency (1h)

F.6.1 Discuss the advantages and disadvantages of energy storage schemes. 3  
 Include both pumped storage and conversion to hydrogen.

## F.7 Nuclear Stability (2h)

F.7.1 Predict nuclear stability and mode of decay from neutron to proton ratios. 3  
 Students should be familiar with the belt of stability in the graph of number of neutrons against number of protons for various stable nuclei.

F.7.2 Calculate the energy released in a nuclear reaction. 2

F.7.3 Define and determine *mass defect* and *nuclear binding energy*. 1, 3  
 Nuclear binding energy is a quantitative measure of nuclear stability. The graph of nuclear binding energy per nucleon against mass number should be used to explain why the products are more stable than the reactants in both nuclear fission and nuclear fusion, and consequently why both processes are exothermic.

## F.8 Radioactive Decay (2h)

F.8.1 Calculate the change in activity over a period of time. 2  
 See the data booklet for the integrated form of the rate equation.

F.8.2 Describe the different types of nuclear waste, their characteristics and their sources. 2

F.8.3 Compare the storage and disposal methods for different types of nuclear waste. 2

## F.9 Photovoltaics (2h)

F.9.1 State that silicon and germanium are semiconductors. 1

F.9.2 Compare the electrical conductivity of a semiconductor with the conductivity of metals and non-metals. 2  
 Relate this to the ionization energies of semiconductors compared to metals and non-metals.

F.9.3 Explain the doping of silicon to produce n-type and p-type semiconductors. 3  
 In p-type semiconductors, electron holes in the crystal are created by introducing a small percentage of a group 3 element (eg In, Ga). In n-type semiconductors inclusion of a group 5 element (eg As) provides extra electrons.

F.9.4 Describe how sunlight interacts with semiconductors. 2  
 Photons interact with crystals to release electrons.



## Option G: Modern Analytical Chemistry

Emphasize problem solving and using the information gained from one or more techniques throughout this option. Students should understand the chemical principles behind each analytical technique but are not expected to have a detailed knowledge of the instruments themselves.

A.S.		Obj
	<b>G.1 Analytical Techniques (2h)</b>	
<b>G.1.1</b>	State the reasons for using analytical techniques.  Analytical techniques are used in structure determination, in analysis of composition of substances and to determine purity.	<b>1</b>
<b>G.1.2</b>	Outline the information that can be obtained from analytical techniques, singly or in combination.  Students should be able to draw upon a range of contexts to illustrate the information obtained by using a technique or range of techniques. <ul style="list-style-type: none"> <li>• Visible and ultraviolet (uv) spectroscopy—assaying of metal ions, organic structure determination and detection of drug metabolites</li> <li>• Infrared (ir) spectroscopy—organic structure determination, information on strengths of bonds, secondary structure of proteins and measuring degree of unsaturation of oils and fats</li> <li>• Mass spectrometry—organic structure determination and isotopic dating (eg <math>^{14}\text{C}</math> dating)</li> <li>• Gas chromatography-mass spectrometry (GC-MS)—drug and food testing and forensic science</li> </ul>	<b>2</b>
	<b>G.2 Principles of Spectroscopy (2h)</b>	
<b>G.2.1</b>	Describe the electromagnetic spectrum.  X-ray, uv, visible, ir and radio (including microwave) should be identified. Highlight the variation in wavelength, frequency and energy across the spectrum.	<b>2</b>
<b>G.2.2</b>	Distinguish between absorption and emission spectra and how each is produced.  Cross reference with 2.2.1.	<b>2</b>
<b>G.2.3</b>	Describe the atomic and molecular processes in which absorption of energy takes place.  Cross reference with 2.2. The description should cover vibrations, rotation and electronic transitions only.	<b>2</b>
<b>G.2.4</b>	Describe the operating principles of a double-beam infrared spectrometer.  A schematic diagram of a simple double-beam spectrometer is sufficient. This example is chosen to illustrate the general principles of how spectrometers operate. Mention could be made of modern methods of processing signals by Fourier transformation.	<b>2</b>

A.S.		Obj
	<b>G.3 Visible and Ultraviolet Spectroscopy (4h)</b>	
<b>G.3.1</b>	Describe the factors that affect the colour of transition metal complexes. Cross reference with 13.2.6. The factors are the identity of the metal (eg $\text{Mn}^{2+}$ , $\text{Fe}^{2+}$ ), oxidation number (eg $\text{Fe}^{2+}$ , $\text{Fe}^{3+}$ ) and the identity of the ligand. Limit this to octahedral complexes in aqueous solution.	<b>2</b>
<b>G.3.2</b>	Describe the effect of different ligands on the splitting of the d orbitals in transition metal complexes. The ligands should be limited to $\text{NH}_3$ , $\text{H}_2\text{O}$ and $\text{Cl}^-$ .	<b>2</b>
<b>G.3.3</b>	State that organic molecules containing a double bond absorb ultraviolet radiation. Refer to conjugated and delocalized systems: arenes, alkenes and natural products, eg chlorophyll.	<b>1</b>
<b>G.3.4</b>	Describe the effect of the conjugation of double bonds in organic molecules on the wavelength of the absorbed light. Retinol and phenolphthalein are suitable examples.	<b>2</b>
<b>G.3.5</b>	Predict whether or not a particular molecule will absorb ultraviolet or visible radiation.	<b>3</b>
<b>G.3.6</b>	State the Beer–Lambert law. $\log_{10} \frac{I_0}{I} = \epsilon lc$	<b>1</b>
<b>G.3.7</b>	Construct a calibration curve and use the Beer–Lambert law to determine the concentration of an unknown solution.	<b>3</b>
	<b>G.4 Infrared Spectroscopy (3h)</b>	
<b>G.4.1</b>	Describe what occurs at a molecular level during the absorption of infrared radiation by molecules. $\text{H}_2\text{O}$ , $-\text{CH}_2-$ , $\text{SO}_2$ and $\text{CO}_2$ are suitable examples. Stress the change in bond polarity as the vibrations (stretching and bending) occur.	<b>2</b>
<b>G.4.2</b>	State the relationship between wavelength and wavenumber. An inverse relationship exists (ie the wavenumber is the number of wavelengths that make up one cm). High wavenumber implies high energy.	<b>1</b>
<b>G.4.3</b>	Deduce the functional groups in an organic molecule from its infrared spectrum. Examples should contain up to three functional groups. Students are not required to learn the characteristic absorption frequencies of functional groups, but must be familiar with the relevant information in the data booklet. The precise wavenumber of the absorption depends upon neighbouring atoms.	<b>3</b>

A.S.		Obj
	<b>G.5 Nuclear Magnetic Resonance (NMR) Spectroscopy (4h)</b>	
<b>G.5.1</b>	State that atoms with an odd mass number can be detected by NMR spectroscopy.	<b>1</b>
<b>G.5.2</b>	Analyse simple NMR spectra. The emphasis is on $^1\text{H}$ spectra. Interpretation should include the: <ul style="list-style-type: none"><li>• number of peaks</li><li>• chemical shift (with tetramethylsilane (TMS) as the reference standard)</li><li>• area under each peak</li><li>• splitting patterns (treatment of spin-spin coupling constants is not required, but students should be familiar with splitting patterns for simple molecules ie doublet, triplet and quartet).</li></ul>	<b>3</b>
<b>G.5.3</b>	Outline how NMR is used in body scanners. Protons in water in human cells can be detected by magnetic resonance imaging (MRI), giving a three-dimensional view of organs in the human body.	<b>2</b>
	<b>G.6 Mass Spectrometry (3h)</b>	
<b>G.6.1</b>	Discuss how the molecular mass and molecular formula of a compound may be obtained from the molecular ion peak. Spectrometers have sufficient accuracy to allow identification of the molecular formula from the molecular mass using the masses of the commonest isotopes of C, H, N and O.	<b>3</b>
<b>G.6.2</b>	Analyse molecular mass spectra. Stress the importance of isotopes and relate these to the $(M + 1)^+$ peak for $^{13}\text{C}$ and the $(M + 2)^+$ and $(M + 4)^+$ peaks for chlorine and bromine. Include recognition of molecular fragments (see 20.1.3).	<b>3</b>
	<b>G.7 Chromatography (4h)</b>	
<b>G.7.1</b>	State the reasons for using chromatography. Chromatography can be used to separate substances for analysis and to determine purity. Highlight the coupling of chromatography with other techniques.	<b>1</b>
<b>G.7.2</b>	State that all chromatographic techniques require a stationary phase and a mobile phase. 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.	<b>1</b>

A.S.		Obj
<b>G.7.3</b>	Explain how the phenomena of adsorption and partition can be used in chromatographic techniques. Each of these phenomena gives rise to different chromatographic techniques. Molecular exclusion is not required.	<b>3</b>
<b>G.7.4</b>	Outline the use of paper chromatography, thin-layer chromatography (TLC), column chromatography, gas-liquid chromatography (GLC) and high performance liquid chromatography (HPLC). An outline of the operation for each technique is all that is required. This should include an understanding of $R_f$ values where relevant.	<b>2</b>
<b>G.7.5</b>	Deduce which chromatographic technique is most appropriate for separating the components in a particular mixture.	<b>3</b>

## Option H: Further Organic Chemistry

A.S.		Obj
	<b>H.1 Stereoisomerism (3h)</b>	
H.1.1	Describe and explain geometrical isomerism in non-cyclic alkenes. The existence of geometric ( <i>cis-trans</i> ) isomers is the result of restricted rotation around the C=C bond.	2, 3
H.1.2	Explain the difference in physical and chemical properties of geometrical isomers. Include different boiling points, eg <i>cis</i> -1,2-dichloroethene and <i>trans</i> -1,2-dichloroethene and different reactions when heated, eg <i>cis</i> - and <i>trans</i> -but-2-ene-1,4-dioic acid.	3
H.1.3	Describe geometrical isomerism in C <sub>3</sub> and C <sub>4</sub> cyclo-alkanes. Use dichloro-derivatives of cyclopropane and cyclobutane as examples. Rotation is restricted because the C-C bond is now part of a cyclic system.	2
H.1.4	Define <i>plane-polarized light</i> and describe how it interacts with enantiomers. Cross reference with 11.3.3. Include the use of a polarimeter.	1, 2
H.1.5	Define the term <i>racemic mixture</i> .	1
H.1.6	Compare the physical and chemical properties of enantiomers.	2
	<b>H.2 Free Radical Substitution Reactions (3h)</b>	
H.2.1	Describe the gas phase reactions of alkanes and methylbenzene with halogens. Consider the free radical mechanism for the reactions of methane and methylbenzene with chlorine, and identify the initiation, propagation and termination steps.	2
H.2.2	Describe how the gas phase reactions of chloroalkanes affect the level of ozone in the atmosphere.	2
	<b>H.3 Electrophilic Addition Reactions (4h)</b>	
H.3.1	Describe and explain the electrophilic addition reactions of symmetrical alkenes. A stepwise mechanistic approach is required. Reacting species should include halogens, mixed halogens and hydrogen halides.	2, 3
H.3.2	Apply Markovnikov's rule to predict the outcome of the electrophilic addition reactions of asymmetrical alkenes. A stepwise mechanistic approach is required. Reacting species should include mixed halogens and hydrogen halides.	2

<b>A.S.</b>		<b>Obj</b>
<b>H.3.3</b>	State and explain the relative stabilities of carbocations in order to account for Markovnikov's rule.	<b>1, 3</b>

Consider the stability of primary, secondary and tertiary carbocations, eg  $\text{CH}_3^+$ ,  $(\text{CH}_3)_2\text{CH}^+$  and  $(\text{CH}_3)_3\text{C}^+$ .

## H.4 Electrophilic Substitution Reactions (4h)

<b>H.4.1</b>	Describe and explain the mechanism for the nitration of benzene.	<b>2, 3</b>
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A stepwise electrophilic substitution mechanism is required. The formation of  $\text{NO}_2^+$  should also be shown.

<b>H.4.2</b>	Describe and explain the chlorination and alkylation reactions of benzene and methylbenzene in the presence of a halogen carrier.	<b>2, 3</b>
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<b>H.4.3</b>	Describe and explain the directing effects and relative rates of reaction of different substituents on a benzene ring.	<b>2, 3</b>
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Examples should be restricted to  $-\text{CH}_3$ ,  $-\text{OH}$ ,  $-\text{Cl}$ ,  $-\text{NO}_2$  and  $-\text{CO}_2\text{CH}_3$ . The reaction of phenol with chlorine to form trichlorophenol (TCP) should be covered.

## H.5 Nucleophilic Addition Reactions (1h)

<b>H.5.1</b>	Describe and explain the mechanism for the addition of hydrogen cyanide to aldehydes and ketones, followed by hydrolysis to give carboxylic acids.	<b>2, 3</b>
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## H.6 Nucleophilic Substitution Reactions (2h)

<b>H.6.1</b>	Outline how the relative rate of nucleophilic substitution is affected by different nucleophiles.	<b>2</b>
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Consider, for example, the relative rate of reaction using hydroxide or water (polarity differences).

<b>H.6.2</b>	Describe and explain inductive and steric effects of substituents on substitution reaction.	<b>2, 3</b>
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<b>H.6.3</b>	Describe and explain the relative rates of hydrolysis of halogenated benzene compounds.	<b>2, 3</b>
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Compare the inertness of halogenated benzene compounds towards substitution relative to halogenoalkanes. Cross reference with 20.3.

## H.7 Elimination Reactions (2h)

<b>H.7.1</b>	Describe the mechanism for the elimination of water from alcohols.	<b>2</b>
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<b>H.7.2</b>	Describe and explain the mechanism for the elimination of HBr from bromoalkanes.	<b>2, 3</b>
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Under different conditions, the same reactants can undergo either nucleophilic substitution or elimination reactions, eg 1-bromobutane with  $\text{OH}^-$ .

A.S.		Obj
	<b>H.8 Addition–elimination Reactions (1h)</b>	
<b>H.8.1</b>	Describe and explain the reactions of 2,4-dinitrophenylhydrazine with aldehydes and ketones. A detailed mechanism is not required.	<b>2, 3</b>
	<b>H.9 Acid–base Reactions (2h)</b>	
<b>H.9.1</b>	Describe and explain the acidic properties of phenol and substituted phenols in terms of bonding. Compare the acidity of phenol with alcohols, and the acidity of 2,4,6-trinitrophenol with phenol.	<b>2, 3</b>
<b>H.9.2</b>	Describe and explain the acidic properties of substituted carboxylic acids in terms of bonding. Relative acidities can be explained in terms of the ease of dissociation of the hydrogen ion or in terms of the relative stability of the conjugate base.	<b>2, 3</b>
<b>H.9.3</b>	Compare and explain the relative basicities of ammonia, amines and amides. Include the formation of salts and the liberation of the amine with NaOH from the salt. Cross reference with topic 18.	<b>2, 3</b>

# MATHEMATICAL REQUIREMENTS

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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 (eg  $3.6 \times 10^6$ )
- 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 (eg bar charts, histograms, pie charts).