



**Cambridge Assessment
International Education**

Cambridge
Pre-U

SYLLABUS

**Cambridge International Level 3
Pre-U Certificate in
Chemistry (Principal)**

9791

For centres in the UK

For examination in 2022

This syllabus is regulated for use in England, Wales and Northern Ireland as a Cambridge International Level 3 Pre-U Certificate. QN: 500/3683/X

Changes to the syllabus for 2022

The syllabus has been updated. The latest syllabus is version 1, published September 2019.

There are no significant changes which affect teaching.

You are strongly advised to read the whole syllabus before planning your teaching programme.

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Introduction

Why choose Cambridge Pre-U?

Cambridge Pre-U is designed to equip learners with the skills required to make a success of their studies at university. Schools can choose from a wide range of subjects.

Cambridge Pre-U is built on a core set of educational aims to prepare learners for university admission, and also for success in higher education and beyond:

- to support independent and self-directed learning
- to encourage learners to think laterally, critically and creatively, and to acquire good problem-solving skills
- to promote comprehensive understanding of the subject through depth and rigour.

Cambridge Pre-U Principal Subjects are linear. A candidate must take all the components together at the end of the course in one examination series. Cambridge Pre-U Principal Subjects are assessed at the end of a two-year programme of study.

The Cambridge Pre-U nine-point grade set recognises the full range of learner ability.

Why choose Cambridge Pre-U Chemistry?

- Cambridge Pre-U Chemistry promotes the development of problem solving and genuine chemical skills while allowing teachers to choose the context and applications they prefer. In this way, problem solving can be taught in varied contexts, new developments can be incorporated into the course, and the emphasis is placed on learning the fundamentals rather than simply the facts about what is current.
- Cambridge Pre-U Chemistry offers opportunities to incorporate cutting-edge science, such as the emerging fields of molecular genetics, biotechnology, materials, semiconductors and nanotechnology, for which chemistry, being a mature science, has become a collaborative subject.
- Cambridge Pre-U Chemistry highlights the principles that unify the subject and seeks to examine them through their application to chemical situations. The linear assessment structure means that learners are tested at the end of the two-year course, allowing them to rationalise and relate the facts they learn to the wider subject.
- Assessment includes a practical examination that will encourage the teaching and learning of practical skills as an integrated part of the course, and is designed to reward a wide range of laboratory and higher-order practical skills.
- Distinctive approaches such as functional group level provide an essential framework for appreciating the subject as a whole and furnish the learner with valuable methods for solving theoretical or practical problems, from the synthesis or characterisation of molecules to making meaningful predictions and calculating useful quantities.
- The course places an emphasis on the appreciation of three-dimensional structure, enabling a true appreciation of the way chemical systems work.

Prior learning

Cambridge Pre-U builds on the knowledge, understanding and skills gained by learners achieving a good pass in Level 1/Level 2 qualifications in Chemistry or related subjects.

Progression

Cambridge Pre-U is considered to be an excellent preparation for university and employment. It helps to develop the in-depth subject knowledge and understanding which are so important to universities and employers. Cambridge Pre-U Chemistry equips learners with a theoretical and practical base of transferable skills and key knowledge for future study and employment in chemistry and related fields (e.g. medicine, engineering, applied sciences) while providing thought-provoking material to appeal to those who do not wish to pursue a scientific career.



Cambridge Assessment International Education is an education organisation and politically neutral. The content of this syllabus, examination papers and associated materials do not endorse any political view. We endeavour to treat all aspects of the exam process neutrally.

Cambridge Pre-U Diploma

If learners choose, they can combine Cambridge Pre-U qualifications to achieve the Cambridge Pre-U Diploma; this comprises three Cambridge Pre-U Principal Subjects* together with Global Perspectives and Independent Research (GPR). The Cambridge Pre-U Diploma, therefore, provides the opportunity for interdisciplinary study informed by an international perspective and includes an independent research project.

first year	second year
CAMBRIDGE PRE-U DIPLOMA	
Cambridge Pre-U Principal Subject	
Cambridge Pre-U Principal Subject*	
Cambridge Pre-U Principal Subject*	
Cambridge Pre-U Global Perspectives and Independent Research (GPR)	

* Up to two A Levels, Scottish Advanced Highers or IB Diploma programme courses at higher level can be substituted for Principal Subjects.

Learn more about the Cambridge Pre-U Diploma at www.cambridgeinternational.org/cambridgepreu

Support

Cambridge International provides a wide range of support for Pre-U syllabuses, which includes recommended resource lists, Teacher Guides and Example Candidate Response booklets. Teachers can access these support materials at www.cambridgeinternational.org/support

Syllabus aims

The aims of the syllabus, listed below, are the same for all candidates and are to:

- develop and nurture in learners a philosophy of evidence-based thinking
- equip learners with the principles with which they can make sense of the large body of chemical knowledge and enable them to develop an understanding of and insight into chemical reactions and structure
- develop learners' skills in solving chemical problems and rationalising unfamiliar material
- instil in learners a sense of safe laboratory practice and equip them with the necessary laboratory skills to pursue the subject beyond this course
- develop learners' understanding of the link between theory and experiment and foster the development of skills required for the design and evaluation of experiments
- foster the development of attitudes relevant to science, such as a concern for accuracy and precision, objectivity, integrity and the skills of enquiry, initiative and inventiveness
- promote an awareness of the use and development of scientific models
- promote independent learning and analysis and the development of an informed interest in major scientific issues
- develop transferable skills applicable to the study and communication of science
- develop an understanding of the links between chemistry and other scientific and technological subjects
- promote an awareness that chemistry is a cooperative and cumulative activity, subject to technological, economic, historical, cultural, social and ethical factors
- promote the value of chemistry to society and stimulate interest in, and care for, the environment in relation to the impact of chemical science and its applications.

Scheme of assessment

For Cambridge Pre-U Chemistry, candidates take all four components.

Components	Weighting
<p>Paper 1 – Multiple Choice 1 hour</p> <p>Candidates answer 40 multiple choice questions based on Parts A and B of the syllabus.</p> <p>40 marks</p> <p>Externally assessed</p>	15%
<p>Paper 2 – Part A Written 2 hours 15 minutes</p> <p>Candidates answer long structured questions consisting of short answers or calculations and some longer answers, based on Part A of the syllabus. One or more questions assess practical knowledge and skills and are based on Part C of the syllabus.</p> <p>100 marks</p> <p>Externally assessed</p>	35%
<p>Paper 3 – Part B Written 2 hours 15 minutes</p> <p>Candidates answer long structured questions consisting of short answers or calculations and some longer answers. The questions are focused on Part B of the syllabus, but require a synoptic knowledge of Parts A and B of the syllabus.</p> <p>100 marks</p> <p>Externally assessed</p>	35%
<p>Paper 4 – Practical 2 hours</p> <p>Candidates are assessed on practical skills from Part C of the syllabus. The questions are focused on carrying out practical tasks and include one question on qualitative analysis and one or more questions on quantitative analysis.</p> <p>40 marks</p> <p>Externally assessed</p>	15%

Availability

This syllabus is examined in the June examination series.

This syllabus is available to private candidates with the exception of Paper 4. For more information, please refer to the *Cambridge Guide to Making Entries (UK)* for the relevant series.

Combining this with other syllabuses

Candidates can combine this syllabus in a series with any other Cambridge International syllabus, except syllabuses with the same title at the same level.

Assessment objectives

AO1	<p>Knowledge with understanding</p> <p>Candidates will be expected to demonstrate knowledge and understanding in relation to:</p> <ul style="list-style-type: none">• scientific phenomena, facts, laws, definitions, quantities, principles, concepts and theories and the relationships and models used to explain them• scientific vocabulary, terminology and conventions (including symbols, quantities and units)• scientific instruments, apparatus and methods, and their uses• scientific developments and the methodology used to develop knowledge. <p>The syllabus content defines the actual knowledge that candidates may be required to recall and explain.</p>
AO2	<p>Application of knowledge and problem solving</p> <p>Candidates will be expected to:</p> <ul style="list-style-type: none">• select, organise, interpret and present scientific information• translate information from one form to another (including manipulating numerical and other data)• analyse scientific information by identifying and explaining patterns and trends, drawing inferences and conclusions and constructing arguments• evaluate scientific information in terms of validity, accuracy and precision• apply and synthesise scientific skills, knowledge and understanding to solve problems and explain phenomena. <p>This assessment objective relates primarily to unfamiliar data, phenomena or situations which, by definition, cannot be listed in the syllabus content.</p>
AO3	<p>Experimental and investigative skills</p> <p>Candidates will be expected to:</p> <ul style="list-style-type: none">• plan scientific investigations• use scientific apparatus, methods and techniques skilfully and safely• make, record and communicate observations, measurements and methods methodically with appropriate clarity, precision and accuracy• manipulate, present and analyse raw data from scientific experiments and investigations• report findings and conclusions, supported by evidence• evaluate experimental methods, techniques, raw data and conclusions; identify limitations and suggest improvements.

Relationship between scheme of assessment and assessment objectives

The approximate weightings allocated to each of the assessment objectives (AOs) are summarised below.

Assessment objectives as a percentage of the qualification

Assessment objective	Weighting in Pre-U %
AO1 Knowledge with understanding	40
AO2 Application of knowledge and problem solving	40
AO3 Experimental and investigative skills	20

Assessment objectives as a percentage of each component

Assessment objective	Weighting in components %			
	Paper 1	Paper 2	Paper 3	Paper 4
AO1	50	40	50	0
AO2	50	40	50	0
AO3	0	20	0	100

Grading and reporting

Cambridge International Level 3 Pre-U Certificates (Principal Subjects and Global Perspectives Short Course) are qualifications in their own right. Cambridge Pre-U reports achievement on a scale of nine grades: Distinction 1, Distinction 2, Distinction 3, Merit 1, Merit 2, Merit 3, Pass 1, Pass 2 and Pass 3.

Cambridge Pre-U band	Cambridge Pre-U grade
Distinction	1
	2
	3
Merit	1
	2
	3
Pass	1
	2
	3

Grade descriptions

Grade descriptions are provided to give an indication of the standards of achievement likely to have been shown by candidates awarded particular grades. Weakness in one aspect of the examination may be balanced by a better performance in some other aspect.

The following grade descriptions indicate the level of attainment characteristic of the middle of the given grade band.

Distinction (D2)

Candidates recall and use knowledge of chemistry from the whole syllabus with few omissions and show good understanding of many of the most demanding principles and concepts in the syllabus. They select appropriate information from which to construct arguments or techniques with which to solve problems. In the solution of problems, candidates are usually able to bring together fundamental principles from different content areas of the syllabus and demonstrate a clear understanding of the relationships between these.

Candidates apply knowledge and chemical principles contained within the syllabus in both familiar and unfamiliar contexts. In questions requiring numerical calculations, candidates demonstrate good understanding of the underlying relationships between quantities involved and carry out all elements of extended calculations correctly in situations where little or no guidance is given. They are often successful on questions which require a combination of applying demanding concepts to unfamiliar contexts, extended problem-solving and synthesis of ideas from different areas of chemistry.

In experimental activities, candidates identify a problem, formulate a clear and effective plan using knowledge and understanding of chemistry, and use a range of relevant techniques with care and skill. They are organised and methodical in the way they carry out their work and present their results. They make and record measurements which are sufficient and with a precision which is appropriate to the task. They interpret and explain their results with sound use of chemical principles and critically evaluate the validity of their methods.

Merit (M2)

Candidates recall and use knowledge of chemistry from most parts of the syllabus with some omissions and show good understanding of many of the principles and concepts within it. They select appropriate information from which to solve problems, including some problems in unfamiliar contexts. Candidates show some signs of an ability to bring together fundamental principles from different content areas of the syllabus, but do not do so consistently. They usually make good use of the concepts and terminology of chemistry in communicating their answers.

Candidates apply knowledge and principles of chemistry contained within the syllabus in familiar and some unfamiliar contexts. In questions requiring numerical calculations, candidates demonstrate some understanding of the underlying relationships between quantities involved and are usually aware of the magnitudes of common quantities. Candidates are usually successful in calculations where some structure is provided and can carry out some elements of extended calculations correctly.

In experimental activities, candidates are usually able to identify a problem and to formulate a plan, many aspects of which are realistic and practicable. They use a range of relevant techniques with care and skill. They make and record measurements, usually with a precision which is appropriate to the task. They interpret and explain their results using chemical principles and make some critical evaluation of their methods.

Pass (P2)

Candidates recall and use knowledge of chemistry from many parts of the syllabus and demonstrate some understanding of a number of the main principles and concepts within it. Their level of knowledge and understanding may vary significantly across major areas of the syllabus. They select discrete items of knowledge and make some use of information that is presented in familiar ways to solve problems. They make some use of the concepts and terminology of chemistry in communicating their answers.

Candidates apply knowledge and principles of chemistry contained within the syllabus to material presented in a familiar or closely related context. They show some understanding of the magnitudes of common quantities when carrying out numerical work. Candidates carry out straightforward calculations in most areas of chemistry correctly when these calculations are of a familiar kind and when structure is provided, usually using correct units.

In experimental activities, candidates are able to plan some aspects of the solution to a practical problem. They make and record appropriate measurements and show some awareness of the need for precision. They usually offer an interpretation of their experimental results, making some use of fundamental principles of chemistry.

Description of components

Theory assessment

Questions, where possible, are set in novel contexts to show applications of chemistry. Contexts may include medicinal and pharmaceutical chemistry, industrial processes, materials chemistry, biochemistry, analytical science and environmental issues. Some questions may be set in the context of recent chemical research.

Component 1

This is a multiple choice paper consisting of 40 questions which involve choosing a single correct answer from a choice of four. The questions cover Part A and Part B of the syllabus.

Component 2

This component involves long structured questions totalling 100 marks. The questions contain many parts, most parts involving short answers or calculations, with some longer answers. Candidates should expect the questions to cross the boundaries of the different fields of chemistry covered in Part A of the syllabus, to require application of Part A knowledge and skills to unfamiliar contexts, and to require an appreciation of the practical side of the subject. One or more questions address learning outcomes in Part C of the syllabus. See under 'Practical assessment' for further details.

Component 3

This component involves long structured questions totalling 100 marks. The questions contain many parts, most parts involving short answers or calculations, with some longer answers. The questions focus on Part B topics but will cross the boundaries of the different fields of chemistry and cover Part A topics too.

The *Data Booklet* (see page 42) will be available to candidates for all three written components.

Practical assessment

Component 2

One or more questions in Component 2 assess the higher-order practical skills of planning and evaluation as set out in Part C of the syllabus (C5.3 and C5.4). It should be stressed that candidates cannot be adequately prepared for these questions without the following laboratory experience:

- planning an experiment
- performing the experiment according to their plan
- evaluating what they have done.

In these questions, candidates may be required to design an experimental investigation of a given problem. Such questions are not highly structured: candidates are expected to answer using extended, structured writing, illustrated with appropriate diagrams, flow charts, tables or equations.

These questions may be set in areas of chemistry that are difficult to investigate experimentally in school laboratories, either because of the cost of equipment, such as colorimeters or spectrometers, or because of restrictions on the availability of samples and materials such as expensive chemicals or biochemicals, or for safety reasons. No question will require knowledge of theory or equipment that is beyond Part A of the syllabus. Information that candidates are not expected to know will be provided in the examination paper.

Component 4

Component 4 is a timetabled, laboratory-based practical paper focusing on the following experimental skills, set out in Part C of the syllabus:

- C5.1 Manipulation, measurement and observation
- C5.2 Presentation of data and observations
- C5.3 Analysis, conclusions and evaluation.

Component 4 involves a question on qualitative analysis and one or more questions on quantitative analysis, totalling 40 marks. Specifically, the following may be included:

- a volumetric analysis problem requiring titration
- an experiment that involves the determination of some quantity, e.g. the measurement of enthalpy changes or reaction rate, thermometric titration or a gravimetric exercise; such experiments will depend on the simple manipulation of standard laboratory apparatus
- an observational problem in which the candidate will be asked to investigate, by specified experiments, an unknown substance; the substance may be an element, a compound or a mixture.

Examiners may not be strictly bound by the subject content of the syllabus in finding contexts for the setting of questions. Within what may be unfamiliar contexts, candidates will be told the necessary details. Knowledge of theory will be drawn only from within the syllabus (Parts A and B).

Candidates are not allowed to refer to notebooks, textbooks or any other information in the practical examination. The *Data Booklet*, which includes qualitative analysis notes, will be supplied in addition to the question paper. Candidates may also be required to carry out calculations as detailed in the syllabus.

Candidates who are not able to perform manipulative or observational skills may have a practical assistant or other arrangements to enable them to access the non-manipulative/observational parts of the paper. Candidates will not be credited with marks for any skill which has been performed by a practical assistant.

Nomenclature and units

Candidates are expected to be familiar with the nomenclature used in the syllabus. The proposals in *Signs, Symbols and Systematics* (The Association for Science Education Companion to 16–19 Science, 2000) will generally be adopted, although the traditional names sulfate, sulfite, nitrate, nitrite, sulfurous acid and nitrous acid will be used in question papers, except in questions relating to learning outcome A2.1 (g). Candidates will be credited for traditional or systematic names in their answers, except when specifically asked to use oxidation numbers to deduce or understand systematic names.

Sulfur (and all compounds of sulfur) will be spelled with f (not with ph) in the syllabus and question papers. Candidates will be credited for either spelling in their answers. See section 3, Organic chemistry, for learning outcomes concerning organic formulae and representation.

In practical work, candidates will be expected to use SI units or, where appropriate, units approved by the BIPM for use with the SI (e.g. minute). A list of SI units, and units approved for use with the SI, may be found in the SI brochure at <http://www.bipm.org>. The use of imperial/customary units such as the inch and degree Fahrenheit is not acceptable and should be discouraged.

In all examinations, where data are supplied for use in questions, candidates will be expected to use units that are consistent with the units supplied, and should not attempt conversion to other systems of units unless this is a requirement of the question.

Mark scheme for Component 4

Component 4 is marked according to the generic mark scheme below. The learning outcomes for each mark category are listed in section 5 of the syllabus.

Skill	Minimum mark allocation*	Breakdown of skills	Minimum mark allocation*
C5.1 Manipulation, measurement and observation	12 marks	C5.1.1 Successful collection of data and observations	8 marks
		C5.1.2 Quality of measurements or observations	2 marks
		C5.1.3 Decisions relating to measurements or observations	2 marks
C5.2 Presentation of data and observations	6 marks	C5.2.1 Recording data and observations	2 marks
		C5.2.2 Display of calculation and reasoning	2 marks
		C5.2.3 Data layout	2 marks
C5.3 Analysis, conclusions and evaluation	10 marks [†]	C5.3.1 Interpretation of data or observations	4 marks [†]
		C5.3.2 Drawing conclusions	5 marks [†]
		C5.3.3 Evaluation	0 marks [†]
		C5.3.4 Suggesting improvements	1 mark [†]

* The remaining 12 marks will be allocated across the skills in this grid and their allocation may vary from session to session.

[†] C5.3 is also assessed in Component 2.

Syllabus content

This syllabus gives you the flexibility to design a course that will interest, challenge and engage your learners. Where appropriate you are responsible for selecting suitable subject contexts, resources and examples to support your learners' study. These should be appropriate for the learners' age, cultural background and learning context as well as complying with your school policies and local legal requirements.

The syllabus is divided into five sections.

1 Physical chemistry

- A1.1 Introductory physical chemistry
- A1.2 Atomic structure
- A1.3 Chemical forces
- A1.4 Energy changes
- B1.5 Free energy and entropy
- B1.6 Equilibrium
- B1.7 Gases and kinetics
- B1.8 Chemical models and evidence

2 Inorganic chemistry

- A2.1 Periodic Table
- A2.2 Main group chemistry (except Group 14)
- B2.3 From non-metals to metals: Group 14
- B2.4 Transition elements
- B2.5 Crystal structures

3 Organic chemistry

- A3.1 Preliminaries
- A3.2 Functional group level
- A3.3 Lower functional group level reactions – Alcohol level
- A3.4 Lower functional group level reactions – Carbonyl level
- A3.5 Addition and elimination reactions
- A3.6 Green chemistry
- B3.7 Higher functional group level reactions – Carboxylic Acid level
- B3.8 Higher functional group level reactions – Carbon Dioxide level
- B3.9 Mechanisms
- B3.10 Aromatic chemistry
- B3.11 Acidity and basicity
- B3.12 Stereochemistry

4 Analysis

- A4.1 Qualitative and quantitative analysis
- A4.2 Mass spectrometry
- A4.3 Electronic spectroscopy
- A4.4 Infra-red
- A4.5 Carbon-13 NMR
- B4.6 NMR of other spin $\frac{1}{2}$ nuclei

5 Practical chemistry

C5.1 Manipulation, measurement and observation

C5.2 Presentation of data and observations

C5.3 Analysis, conclusions and evaluation

C5.4 Planning

Each subsection belongs to Part A, B or C of the syllabus. These three parts are assessed by different components as detailed in the scheme of assessment on page 5.

Distinctive approaches

Attention is drawn to a number of distinctive approaches within the syllabus, which are not commonly examined at this level. These topics should allow candidates to develop an important insight into chemical processes and should help to rationalise new and unfamiliar compounds and reactions.

- **Van Arkel diagrams** These diagrams put all binary compounds, be they ionic, covalent, giant covalent, metallic or semiconducting, on a single graph which explains their bonding type in terms of the difference in electronegativity and the average electronegativity of their constituent elements. It thus unifies all the chemical bonding types through an easily comprehensible concept.
- **Functional group level** This idea provides a simple framework through which a vast number of organic reactions can be understood: simply the number of bonds from a carbon atom to an electronegative element. Functional groups can be classified very simply by this scheme and so reactions between functional groups can thus immediately be understood as reduction, oxidation, or a reaction within a level such as substitution, hydrolysis or condensation.
- **Orbitals** An appreciation that electrons occupy orbitals in molecules as well as in atoms leads to the concept of bonding and anti-bonding molecular orbitals and an understanding that putting electrons into a bonding orbital leads to the nuclei being held together (i.e. bonded) whereas putting electrons into an anti-bonding orbital weakens bonding by pulling the nuclei apart from one another as these orbitals lie outside the internuclear region. An appreciation that vacant anti-bonding molecular orbitals exist is vital for a proper understanding of molecular electronic spectroscopy, and for understanding mechanism in further study.

1 Physical chemistry

Part A of this section gives candidates insight into the structure of atoms and molecules and the forces between them, and the theory and measurement of enthalpy changes. In Part B, candidates are exposed to the driving forces of chemical reactions, the mechanisms of reactions and how their rate is studied, and the analysis of equilibrium conditions. Throughout this study, candidates should be encouraged to consider the importance of evidence gathering and the limitations of theories.

Part A

A1.1 Introductory physical chemistry

The following material may or may not have been covered as part of a Level 2 course (GCSE, IGCSE™, O Level). If it has not previously been covered, it should be taught as part of this course and may be assessed.

Candidates should be able to:

- balance equations, including ionic equations, and use stoichiometric relationships
- use amount of substance (in moles) and Avogadro's constant
- calculate reacting masses from chemical formulae and equations
- appreciate relative mass (atomic, isotopic, molecular and formula)
- appreciate relative charges, masses and location of protons, neutrons and electrons, and their behaviour in an electric field
- appreciate proton, electron, neutron and nucleon (mass) numbers in atoms and ions
- appreciate isotopes and their composition in terms of protons and neutrons
- appreciate electron sharing in covalent bonding, transfer in ionic bonding, and delocalisation in metallic bonding
- understand the terms endothermic and exothermic and how they relate to bond making and bond breaking
- appreciate the concepts of reversible reactions and dynamic equilibria
- appreciate the kinetic-molecular model of change of state
- understand simple collision theory as an explanation for factors affecting reaction rate.

A1.2 Atomic structure

Content

- atomic shells, subshells, orbitals and electron spin
- aufbau principle and electron configurations
- periodic trends in atomic properties
- ionisation energies

Candidates should be able to:

- recall the relationship between shell number and number of subshells
- recognise an orbital as a mathematical function giving rise to a probability distribution, as illustrated by orbitals such as 1s, 2s, 2p_x etc. (no knowledge of orbitals from f or higher subshells is required)
- draw the approximate shapes of the s, p and d orbitals
- describe qualitatively the relative energies of the s, p, d and f subshells within a principal shell and describe the concept of shielding in multi-electron atoms
- recall that all electrons possess spin and that electrons are spin-paired in orbitals

- (f) apply the aufbau principle
- (g) state the ground state electronic configurations of the first 36 elements and any common ion using conventional notation and shorthand (e.g. [Ar] 4s² for Ca) given proton number and charge
- (h) describe the ground state configuration of electrons in a subshell using electron-in-box notation
- (i) explain the variation of atomic radii, ionic radii, first ionisation energies and electronegativities down groups and across the third period in terms of shell number, nuclear charge and shielding; explain the effect of ionisation on atomic radius
- (j) understand and use the relationship between group number and successive ionisation energies; write equations for successive ionisation energies.

A1.3 Chemical forces

Content

- molecular bonding and antibonding orbitals
- σ and π bonds, bond order
- molecular shape and bond angles
- intermolecular forces

Candidates should be able to:

- (a) use dot-cross diagrams to describe ionic and covalent bonding, including dative covalent bonding
- (b) understand that electrons occupy orbitals in molecules as well as atoms; understand that putting electrons into a bonding orbital leads to the nuclei being held together (i.e. bonded) whereas putting electrons into an antibonding orbital weakens bonding by pulling the nuclei apart from one another (as these orbitals lie outside the internuclear region) (N.B. there is no requirement to appreciate the formation of molecular orbitals from the linear combination of atomic orbitals)
- (c) understand that the strength of the covalent bond can be related to the extent to which the energy of the bonding molecular orbital is lowered relative to the atomic orbitals
- (d) understand how σ and π bonds result from overlap of atomic orbitals
- (e) appreciate the relative strengths of σ and π bonds
- (f) understand the concept of bond order and its qualitative relationship to bond length and strength
- (g) deduce the shapes and bond angles of simple molecules and ions (typified by examples such as BF₃, CH₄, NH₃, H₂O, CO₂, C₂H₄, CH₃⁺) and hypervalent species (typified by examples such as PCl₅, SF₆, IF₇, XeO₄, PCl₆⁻) using the VSEPR model
- (h) deduce changes in geometry and bond angle during a chemical reaction, e.g. protonation of ammonia, addition to double bonds
- (i) describe the concept of electronegativity and its use in predicting bond dipoles
- (j) describe van der Waals forces (all intermolecular forces weaker than hydrogen bonds) in terms of instantaneous, permanent and induced dipoles and the increase of these forces with polarisability
- (k) describe hydrogen bonding as a special case of a dipole-dipole interaction and its influence on the structure of ice and the anomalous properties of water; outline its importance in base-pairing in the double helix of DNA (structure of DNA bases is not required)
- (l) understand the importance of van der Waals forces and hydrogen bonding in determining protein structure (recall of alpha helix and beta sheet structures is not required).

A1.4 Energy changes

Content

- standard enthalpy changes and the link with temperature
- Hess's law and Born-Haber cycles
- reaction pathway diagrams, including the effect of catalysis

Candidates should be able to:

- (a) define and use the terms standard enthalpy change of reaction, formation, combustion, hydration, solution, neutralisation, atomisation and vaporisation
- (b) use the relationship $q = mc\Delta T$ (Equation 1 in the *Data Booklet*)
- (c) state Hess's law and the first law of thermodynamics
- (d) apply Hess's law to the indirect determination of enthalpy changes, including the use of average gas-phase bond energies
- (e) calculate lattice energies from Born-Haber cycles
- (f) understand the effect of a catalyst in providing an alternative reaction route with a lower activation energy
- (g) interpret and construct reaction profile energy diagrams, including the effect of a catalyst on the activation energy, and deduce the different energy changes involved
- (h) interpret the effect of a catalyst in terms of the Maxwell-Boltzmann distribution.

Part B

B1.5 Free energy and entropy

Content

- entropy and standard entropy change
- the second law of thermodynamics
- the Gibbs energy equation and the equilibrium constant

Candidates should be able to:

- (a) understand entropy in terms of: (i) the random dispersal of molecules in space, and (ii) the random dispersal of quanta of energy among molecules
- (b) understand that the total entropy change is the entropy change of the system plus the entropy change of the surroundings
- (c) calculate ΔS^\ominus given the standard entropies of the reactants and products
- (d) define the entropy change of the surroundings as $-\Delta_r H / T$ where T is the thermodynamic temperature of the surroundings in kelvin and $\Delta_r H$ is the enthalpy change of the reaction
- (e) recall and apply the second law of thermodynamics – that the total entropy (i.e. system plus surroundings) increases in every chemical reaction until equilibrium is reached – and explain how it can account for endothermic phenomena
- (f) use the Gibbs energy equation (Equation 2 in the *Data Booklet*)
- (g) use the equation that relates the standard Gibbs energy change to the equilibrium constant (Equation 3 in the *Data Booklet*).

B1.6 Equilibrium

Content

- equilibrium constants and Le Chatelier's principle
- Brønsted-Lowry and Lewis theories of acids and bases
- pH and buffers
- oxidation number; quantitative electrolysis
- standard electrode and cell potentials
- electron flow in cells; Gibbs energy change

Candidates should be able to:

- state Le Chatelier's principle and apply it to deduce qualitatively the effects of changes in temperature, concentration or pressure on a system at equilibrium
- describe weak acids and alkalis in terms of equilibria; describe the Brønsted-Lowry theory of acids, including conjugate pairs; describe the Lewis theory of acids and bases; understand the difference between mono-, di- and triprotic (tribasic) acids
- understand that equilibrium constant expressions take the form outlined in Equation 4 of the *Data Booklet*, and apply this to K_c
- understand that in the case of K_p only gas phase constituents are included in the equilibrium constant expression, that in the case of K_{sp} solids are omitted, and that in the case of K_a and K_w the solvent is omitted
- calculate quantities based on equilibrium constant expressions
- define pH and determine pH for strong and weak acids (solving of quadratic equations is not required); understand how pK_a is a measure of acid strength
- describe and explain the change in pH during strong/weak acid-base titrations and explain the choice of indicator
- understand and explain how simple buffer solutions work; calculate the pH of buffer solutions
- explain the electrolysis of a molten compound using inert electrodes; predict the products of the electrolysis of an aqueous electrolyte, given relevant electrode potentials; construct half-equations for the reactions occurring at each electrode during electrolysis
- calculate quantities of substances involved during electrolysis using the Faraday constant (given in the *Data Booklet*)
- understand the concept of redox with reference to oxidation number
- understand the concept of standard electrode potential and describe the standard hydrogen electrode
- describe methods used to measure standard electrode potentials of: (i) metals or non-metals in contact with their ions in aqueous solution, and (ii) ions of the same element in different oxidation states
- understand and be able to use standard notation to construct and interpret conventional cell diagrams, e.g. $Zn(s) | Zn^{2+}(aq) || Cu^{2+}(aq) | Cu(s); Pt | H_2(g) | 2H^+(aq) || MnO_4^-(aq) + 8H^+(aq), Mn^{2+}(aq) + 4H_2O(l) | Pt$; be able to relate cell diagrams to pictorial diagrams of cells
- calculate standard cell potential from standard electrode potentials
- understand the link between the standard cell potential and the standard Gibbs energy change and use Equation 5 in the *Data Booklet*
- deduce the direction of electron flow in an electrochemical cell and therefore the feasible direction of reaction using cell potentials
- understand how the cell potential changes from its standard value during the course of a reaction in an electrochemical cell and approaches zero as equilibrium is approached; interpret the variation of the cell potential as the concentrations of the solutions change using Le Chatelier's principle (knowledge of the Nernst equation is not required)
- describe the hydrogen/oxygen fuel cell.

B1.7 Gases and kinetics

Content

- kinetic theory and ideal gases
- rate of reaction, Arrhenius equation
- homogeneous and heterogeneous catalysis
- formulating rate equations from data; multi-step reaction mechanisms
- rate-concentration and concentration-time dependence

Candidates should be able to:

- (a) state the assumptions of the kinetic theory applied to an ideal gas, and understand their limitations
- (b) state Boyle's law and Charles's law and use the ideal gas equation, $pV = nRT$ (Equation 6 in the *Data Booklet*)
- (c) explain the dependence of the rate of reaction on the activation energy of the reaction and temperature in terms of the Boltzmann distribution of molecular energies
- (d) rationalise the rate constant as the product of collision frequency (per unit concentration), the steric factor and a Boltzmann term; use the Arrhenius equation (Equation 7 in the *Data Booklet*)
- (e) describe the homogeneous and heterogeneous modes of catalytic activity, and that it is the shape of the active site in enzymes that is central to their function and makes them highly specific
- (f) understand how rate equations are based on experimental data; deduce the orders and overall order of reaction from a rate equation; deduce the molecularity of a given step; deduce the units of rate of reaction, and of rate constants for different orders of reaction
- (g) interpret simple multi-step reactions in terms of a series of elementary steps with a rate-determining step; predict orders and overall order of reaction from a given mechanism
- (h) suggest a mechanism that is consistent with a given rate equation
- (i) deduce rate equations using initial rates data; interpret rate-concentration graphs
- (j) understand that only first-order reactions have a constant half-life; use the equation for the concentration-time dependence for first-order reactions (Equation 8 in the *Data Booklet*) to calculate the first-order rate constant and half-lives from provided data.

B1.8 Chemical models and evidence

Content

- the relationship between evidence, models and theories
- the limitations of scientific models

Candidates should be able to:

- (a) appreciate that chemistry is an evidence-based subject. The experimental basis, in particular, of rate equations and organic mechanisms provide useful examples (see section 3, Organic chemistry)
- (b) understand the distinction between theories, models, facts and definitions
- (c) recognise the ideal gas model and equation as an example of a model based on a series of assumptions and appreciate that it is useful up to a point but breaks down under certain conditions
- (d) recognise the limitations (increasing with covalent character) of the ionic model of crystal lattices to predict lattice energies found from Born-Haber cycles.

2 Inorganic chemistry

This section is intended to give candidates understanding of the three main types of bonding within the framework of electronegativity and in the continuum of the van Arkel diagram; to enable candidates to rationalise a body of descriptive chemistry in terms of group and periodic trends; knowledge and understanding of the structure, isomerism and redox properties of transition metal complexes; and appreciation of three-dimensional relationships in crystal structures.

Part A

A2.1 Periodic Table

Content

- division of the Periodic Table by element and structure type
- rationalisation and prediction of bonding type using the van Arkel diagram
- periodic trends in physical and chemical properties

Candidates should be able to:

- appreciate that the elements can be divided into metals, metalloids and non-metals, and the locations of these regions on the Periodic Table
- appreciate that elemental structures can be divided into simple and giant
- appreciate that some elements exist as different allotropes; recall the allotropes of oxygen; describe the structure and properties of the allotropes of carbon, including buckminsterfullerene and graphene
- understand the variation of melting and boiling points and electrical conductivity of elements across Period 3 in terms of structure and bonding
- predict the bonding type, and hence properties, in elements and compounds using electronegativity values and the van Arkel diagram; plot points on a template van Arkel diagram
- deduce unfamiliar half-equations and construct redox equations from the relevant half-equations
- understand and apply the concept of oxidation number (including use in nomenclature) and appreciate that the maximum oxidation states of elements are found in compounds with oxygen and fluorine
- describe the reactivity of Period 3 elements with oxygen and water
- describe the reactivity of Period 3 oxides with water, and the acid-base character of the oxides as the periodic table is crossed
- describe the reactivity of Period 3 chlorides with water, including reactions of SiCl_4 and PCl_5 with water in terms of replacement of $-\text{Cl}$ with $-\text{OH}$ and subsequent dehydration; analogy with dehydration of unstable hydroxyl group in organic chemistry
- appreciate that there is a thermodynamic preference for bonds to oxygen compared to chlorine, as illustrated by the natural occurrence of mineral oxides.

A2.2 Main group chemistry (except Group 14)

Content

- thermal stability of carbonates
- properties of nitrogen, phosphorus and ammonia
- chemistry of oxygen and sulfur
- halogen chemistry and the exceptional behaviour of fluorine

Candidates should be able to:

- (a) describe the thermal decomposition reactions of carbonates, and explain the trends in thermal stability in terms of the charge density of the cation and the polarisability of the anion
- (b) recall and compare the structures of nitrogen and white phosphorus
- (c) explain why nitrogen is unreactive
- (d) describe the acid-base behaviour of ammonia and the ammonium ion
- (e) describe the redox properties of hydrogen peroxide
- (f) describe the formation of sulfur oxides in the atmosphere from carbon fuels containing sulfur, and the removal of SO_2 from power station emissions
- (g) describe sulfuric acid as a strong involatile acid, oxidising agent, dehydrating agent and catalyst; understand the importance of sulfuric acid as an industrial chemical
- (h) recall the trends in volatility and colour, and understand the trend in oxidising power of the halogens, including fluorine
- (i) explain the trend in bond energy of the halogens, with the reason for the exceptional nature of F_2
- (j) explain the trend in acidity of the hydrogen halides in terms of the bond energy, including the weak acid behaviour of HF
- (k) recall the reaction of halides with concentrated (conc.) H_2SO_4 and explain the trend towards oxidation
- (l) recall the reaction of iodine with sodium thiosulfate and its use in analysis
- (m) recall the reactions of the halogens with cold $\text{NaOH}(\text{aq})$ in terms of disproportionation
- (n) state reasons for the anomalous reactivity of fluorine (see above), and understand why elements can form high-oxidation state fluorides, such as UF_6 , SF_6 .

Part B

B2.3 From non-metals to metals: Group 14

Content

- trends in the properties of the elements
- properties of the oxides

Candidates should be able to:

- (a) describe the transition from non-metal through metalloid to metal, and its manifestation in the electrical conductivities of the elements
- (b) recall that lead chemistry is dominated by the +2 oxidation state
- (c) recall that the oxides are essentially covalent at the top of the group and largely ionic at the bottom
- (d) explain the bonding in the divalent and tetravalent oxides, making reference to the van Arkel diagram and polarisation.

B2.4 Transition elements

Content

- physical and atomic properties
- geometry and isomerism of complexes
- colour and ligand substitution
- redox chemistry of complexes

Candidates should be able to:

- explain what is meant by a transition element
- state a qualitative comparison between the properties of a transition element and an s-block element in terms of atomic radius, melting and boiling points and first ionisation energy
- state that there is little variation in the above properties across the series compared to the rest of the period
- recall the characteristic properties of transition elements, including variable oxidation states, formation of stable complexes and catalysis, using common examples
- describe the geometry and bond angles around the following transition metal ions in complexes: octahedral hexaqua ions of first row transition metals, tetrahedral complexes of these ions with larger ligands (e.g. $[\text{CoCl}_4]^{2-}$), and square planar complexes with Group 10 metals, especially platinum (e.g. $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$)
- explain the isomerism in complexes: geometric and optical
- state that the d orbitals point either along or between the cartesian axes, which explains a splitting of energy levels in transition metal complexes
- explain qualitatively the origin of colour in transition metal complexes
- understand that different ligands give different coloured complexes and hence colour changes are often observed during ligand exchange
- describe the following redox chemistry: $\text{Fe}^{3+}/\text{Fe}^{2+}$; $\text{MnO}_4^-/\text{Mn}^{2+}$; $\text{Cr}_2\text{O}_7^{2-}/\text{Cr}^{3+}$; and $\text{Cu}^{2+}/\text{Cu}^+$
- outline the essential biological role of the following iron complexes: haemoglobin, myoglobin and ferritin
- recall that a ligand may affect the relative stability of oxidation states of a transition metal complex, e.g. the +2 and +3 oxidation states of cobalt: $[\text{Co}(\text{H}_2\text{O})_6]^{2+}/[\text{Co}(\text{H}_2\text{O})_6]^{3+}$ versus $[\text{Co}(\text{NH}_3)_6]^{2+}/[\text{Co}(\text{NH}_3)_6]^{3+}$.

B2.5 Crystal structures

Content

- close packing in metals
- unit cell properties
- occupying holes in unit cells

Candidates should be able to:

- describe and recognise the cubic close-packed (CCP) and hexagonal close-packed (HCP) structures in metals, including the ABC and AB representations of the close-packed structures
- define the unit-cell representation as the simplest repeating unit of the lattice which displays the full symmetry of the crystal
- explain the relationship between neighbouring atoms/ions in a lattice in terms of geometry (limited to tetrahedral and octahedral) and coordination number

- (d) appreciate that there are octahedral and tetrahedral holes in close-packed structures and recall the ratio of holes to atoms in each case
- (e) understand the derivation of lattice structures by occupying holes in a close-packed lattice of ions with counter-ions: NaCl by filling all the octahedral holes in the CCP lattice, CaF_2 from filling all the tetrahedral holes
- (f) explain that lattice energies may be calculated from the crystal structure using electrostatics and the ionic model, and the deficiencies of this method (recall of the Born-Landé equation is **not** required).

3 Organic chemistry

This section is intended to equip candidates with the tools to understand organic reactions through the framework of the functional group level, to suggest reagents and conditions for the transformations they have studied when encountered in unfamiliar reaction schemes, to consider the three-dimensional nature of organic reactions, and to understand mechanisms of organic reactions and the acid-base properties of organic molecules.

Greater emphasis is placed on understanding what kind of reagent is required for a chemical transformation, rather than the learning of reagents and conditions for all reactions. Those reactions where specific reagents are required are detailed in the learning outcomes; in other cases only the kind of reagent (e.g. oxidising agent) and an example of each kind of reagent will be expected.

Part A

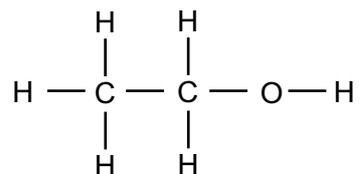
A3.1 Preliminaries

Content

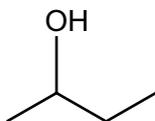
- formulae, structures and geometry
- structural, geometric and optical isomerism
- nomenclature
- types of reaction

Candidates should be able to:

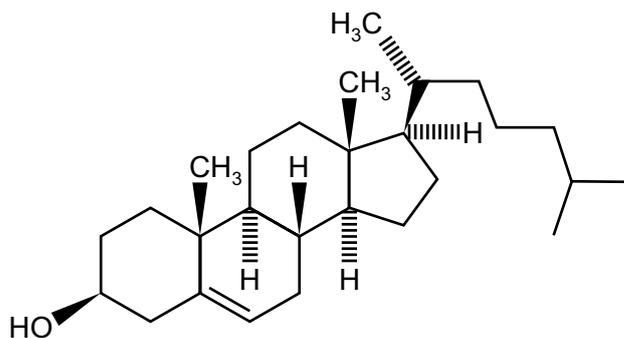
- (a) interpret and use the terms:
- *molecular formula*, as the actual number of atoms of each element in a molecule, e.g. $\text{C}_3\text{H}_8\text{O}$ for propan-1-ol, **not** $\text{C}_3\text{H}_7\text{OH}$;
 - *general formula*, as the simplest algebraic formula of a member of a homologous series, e.g. $\text{C}_n\text{H}_{2n+2}$ for an alkane;
 - *structural formula*, as the minimal detail that shows the arrangement of atoms in a molecule, e.g. $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$ for propan-1-ol, **not** $\text{C}_3\text{H}_7\text{OH}$;
 - *displayed formula*, as the relative positioning of atoms and the bonds between them, e.g. for ethanol:



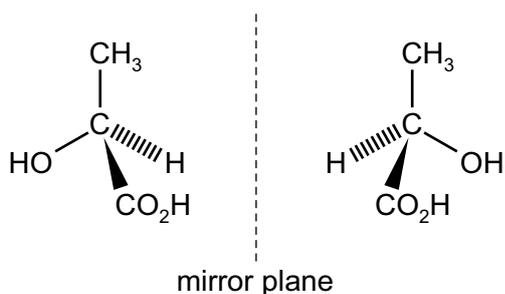
- *skeletal (or partial skeletal) formula*, as the simplified organic formula, shown by removing hydrogen atoms from alkyl chains, leaving just a carbon skeleton and associated functional groups, e.g. for butan-2-ol (skeletal):



and for cholesterol (partial skeletal):



- appreciate the tetravalent nature of carbon and the shapes of the ethane, ethene and benzene molecules; use this to write structural formulae and predict the shapes of, and bond angles in, other related organic molecules
- draw carbon backbones (i.e. skeletal formulae), showing realistic geometry (zig zag)
- draw structures and derive molecular formulae from structures (molecular formulae being of the form $C_aH_bX_cY_d$, where heteroatoms are listed in atomic number order)
- understand structural (including functional group) and geometric (*cis-trans*) isomerism
- understand optical isomerism in terms of asymmetric carbons (chiral carbons)
- use hashed and wedged bonds to represent 3D structures, e.g.



- understand and use nomenclature of molecules with functional groups mentioned in the syllabus, up to six carbon atoms (six plus six for esters)
- use and interpret the terms: *oxidation, reduction, hydrolysis, condensation, isomerisation, substitution, addition, elimination, nucleophile/nucleophilic, electrophile/electrophilic, free-radical, homolytic/heterolytic fission*, as appropriate to Part A or Part B; recognise such reactions, as appropriate to Part A or Part B
- understand and use curly arrows to represent movement of electron pairs in reaction mechanisms.

A3.2 Functional group level

Content

- the inactivity of C–H and C–C bonds
- the diversity of heteroatom chemistry
- the concept of functional group level
- moving between functional group levels
- unstable groups

Candidates should be able to:

- (a) explain the relative inactivity of C–H and C–C single bonds in terms of the absence of lone pairs and dipole moments
- (b) explain in terms of dipole moments and lone pairs, why heteroatoms (O, N, X, etc.) lead to more diverse chemistry (dipole moments, high-energy lone pairs)
- (c) recognise functional groups (limited to the examples in the syllabus, as appropriate to Part A or Part B) present in a given structure, and name simple molecules containing these groups
- (d) use the concept of functional group level of a carbon atom from counting the number of bonds to electronegative atoms on the carbon (no such bond is called the Hydrocarbon level; one bond is called the Alcohol level; two bonds is the Carbonyl level; three bonds is the Carboxylic Acid level; and four bonds is the Carbon Dioxide level); appreciate that functional group level applies to a single carbon atom, not the whole molecule
- (e) state the functional group level of a carbon atom in an unfamiliar example, and deduce changes in functional group level in a reaction scheme
- (f) understand that reaction within a level simply swaps one heteroatom for another, e.g. hydrolysis; that moving a carbon atom up a level requires an oxidizing agent, that moving a carbon atom down a level requires a reducing agent or carbanion equivalent; that hydrolysis ultimately yields the functional group after which the level is named (note that not all heteroatoms hydrolyse under typical conditions, e.g. $-\text{NH}_2$, $-\text{SH}$, $-\text{F}$)
- (g) recognise common examples within the Alcohol level: alcohols, amines, alkyl halides; the Carbonyl level: aldehydes, ketones; the Carboxylic Acid level: carboxylic acids, esters, amides, nitriles; the Carbon Dioxide level: carbon dioxide
- (h) describe what happens when there are unstable groups, e.g. two hydroxyls on the same carbon atom (geminal diol or hydrate) forming aldehyde/ketone; three hydroxyls on one carbon atom forming a carboxylic acid; four hydroxyl groups on one carbon atom forming carbonic acid and carbon dioxide.

A3.3 Lower functional group level reactions – Alcohol level

Content

- moving within the level:
 - synthesis of alcohols and amines from halogenoalkanes
 - synthesis of halogenoalkanes from alcohols
- moving down a level:
 - substitution of halogenoalkanes with cyanide
- moving up a level:
 - oxidation to aldehydes and ketones

Candidates should be able to:

- (a) appreciate that the hydrolysis of any member within the group is an example of moving within the functional group level and leads to an alcohol
- (b) explain how alcohols and amines may be synthesised from halogenoalkanes (using aqueous sodium hydroxide and ethanolic ammonia, respectively), and halogenoalkanes may be synthesised from alcohols using phosphorus halides, and how these are examples of moving within the level
- (c) understand how substitution of halogenoalkanes by cyanide brings the carbon down from the Alcohol level to the Hydrocarbon level
- (d) understand how oxidation, including aldehydes and ketones from primary and secondary alcohols using acidified dichromate(VI), is an example of moving a carbon atom up a level.

A3.4 Lower functional group level reactions – Carbonyl level

Content

- moving within the level:
 - hydrolysis to aldehyde or ketone
 - addition of bisulfite
- moving up a level:
 - oxidation reactions
- moving down a level:
 - addition reactions

Candidates should be able to:

- (a) appreciate that hydrolysis of any member within the group leads to an aldehyde or ketone, and that this is an example of moving within the level
- (b) understand that addition (where the π bond of the carbonyl breaks) of bisulfite (hydrogensulfate(IV)) is an example of reaction within the level
- (c) understand and recall that oxidation, including the use of acidified dichromate(VI) and Tollens' reagent to form carboxylic acids from aldehydes, is an example of moving up a level
- (d) understand and recall that addition of hydrogen cyanide, Grignard reagents or metallic hydrides (e.g. NaBH_4), where the π bond of the carbonyl breaks and a new C–C or C–H bond forms, is an example of a carbon atom moving down a level.

A3.5 Addition and elimination reactions

Content

- C=C and C=O in terms of dipole moments
- addition reactions to C=C
- addition polymerisation
- elimination reactions
- formation of alkenes by elimination

Candidates should be able to:

- (a) compare C=C and C=O π bonds in terms of dipole moments to explain why there is no nucleophilic attack on C=C
- (b) describe addition reactions to C=C: the reaction with H_3O^+ , HBr, H_2 and Br_2
- (c) describe addition polymerisation as an example of an addition reaction and in terms of the repeat unit in the polymer; suggest the monomer given the structure of an addition polymer
- (d) understand that elimination reactions are essentially the reverse of addition reactions and that elimination competes with substitution, the former being favoured by high temperature and high pH
- (e) describe the formation of alkenes by the elimination of HX from alkyl halides or H_2O from alcohols.

A3.6 Green chemistry

Content

- atom economy
- reducing environmental impact

Note that the application of green chemistry principles in question papers may not be restricted to organic chemistry.

Candidates should be able to:

- (a) use the concept of atom economy as a measure of the efficiency of use of reagents in a synthesis (expressed as a percentage using $[\text{relative formula mass of utilised product(s)}] / [\text{relative formula mass of all the reactants used}] \times 100\%$)
- (b) recall and discuss measures that can reduce the impact of the chemical industry and research on the environment, including: finding benign alternatives to hazardous chemicals, using renewable feedstocks, using catalysts rather than stoichiometric reagents, etc.

Part B

B3.7 Higher functional group level reactions – Carboxylic Acid level

Content

- substitution within the level:
 - hydrolysis to carboxylic acids
 - esters from carboxylic acids
 - reactions of acyl chlorides with alcohols/phenols
 - synthesis of amides from acyl chlorides and amines
 - synthesis of acyl chlorides from carboxylic acids
 - condensation polymerisation
- moving down a level:
 - reduction with metal hydrides

Candidates should be able to:

- appreciate that hydrolysis of any member within the group leads to carboxylic acids, e.g. nitriles, amides, esters, acyl chlorides to carboxylic acids, and that these are examples of moving within the level
- understand that the synthesis of esters from carboxylic acids and alcohols, the reaction of acyl chlorides with alcohols/phenols, the synthesis of amides from acyl chlorides and amines, and the synthesis of acyl chlorides from carboxylic acids, are examples of substitution within the level
- understand how condensation polymerisation can occur when there is more than one functional group on reagents, forming, for example, amide links (and peptides from amino acids), glycosidic links (between simple monosaccharides) and ester links
- understand that reductions with metallic hydrides, e.g. esters to alcohols, amides to amines, and nitriles to amines, are examples of moving down level(s); NaBH_4 is capable of reducing aldehydes and ketones to alcohols, whereas the more powerful LiAlH_4 can affect all the above examples.

B3.8 Higher functional group level reactions – Carbon Dioxide level

Content

- moving within the level:
 - hydrolysis to carbon dioxide
- moving down a level:
 - synthesis of carboxylic acids from Grignard reagents

Candidates should be able to:

- appreciate that the hydrolysis of any member within the group leads to carbon dioxide, and that these are examples of moving within the level
- understand that the synthesis of carboxylic acids from Grignard reagents and carbon dioxide is an example of moving down a level.

B3.9 Mechanisms

Content

- S_N1 and S_N2 mechanisms; their determination from kinetics experiments
- transition-state geometry and bond angles; inversion of configuration vs racemisation
- primary, secondary and tertiary classification of halogenoalkanes; C–Hal bond strength
- electrophilic addition mechanism, including Markovnikov's rule
- nucleophilic addition mechanism

Candidates should be able to:

- describe the S_N1 and S_N2 mechanisms and outline their determination from kinetics experiments
- describe the geometry and bond angles in transition states and intermediates, e.g. in S_N1 and S_N2 reactions of halogenoalkanes
- understand that there is inversion of configuration with S_N2 and racemisation with S_N1
- understand the importance of the primary/secondary/tertiary classification of halogenoalkanes on the mechanism of nucleophilic substitution and on C–Hal bond strength
- describe the electrophilic addition mechanism using Br_2 or HBr and alkenes
- explain Markovnikov's rule in terms of the stability of the intermediate carbocation
- explain that Markovnikov products and the interference of nucleophiles are evidence of the mechanism proceeding via a carbocation intermediate
- describe the nucleophilic addition mechanism using hydrogen cyanide and carbonyl compounds
- understand that a racemic product from the addition of HCN to an unsymmetrical carbonyl compound suggests that the nucleophile has no bias for which side of the plane containing the carbonyl bond it attacks.

B3.10 Aromatic chemistry

Content

- stability of aromatic systems
- electrophilic substitution mechanism
- activation and deactivation of the benzene ring
- directing effects

Candidates should be able to:

- appreciate that enthalpies of hydrogenation and resistance to addition reactions indicate the stability of aromatic systems such as benzene in contrast to alkenes
- describe the electrophilic substitution mechanism of the π bond reacting with electrophiles, limited to NO_2^+ (nitration), Br^+ (bromination), R^+ (Friedel-Crafts alkylation), and RCO^+ (Friedel-Crafts acylation)
- appreciate that the benzene ring is activated by electron-donating groups ($-R$, $-OH$, $-OR$, $-NH_2$, $-NR_2$) and deactivated by electron-withdrawing groups ($-C=O$, $-NO_2$), as typified by the reactions of phenol, phenylamine and nitrobenzene
- recall that $-NO_2$, $-COOH$, $-CHO$ and $-CRO$ groups are 3, 5-directors and $-R$, $-OH$, $-OR$, $-NH_2$, $-NR_2$ and $-X$ groups are 2, 4, 6-directors, and appreciate that this distinction is important when synthesising polysubstituted aromatic compounds
- appreciate the utility of aromatic nitro compounds in producing aryl amines.

B3.11 Acidity and basicity

Content

- water, alcohols, phenols and their reactions with sodium
- classification of amines; relative basicities
- substituents on carboxylic acids – inductive effects
- reactions of amino acids with acids and alkalis; zwitterions

Candidates should be able to:

- (a) explain the relative acidities of water, alcohols and phenols, and describe the reaction of these with sodium
- (b) understand the importance of the primary/secondary/tertiary classification of amines and explain the relative basicities of ammonia, aliphatic and aromatic amines
- (c) describe the effect of substituents on carboxylic acids on their acidity in terms of inductive effects, positive (+I) and negative (–I)
- (d) describe the reaction of α -amino acids with acids and alkalis; define zwitterion.

B3.12 Stereochemistry

Content

- Cahn-Ingold-Prelog rules; *R/S* assignment
- chiral molecules and rotation of polarised light; +/– notation
- enantiomers, diastereoisomers, meso compounds

Candidates should be able to:

- (a) use the Cahn-Ingold-Prelog priority rules to assign *R/S* to simple examples
- (b) understand that chiral molecules rotate polarised light and how this is used in following biochemical reactions and assessing purity; explain the +/– notation
- (c) appreciate that there is no connection between the *R/S* and +/– assignments
- (d) define *enantiomer*, *diastereoisomer* and *meso compound* in the case of molecules with two chiral centres, e.g. tartaric acid, and identify these characteristics in simple examples.

4 Analysis

This section is intended to give candidates insight into the physical background of spectroscopic techniques, and the skills to interpret spectra; an appreciation of molecular symmetry and its importance in carbon-13 NMR in particular; the ability to interpret measurements and observations in classical laboratory analytical techniques.

Part A

A4.1 Qualitative and quantitative analysis

Content

- interpreting experimental observations
- performing mole calculations using quantitative data

Candidates should be able to:

- (a) interpret experimental observations of qualitative analysis (with reference to the qualitative analysis notes in the *Data Booklet*)
- (b) calculate percentages by mass from empirical formula, empirical formula from percentages by mass, and molecular formula from relevant information
- (c) calculate quantities from volumetric analysis using mass and amount concentrations, volumes and stoichiometry
- (d) calculate quantities from gravimetric analysis
- (e) recall that one mole of any gas occupies approximately 24 dm^3 at room temperature and pressure.

A4.2 Mass spectrometry

Content

- the physical process of mass spectrometry
- interpreting spectra, including isotope effects

Candidates should be able to:

- (a) outline the physical processes involved: ionisation (either by removing an electron or adding an ion), acceleration and separation by time-of-flight detection
- (b) interpret spectra in terms of the molecular ion and simple fragmentation
- (c) understand the effect of isotopes: intensity of carbon-13 M+1 peak, chlorine and bromine signatures (one halogen only).

A4.3 Electronic spectroscopy

Content

- the physical process
- explaining line spectra qualitatively

Candidates should be able to:

- (a) explain the principle of atomic absorption and emission in terms of electrons moving between energy levels and absorbing/emitting electromagnetic radiation
- (b) use the relationship between energy and frequency, $E = hf$ (Equation 9 in the *Data Booklet*)
- (c) explain qualitatively the line spectrum for hydrogen in terms of electronic transitions between levels, noting that subshells within a quantum shell have the same energy due to the absence of any shielding.

A4.4 Infra-red

Content

- the physical process of infra-red (IR) spectroscopy
- interpreting and predicting spectra

Candidates should be able to:

- explain the principle of the process: excitation of bond vibrations with resonant electromagnetic radiation
- predict relative frequencies of bond vibrations based on bond strength and atomic masses (recall of Hooke's law is not required), and hence appreciate that IR stretching frequency increases in the order: single bonds (except those to hydrogen), double bonds, triple bonds, bonds to hydrogen
- interpret and predict IR spectra for simple organic functional groups, recognising the bond stretch regions as specified in the *Data Booklet*
- appreciate the characteristic appearances of the C=O stretch and O–H stretches in alcohols and carboxylic acids.

A4.5 Carbon-13 NMR

Content

- interpreting and predicting spectra

All spectra will be presented as decoupled, and problems related to carbon-13 will assume all signals are decoupled.

Candidates should be able to:

- appreciate that carbon-13 chemical shift values fall in characteristic ranges as given in the *Data Booklet*
- interpret and predict decoupled carbon-13 NMR spectra, considering the number of peaks in each of the approximate divisions only.

Part B

B4.6 NMR of other spin $\frac{1}{2}$ nuclei

Content

- the physical process, including the origin of the chemical-shift scale
- interpreting spin $\frac{1}{2}$ spectra, including appreciation of coupling and of the characteristics of labile protons

Candidates should be able to:

- describe the physical process: magnetic dipoles interacting with the external field, shielding and coupling
- understand the origin of the delta (δ) chemical shift scale
- interpret spin $\frac{1}{2}$ NMR spectra (proton, fluorine-19, etc.) using spin-spin coupling and signal integrations (no knowledge is required of proton chemical shift values)
- understand the meaning of the term *labile proton* and appreciate that labile protons have no characteristic chemical shift; know how to identify the presence of labile protons in a proton NMR spectrum by the disappearance of signals following addition of D₂O
- appreciate that coupling to n equivalent nuclei gives $n + 1$ peaks; use Pascal's triangle to predict multiplet intensities; use integrals in proton NMR to give ratios of hydrogens in different environments.

5 Practical chemistry

Students should be engaged in practical work at all stages of their learning of chemistry. At least 20% of classroom time should be spent doing practical work individually or in small groups (not including teacher demonstration time). This work should reinforce the learning of the theoretical content of the syllabus, instil an understanding of the interplay of experiment and theory in the scientific method, and be used to develop manipulative and observational skills in the laboratory and an awareness of safe practice. Project work can also be highly motivating for candidates.

Candidates' experimental skills will be formally assessed in the practical exam, Component 4 (learning outcomes in sections C5.1, C5.2 and C5.3), and in one or more written questions in Component 2 (learning outcomes in sections C5.3 and C5.4).

In order to prepare candidates fully for these assessments, it is recommended that at least one practical investigation is undertaken during the course of study. This will allow candidates to appreciate fully the experimental process as a coherent whole, from planning, through manipulation, observation and recording and presentation of data, to analysis of results, drawing conclusions and evaluation of methods and conclusions.

Part C

C5.1 Manipulation, measurement and observation

C5.1.1 Successful collection of data and observations

Candidates should be able to:

- set up apparatus correctly
- follow instructions given in the form of written instructions or diagrams
- use their apparatus to collect an appropriate quantity of data or observations, including subtle differences in colour, solubility or quantity of materials
- make measurements using pipettes, burettes, measuring cylinders, thermometers and other common laboratory apparatus
- take appropriate safety precautions.

Systematic analysis will not be required. It will be assumed that candidates will be familiar with:

- the reactions of the following cations: NH_4^+ , Mg^{2+} , Al^{3+} , Ca^{2+} , Cr^{3+} , Mn^{2+} , Fe^{2+} , Fe^{3+} , Cu^{2+} , Zn^{2+} , Ba^{2+}
- the reactions of the following anions: CO_3^{2-} , NO_3^- , NO_2^- , SO_4^{2-} , SO_3^{2-} , Cl^- , Br^- , I^-
- tests for the following gases: NH_3 , CO_2 , Cl_2 , H_2 , O_2 , SO_2 , as detailed in the qualitative analysis notes.

The substances to be investigated may contain ions not included in the above list; in such cases, candidates will not be expected to identify the ions but only to draw conclusions of a general nature.

Candidates should not attempt tests, other than those specified, on substances, except when it is appropriate to test for a gas, or when the question requires candidates to make their own choice of tests (see 5.1.3).

Owing to safety considerations, SO_2 will not be generated in quantities sufficient for testing in the practical exam. However, candidates are expected to be familiar with this test as it may be performed in class using a fume cupboard.

Exercises requiring a knowledge of simple organic reactions, e.g. test-tube reactions indicating the presence of unsaturated, alcoholic, carbonyl and carboxylic groups, may also be set, but this would be for the testing of observation skills and for drawing general conclusions only, e.g. the use of Tollens' reagent to distinguish between an aldehyde and a ketone.

A knowledge of the following volumetric determinations will be assumed: acids and alkalis using suitable indicators; iron(II) and ethanedioic acid (and its salts) by potassium manganate(VII); iodine and sodium thiosulfate. Simple titrations involving other reagents may also be set but, where appropriate, sufficient working details will be given.

Candidates should normally record burette readings to the nearest 0.05 cm^3 and temperature readings to the nearest 0.5°C when using a thermometer calibrated in 1°C intervals and to the nearest 0.1°C where the interval is 0.2°C .

C5.1.2 Quality of measurements or observations

Candidates should be able to:

- (a) make accurate and consistent measurements and observations.

In qualitative experiments, precise descriptions and comparisons of colour or other observations are expected. In a titration with a good end-point, candidates are expected to record two titres within 0.10 cm^3 .

Marks will be awarded for consistency and accuracy of readings. In some cases, the candidate's data or observations may be compared with information supplied by the supervisor or known to the examiners; in other cases, the award of the mark may be based on the scatter of points on a graph. Examiners will only consider the extent to which the candidate has affected the quality of the data: allowances will be made where the quality of data is limited by the experimental method required or by the apparatus and materials used.

C5.1.3 Decisions relating to measurements or observations

Candidates should be able to:

- (a) decide how many tests or observations to perform
- (b) make measurements that span a range and have a distribution appropriate to the experiment
- (c) decide how long to leave experiments running before taking readings
- (d) identify where repeated readings or observations are appropriate
- (e) replicate readings or observations as necessary
- (f) identify where confirmatory tests are appropriate and the nature of such tests
- (g) choose reagents to distinguish between given ions.

Candidates may need to choose how many tests, measurements and observations can be made in the time available. Candidates will be expected to be able to identify the most appropriate range and distribution of values. In some experiments, a regularly spaced set of measurements will be appropriate.

Repeated readings of particular quantities are often necessary in chemistry in order to obtain accurate values and minimise experimental error. Individual readings or observations should be repeated where they appear to be anomalous. In qualitative analysis experiments, candidates may be expected to identify appropriate confirmatory tests.

C5.2 Presentation of data and observations

C5.2.1 Recording data or observations

Candidates should be able to:

- present numerical data, values or observations in a single table of results
- include in the table of results, if necessary, columns for raw data, for calculated values and for analyses or conclusions
- use column headings that include both the quantity and the unit and that conform to accepted scientific conventions
- record raw readings of a quantity to the same degree of precision, and observations to the same level of detail.

As an example of accepted practice in column headings, if the quantity being measured is volume in cm^3 , then 'volume/ cm^3 ' would be the usual way to write the column heading, but 'volume in cm^3 ' or 'volume (cm^3)' would be allowed. Headings such as 'volume cm^3 ' or just ' cm^3 ' are not acceptable. The quantity or the unit or both may be written in words, or appropriate symbols may be used provided that their meaning is clear and unambiguous in the context (e.g. avoid t , since it may be used for time and for temperature). Conventional symbols or abbreviations, such as ΔH for enthalpy change or ppt. for precipitate, may be used without explanation.

In recording data and observations, if one measurement of mass in a column of raw data is given as 0.06 g, then all the masses in that column should be given to the nearest 0.01 g. The degree of precision used should be compatible with the measuring instrument used; it would be inappropriate to record a mass measured on a gram scale as '0.0542 kg'. With some measuring instruments, e.g. a burette, it may be appropriate to interpolate between the marks, but in general, where the calibration marks are close together, then the reading should be to the nearest calibration mark.

Observations of qualitative variables such as colour should be recorded in simple language such as 'blue' or 'orange'. Where fine discrimination is required, terms such as 'pale' or 'dark' should be used, and comparisons made such as 'darker red than at 3 minutes'.

C5.2.2 Display of calculation and reasoning

Candidates should be able to:

- show their working in calculations, and the key steps in their reasoning
- use the correct number of significant figures for calculated quantities.

Where calculations are done, all of the key stages in the calculation should be recorded by candidates, so the credit can be given for correctly displaying working. Similarly, where observations form the basis for logical deduction (e.g. the concentration of a solution or the identity of an unknown substance), the steps in making the deduction should be shown. Again, where inductive thought processes are used to build up a general prediction or to support a general theory, from specific observations, the sequence of steps used should be reported.

Calculated quantities should be given to the same number of significant figures (or one more than) the measured quantity of least accuracy. For example, if titre volume is measured to three significant figures, then the corresponding molar concentration should be given to three significant figures.

C5.2.3 Data layout

Candidates should be able to:

- choose a suitable and clear method of presenting the data, e.g. tabulations, graph or a mixture of methods of presentation
- use the appropriate presentation medium to produce a clear presentation of the data
- select which variables to plot against which, and decide whether the graph should be drawn as a straight line or a curve
- plot appropriate variables on clearly labelled x- and y-axes
- choose suitable scales for graph axes
- plot all points or bars to an appropriate accuracy
- follow the ASE recommendations for putting lines on graphs.

Generally, candidates are expected to present data in the form in which the key points of the data can be most easily visualised. For qualitative data, this is likely to be a table. For quantitative data, this may be a graph or a table. Candidates should choose scales for the graph axes that allow the graph to be read easily, such as 1, 2 or 5 units to a 20 mm square. It is anticipated that candidates will be able to make the best use of the space available for making their presentation: using over half of the length of a grid in both x- and y-directions so that the data points occupy at least half of the graph grid in both directions; making tables of qualitative observations large enough so that all the entries can be comfortably fitted in the available space. The presentation medium should be pencil for lines on tables and graphs.

The accepted scientific conventions for labelling the axes of a graph are the same as for the column headings in a table of results, with both the quantity and the unit shown (where appropriate). Points should be finely drawn with a sharp pencil, but must still be visible. A fine cross or an encircled dot is suitable; a thick pencil blob is not. Often it is obvious that the data fall on a straight line or smooth curve, and a line of best fit or appropriate curve should be placed on the graph. In some cases candidates may be expected to draw two curves or lines and find the intersection. A line of best fit should show an even distribution of points on either side of the line along its whole length. Lines should be finely drawn and should not contain kinks or breaks. Candidates will be expected to extrapolate lines to read intercepts with axes or other lines or to predict values outside the range of the experiment.

C5.3 Analysis, conclusions and evaluation

C5.3.1 Interpretation of data or observations

Candidates should be able to:

- describe the patterns and trends shown by tables and graphs
- describe and summarise the key points of a set of observations
- find an unknown value by using coordinates or intercepts on a graph
- calculate other quantities from data, or calculate the mean from replicate values, or make other appropriate calculations
- determine the gradient of a straight-line graph.

Descriptions should be precise, giving quotations of figures to support the description, and calculated values where these are appropriate. Unknown values might include a titration end-point or change in mass. Calculations may involve mean, percentage, percentage gain or loss, rate of reaction, concentration, molar mass, volume of gases or other appropriate calculations. When a gradient is to be determined, the points on the line chosen for the calculation should be separated by at least half of the length of the line drawn.

C5.3.2 Drawing conclusions

Candidates should be able to:

- draw conclusions from an experiment, giving an outline description of the main features of the data, considering whether experimental data supports a given hypothesis, and making further predictions
- draw conclusions from interpretations of observations, data and calculated values
- make scientific explanations of the data, observations and conclusions that they have described.

Conclusions may be expressed in terms of support for, or refutation of, hypotheses, or in terms of the deductions or inductions that can logically be made from the data, observations or calculated values.

Simple scientific explanations form a part of such conclusions and therefore form a part of this practical assessment, in which candidates will be expected to refer to knowledge and understanding gained in the theory part of their course in order to provide explanations of their practical conclusions.

C5.3.3 Evaluation

Candidates should be able to:

- identify the most significant sources of error in an experiment
- estimate, quantitatively, the uncertainty in quantitative measurements
- express such uncertainty in a measurement as an absolute or percentage uncertainty
- show an understanding of the distinction between systematic errors and random errors
- identify the extent to which readings have been adequately replicated, and describe the adequacy of the data range
- identify and deal with anomalous values and suggest possible explanations for anomalous readings
- evaluate the effectiveness of control variables
- make informed judgements on the confidence with which conclusions may be drawn.

Candidates should be used to looking at experiments and assessing the relative importance of errors: in measurement; in making observations; or in experiments where limitations of the method introduce errors (e.g. heat loss when trying to assess enthalpy change). They should be able to quantify uncertainties in measurement as half a graduation on the measuring apparatus, and express these uncertainties in standard form, e.g. temperature = $14.0^{\circ}\text{C} \pm 0.5^{\circ}\text{C}$. Candidates should appreciate the doubling of these uncertainties when measuring by difference and be able to calculate percentage uncertainty based on an absolute uncertainty.

Candidates should be able to suggest which of the sources of error described are likely to be systematic errors, such as those resulting from thermometers that consistently read 1°C above actual temperature, or from reading volumes to the wrong part of the meniscus, as well as those which are likely to be random errors due to variability of materials, or random variations in room temperature. It is expected that candidates will be able to identify the sense in which the errors affect the final result.

Candidates will be expected to have knowledge of the advantages of replication of data, and the practical limitations of the data. Candidates should be able to identify instances where it would have been sensible to take readings at lower or higher values, or where there are gaps in the range that reduce the information obtained (e.g. around a turning point). Candidates will be expected to be able to draw together information to make judgements about the reliability of the experiment and the trustworthiness of its outcomes.

C5.3.4 Suggesting improvements

Candidates should be able to:

- suggest modifications to an experimental arrangement that will improve the accuracy of the experiment or the accuracy of the observations that can be made
- suggest improvements to an experiment in order to increase the confidence in the conclusions drawn
- suggest ways in which to extend the investigation to answer a new question
- describe such modifications clearly in words or diagrams.

Candidates' suggestions should be realistic, so that in principle they are achievable in practice, although they may include the use of apparatus that is not available to the candidate (e.g. a colorimeter). The suggestions may relate either to the apparatus used, to the experimental procedure followed or to the nature of the observations or the means used to make them. Candidates may include improvements that they have actually made while carrying out the experiment, such as repeating readings. The suggested modifications may relate to sources of error or uncertainty identified by the candidate or to other sources of error or uncertainty. Extensions of the investigation should only be proposed specifically to permit the answering of a specified new question. In relation to the evaluations they have made, candidates may be offered the opportunity to suggest how the investigation may be improved in order to increase the confidence in the conclusions drawn.

C5.4 Planning

C5.4.1 Methods

Candidates should be able to:

- describe the arrangement of apparatus and the steps in the procedure to be followed
- suggest appropriate volumes and concentrations of reagents, making use of relevant stoichiometry, dilution factors and the requirement for repeats
- describe precautions that should be taken to keep risks to a minimum
- draw up tables for data that they might wish to record
- identify variables that are to be controlled.

The overall arrangement should be workable. It should be possible to collect the data required without undue difficulty if the apparatus were assembled as described. Words and labelled diagrams should be used for describing the apparatus and how to use it.

Candidates should have an appreciation of how accuracy is maintained when transferring materials; the usual sizes of glassware found in a school laboratory, e.g. pipettes (10 cm³, 25 cm³, 50 cm³), burettes (25 cm³, 50 cm³) and volumetric flasks (100 cm³, 250 cm³, 500 cm³); the importance of measuring by difference; the properties of a primary standard; the distinction between limiting and excess reagents and how quantities of these are measured out; the accurate determination of an end-point in a titration. The measuring instruments chosen should measure the correct quantity to a suitable precision.

Candidates should be able to construct a logical sequence of steps for identifying unknown species and describe the observations that might be expected in a given experiment/investigation. Candidates should appreciate the reasons for employing a set of reaction conditions; appreciate the use and choice of solvent for a reaction; describe techniques for the separation, purification and purity-checking of products; appreciate the choice and use of solvents and electrolytes for solvent extraction/work-up; appreciate the different degrees of mixing solvents with other solvents.

Candidates should be able to propose appropriate safety precautions related to the risks that they identify in their plan. Candidates should be able to suggest precautions that might be taken to avoid side-reactions/loss of yield.

C5.4.2 Dealing with data

Candidates should be able to:

- (a) identify the calculations and means of presentation of data that are necessary to be able to draw conclusions from data
- (b) suggest and use calculations to enable simplification or explanation of data
- (c) suggest and use tables and graphs to draw attention to the key points in quantitative data, including the variability of data.

Candidates should know how to choose and carry out calculations required to simplify or make comparable data. These calculations might include the mean, median, mode, percentage and percentage gain or loss. Candidates should also know how to choose and construct appropriate data tables, including columns for calculated values, and headings including quantity and unit where appropriate. Similarly, they should be able to construct suitable graphs displaying the independent variable on the x -axis and dependent variable on the y -axis.

Mathematical requirements

It is assumed that candidates will be competent in the techniques described below.

- (a) making calculations involving addition, subtraction, multiplication and division of quantities
- (b) making approximate evaluations of numerical expressions
- (c) expressing small fractions as percentages, and vice versa
- (d) calculating an arithmetic mean
- (e) transforming decimal notation to power of ten notation (standard form)
- (f) using tables or calculators to evaluate logarithms (for pH calculations), squares, square roots and reciprocals
- (g) changing the subject of an equation (most such equations involve only the simpler operations but may include positive and negative indices and square roots)
- (h) substituting physical quantities into an equation using consistent units so as to calculate one quantity; check the dimensional consistency of such calculations
- (i) solving simple algebraic equations
- (j) comprehending and using the symbols/notations $<$, $>$, \approx , $/$, Δ , \equiv
- (k) testing tabulated pairs of values for direct proportionality by a graphical method or by constancy of ratio
- (l) selecting appropriate variables and scales for plotting a graph, especially to obtain a linear graph of the form $y = mx + c$
- (m) determining and interpreting the gradient and intercept of a linear graph
- (n) choosing by inspection a straight line that will serve as the 'best fit' linear model for a set of data presented graphically
- (o) understanding:
 - (i) the gradient of a tangent to a curve as a measure of rate of change
 - (ii) the 'area' below a curve where the area has physical significance, e.g. Maxwell-Boltzmann distribution curves
- (p) comprehending how to handle numerical work so that significant figures are neither lost unnecessarily nor used beyond what is justified
- (q) estimating orders of magnitude
- (r) formulating simple algebraic equations as mathematical models, e.g. constructing a rate equation, and identifying failures of such models.

Calculators

If calculators are to be used, it is suggested that they should have the following functions:

$+$, $-$, \times , \div , \sqrt{x} , x^2 , x^y , $\log x$, $\ln x$. A memory function may be useful but is not essential.

Data Booklet

Important values and constants

molar gas constant	R	$= 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
the Faraday constant	F	$= 9.65 \times 10^4 \text{ C mol}^{-1}$
the Avogadro constant	L	$= 6.02 \times 10^{23} \text{ mol}^{-1}$
the Planck constant	h	$= 6.63 \times 10^{-34} \text{ J s}$
speed of light in a vacuum	c	$= 3.00 \times 10^8 \text{ m s}^{-1}$
electronic charge	e	$= -1.60 \times 10^{-19} \text{ C}$

Important equations

(1) Specific heat capacity: $q = mc\Delta T$

where q is heat produced in joules (J); m is mass in g; c is specific heat capacity in $\text{J g}^{-1}\text{K}^{-1}$; and ΔT is the temperature change in K

(2) Gibbs energy equation: $\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus$

ΔG^\ominus is the standard Gibbs energy change; ΔH^\ominus is the standard enthalpy change; T is thermodynamic temperature; ΔS^\ominus is the standard entropy change

(3) Gibbs and equilibrium: $\Delta G^\ominus = -RT \ln K$

ΔG^\ominus is the standard Gibbs energy change; R is the molar gas constant; T is thermodynamic temperature; K is the equilibrium constant

(4) Equilibrium constant: $K = \frac{[C]_{\text{eq}}^c}{[A]_{\text{eq}}^a [B]_{\text{eq}}^b}$ for the equilibrium $aA + bB \rightleftharpoons cC$

$[X]$ is the concentration of X divided by the standard concentration

(5) Cell free energy change: $\Delta G^\ominus = -nFE_{\text{cell}}^\ominus$

ΔG^\ominus is the standard Gibbs energy change; n is the number of electrons; F is the Faraday constant; E_{cell}^\ominus is the standard cell potential

(6) Ideal gas equation: $pV = nRT$

p is pressure; V is volume; n is amount; R is the molar gas constant; T is thermodynamic temperature

(7) Arrhenius equation: $k = A \exp\left(\frac{-E_a}{RT}\right)$

k is the rate constant; A is the pre-exponential factor; E_a is the activation energy; R is the molar gas constant; T is thermodynamic temperature

(8) First-order kinetics: $\ln(C_0/C_t) = kt$

C_0 is the concentration at time $t = 0$; C_t is the concentration at time t ; k is the rate constant

(9) Electromagnetic energy: $E = hf$

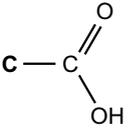
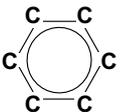
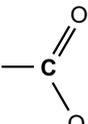
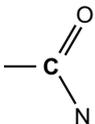
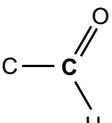
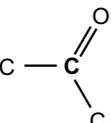
E is the photon energy; h is the Planck constant; f is frequency

Characteristic ranges for infra-red absorption in organic molecules

Bond	Location	Characteristic range wavenumber /cm ⁻¹
C-Cl		700–800
C-O	alcohols, ethers, esters	1000–1300
C=C		1610–1680
C=O	aldehydes, ketones, carboxylic acids, esters	1640–1750 (strong)
C≡C		2070–2250
C≡N		2200–2280
O-H	in carboxylic acids	2500–3300 (very broad)
C-H	alkanes, alkenes, arenes	2840–3100
O-H	in alcohols, phenols	3200–3550 (broad)
N-H	primary amines	3350–3500

Carbon-13 chemical shifts relative to TMS

Chemical shifts are typical values and can vary slightly depending on the solvent.

Type of carbon	Chemical shift δ /ppm
C-C (alkanes)	10–35
	20–30
C-Cl or C-Br	30–70
C-N (amines)	35–60
C-OH	50–65
C=C	115–140
	125–150
carbonyl (ester, carboxylic acid, amide)	160–185
 	
carbonyl (aldehyde, ketone)	190–220
 	

Qualitative Analysis Notes

[Key: ppt. = precipitate]

1 Reactions of aqueous cations

<i>cation</i>	<i>reaction with</i>	
	NaOH(aq)	NH ₃ (aq)
aluminium, Al ³⁺ (aq)	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, NH ₄ ⁺ (aq)	no ppt. ammonia produced on heating	–
barium, Ba ²⁺ (aq)	no ppt. (if reagents are pure)	no ppt.
calcium, Ca ²⁺ (aq)	white ppt. with high [Ca ²⁺ (aq)]	no ppt.
chromium(III), Cr ³⁺ (aq)	grey-green ppt. soluble in excess giving dark green solution	grey-green ppt. insoluble in excess
copper(II), Cu ²⁺ (aq)	pale blue ppt. insoluble in excess	blue ppt. soluble in excess giving dark blue solution
iron(II), Fe ²⁺ (aq)	green ppt., turning brown on contact with air insoluble in excess	green ppt., turning brown on contact with air insoluble in excess
iron(III), Fe ³⁺ (aq)	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
magnesium, Mg ²⁺ (aq)	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), Mn ²⁺ (aq)	off-white ppt., rapidly turning brown on contact with air insoluble in excess	off-white ppt., rapidly turning brown on contact with air insoluble in excess
zinc, Zn ²⁺ (aq)	white ppt. soluble in excess	white ppt. soluble in excess

2 Reactions of anions

<i>ion</i>	<i>reaction</i>
carbonate, CO_3^{2-}	CO_2 liberated by dilute acids
chloride, Cl^- (aq)	gives white ppt. with Ag^+ (aq) (soluble in NH_3 (aq))
bromide, Br^- (aq)	gives cream ppt. with Ag^+ (aq) (partially soluble in NH_3 (aq))
iodide, I^- (aq)	gives yellow ppt. with Ag^+ (aq) (insoluble in NH_3 (aq))
nitrate, NO_3^- (aq)	NH_3 liberated on heating with OH^- (aq) and <i>Al</i> foil
nitrite, NO_2^- (aq)	NH_3 liberated on heating with OH^- (aq) and <i>Al</i> foil; NO liberated by dilute acids (colourless $\text{NO} \rightarrow$ (pale) brown NO_2 in air)
sulfate, SO_4^{2-} (aq)	gives white ppt. with Ba^{2+} (aq) (insoluble in excess dilute strong acids)
sulfite, SO_3^{2-} (aq)	SO_2 liberated with dilute acids; gives white ppt. with Ba^{2+} (aq) (soluble in excess dilute strong acids)

3 Tests for gases

<i>gas</i>	<i>test and test result</i>
ammonia, NH_3	turns damp red litmus paper blue
carbon dioxide, CO_2	gives a white ppt. with limewater (ppt. dissolves with excess CO_2)
chlorine, Cl_2	bleaches damp litmus paper
hydrogen, H_2	"pops" with a lighted splint
oxygen, O_2	relights a glowing splint
sulfur dioxide, SO_2	turns acidified potassium manganate(VII) from purple to colourless

Guidance relating to practical work and assessment

Apparatus and materials list

Details of the specific requirements for apparatus and materials for a particular examination are given in the Confidential Instructions, which are sent to Centres several weeks prior to the examination.

The list below has been drawn up in order to give guidance to schools concerning the apparatus and materials that are expected to be generally available for examination purposes. The list is not intended to be exhaustive: in particular, items that are commonly regarded as standard equipment in a chemical laboratory (such as Bunsen burners, tripods and glass tubing) are not included.

Unless otherwise stated, the rate of allocation is 'per candidate'.

Apparatus

two burettes, 50 cm³
two pipettes, 25 cm³
dropping pipettes
one pipette filler
conical flasks: three within range 150 cm³ to 250 cm³
volumetric flask, 250 cm³
measuring cylinders, 10 cm³, 25 cm³ and 50 cm³
wash bottle
two filter funnels
porcelain crucible, approximately 15 cm³, with lid
evaporating basin, at least 30 cm³
beakers, squat form with lip, 100 cm³ and 250 cm³
thermometers, -10 °C to +110 °C at 1 °C, and -10 °C to +50 °C at 0.5 °C
plastic beaker, e.g. polystyrene, of approximate capacity 150 cm³
test-tubes (some of which should be pyrex or hard glass), approximately 125 mm × 16 mm
boiling tubes, approximately 150 mm × 25 mm
stop-clock or sight of a clock to measure to an accuracy of 1 s
balance, single-pan, direct reading, minimum accuracy 0.1 g (1 per 8–12 candidates), weighing to 300 g
a pen for labelling glassware
a spatula

Materials

It is suggested that the following materials be used in the Centre as part of the practical course. They may also be required for the practical examination. Practical examinations may also require chemicals that are not listed.

For titration

Acid/base titration

common laboratory acids (hydrochloric acid, sulfuric acid, nitric acid)
a weak acid such as ethanoic or propanoic acid
sodium hydroxide
sodium carbonate
thymolphthalein
methyl orange or screened methyl orange indicator

Manganate(VII) titration

potassium manganate(VII)
 hydrogen peroxide
 iron(II) sulfate or ammonium iron(II) sulfate
 sodium nitrite
 ethanedioic acid or its soluble salts
 sulfuric acid

Iodine/thiosulfate titration

potassium manganate(VII)
 hydrogen peroxide
 potassium iodate(V)
 potassium iodide
 sodium thiosulfate
 sulfuric acid
 starch indicator

For qualitative analysis**Bench reagents**

aqueous ammonia (approximately 2.0 mol dm^{-3})
 aqueous sodium hydroxide (approximately 2.0 mol dm^{-3})
 hydrochloric acid (approximately 2.0 mol dm^{-3})
 nitric acid (approximately 2.0 mol dm^{-3})
 sulfuric acid (approximately 1.0 mol dm^{-3})
 aqueous barium nitrate or aqueous barium chloride (approximately 0.1 mol dm^{-3})
 aqueous silver nitrate (approximately 0.05 mol dm^{-3})
 aqueous potassium iodide (approximately 0.1 mol dm^{-3})
 potassium manganate(VII) (approximately 0.02 mol dm^{-3})
 limewater (a saturated solution of calcium hydroxide) and the equipment normally used by the Centre to test for carbon dioxide
 acidified aqueous potassium manganate(VII) (0.01 mol dm^{-3})
 red and blue litmus paper
 splints and a Bunsen burner
 aluminium foil

Inorganic analysis

- the carbonates (where they exist), sulfates, nitrates and chlorides of the cations listed in the qualitative analysis notes
- the sodium and potassium salts of the anions listed in the qualitative analysis notes

Organic analysis

- the reagents necessary to perform the reactions of alcohols (primary, secondary, tertiary), aldehydes, ketones, carboxylic acids and esters listed in the syllabus

Note: tests for aldehydes may be performed by substituting glucose for the aldehyde.

Safety in the laboratory

Responsibility for safety matters rests with Centres. Attention is drawn to the following regulations, associations and publications.

European regulations

The European Chemicals Agency, ECHA, publishes a 'candidate list' of chemicals that are scheduled to require authorisation under EU chemicals legislation and are therefore unsuitable for use in schools: <http://echa.europa.eu/web/guest/candidate-list-table>

UK regulations

Control of Substances Hazardous to Health Regulations (COSHH) 2002. A brief guide may be found at www.hse.gov.uk/pubns/indg136.pdf

Associations

CLEAPSS is an advisory service providing support in practical science and technology, primarily for UK schools. International schools and post-16 colleges can apply for associate membership, which includes access to the CLEAPSS publications listed below, www.cleapss.org.uk

Publications

Safeguards in the School Laboratory, ASE, 11th Edition, 2006

Topics in Safety, ASE, 3rd Edition, 2001

CLEAPSS Laboratory Handbook (available to CLEAPSS members only)

CLEAPSS Hazcards (available to CLEAPSS members only)

Safety in Science Education, DfES, HMSO, 1996

Hazardous Chemicals Manual, SSERC, 1997

Hazardous Chemicals. An interactive manual for science education, SSERC, 2002 (CD)

Hazard codes

The following hazard codes are used where relevant in this syllabus and in Confidential Instructions and are in accordance with information provided by CLEAPSS at the time of publication of this syllabus. Centres should be aware that the United Nations Global Harmonised System for hazard classification and compatible labelling (2015) is in the process of being implemented and therefore Centres are advised to make full use of the 'Safety Data Sheets' supplied with chemicals for current hazard information. The attention of Centres is also drawn to any local regulations relating to safety, first-aid and disposal of chemicals.

C = corrosive

MH = moderate hazard

HH = health hazard

T = acutely toxic

F = flammable

O = oxidising

N = hazardous to the aquatic environment

Guidance for the preparation of reagents

Detailed guidance on preparing standard bench reagents and indicators will **not** be given in the Confidential Instructions. The Confidential Instructions will refer Supervisors to the following guidance notes.

Hazard	Label	Identity	Instructions
	dilute hydrochloric acid	$2.0 \text{ mol dm}^{-3} \text{ HCl}$	Dilute 170 cm^3 of concentrated (35–37%; approximately 11 mol dm^{-3}) hydrochloric acid [C] [MH] to 1 dm^3 .
[C]	dilute nitric acid	$2.0 \text{ mol dm}^{-3} \text{ HNO}_3$	Dilute 128 cm^3 of concentrated (70% w/v) nitric acid [C] [O] to 1 dm^3 .
[MH]	dilute sulfuric acid	$1.0 \text{ mol dm}^{-3} \text{ H}_2\text{SO}_4$	Cautiously pour 55 cm^3 of concentrated (98%) sulfuric acid [C] into 500 cm^3 of distilled water with continuous stirring. Make the solution up to 1 dm^3 with distilled water. Care: concentrated H_2SO_4 is very corrosive.
[C] [MH] [N]	aqueous ammonia	$2.0 \text{ mol dm}^{-3} \text{ NH}_3$	Dilute 112 cm^3 of concentrated (35%) ammonia [C] [MH] [N] to 1 dm^3 .
[C]	aqueous sodium hydroxide	$2.0 \text{ mol dm}^{-3} \text{ NaOH}$	Dissolve 80.0 g of NaOH [C] in each dm^3 of solution. Care: the process of solution is exothermic and any concentrated solution is very corrosive.
	aqueous barium chloride [or aqueous barium nitrate]	0.1 mol dm^{-3} barium chloride [or 0.1 mol dm^{-3} barium nitrate]	Dissolve 24.4 g of $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$ [T] (or 26.1 g of $\text{Ba}(\text{NO}_3)_2$ [HH] [O]) in each dm^3 of solution.
[N]	aqueous silver nitrate	0.05 mol dm^{-3} silver nitrate	Dissolve 8.5 g of AgNO_3 [C] [O] [N] in each dm^3 of solution.
[MH]	1.0 mol dm^{-3} sodium carbonate	1.0 mol dm^{-3} sodium carbonate	Dissolve 286 g of $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ [MH] in each dm^3 of solution.
[MH]	limewater	saturated aqueous calcium hydroxide, $\text{Ca}(\text{OH})_2$	Prepare fresh limewater by leaving distilled water to stand over solid calcium hydroxide [MH] for several days, shaking occasionally. Decant or filter the solution.
	0.1 mol dm^{-3} potassium iodide	$0.1 \text{ mol dm}^{-3} \text{ KI}$	Dissolve 16.6 g of KI in each dm^3 of solution.
	0.02 mol dm^{-3} potassium manganate(VII)	$0.02 \text{ mol dm}^{-3} \text{ KMnO}_4$	Dissolve 3.16 g of KMnO_4 [N] [O] [MH] in each dm^3 of solution.
	starch indicator	freshly prepared aqueous starch indicator (approx. 2% solution w/v)	Mix 2 g of soluble starch with a little cold water until a smooth paste is obtained. Add 100 cm^3 boiling water and stir. Boil until a clear solution is obtained (about 5 minutes).

Hazard	Label	Identity	Instructions
[F] [MH] [HH]	methyl orange indicator	methyl orange indicator (pH range 2.9 to 4.6)	Use commercially produced solution or dissolve 0.4 g of solid indicator [T] in 200 cm ³ of ethanol (IMS) [F] [MH] [HH] and make up to 1 dm ³ with distilled water.
[F] [MH] [HH]	thymolphthalein indicator	thymolphthalein indicator (pH range 9.3 to 10.5)	Dissolve 2.0 g of the solid indicator in 1 dm ³ of ethanol (IMS) [F] [MH] [HH] .
[MH]	acidified aqueous potassium manganate(VII)	0.01 mol dm ⁻³ KMnO ₄ 0.5 mol dm ⁻³ sulfuric acid	Mix equal volumes of 0.02 mol dm ⁻³ KMnO ₄ and 1.0 mol dm ⁻³ sulfuric acid [MH] .

Additional information

Equality and inclusion

This syllabus complies with our *Code of Practice* and *Ofqual General Conditions of Recognition*.

We have taken great care in the preparation of this syllabus and related assessment materials to avoid bias of any kind. To comply with the UK Equality Act (2010), we have designed this qualification with the aim of avoiding direct and indirect discrimination.

The standard assessment arrangements may present unnecessary barriers for candidates with disabilities or learning difficulties. Arrangements can be put in place for these candidates to enable them to access the assessments and receive recognition of their attainment. Access arrangements will not be agreed if they give candidates an unfair advantage over others or if they compromise the standards being assessed. Candidates who are unable to access the assessment of any component may be eligible to receive an award based on the parts of the assessment they have taken. Information on access arrangements is found in the *Cambridge Handbook (UK)*, for the relevant year, which can be downloaded from the website www.cambridgeinternational.org/eoguide

Guided learning hours

Cambridge Pre-U syllabuses are designed on the assumption that learners have around 380 guided learning hours per Principal Subject over the duration of the course, but this is for guidance only. The number of hours may vary according to curricular practice and the learners' prior experience of the subject.

Total qualification time

This syllabus has been designed assuming that the total qualification time per subject will include both guided learning and independent learning activities. The estimated number of guided learning hours for this syllabus is 380 hours over the duration of the course. The total qualification time for this syllabus has been estimated to be approximately 500 hours per subject over the duration of the course. These values are guidance only. The number of hours required to gain the qualification may vary according to local curricular practice and the learners' prior experience of the subject.

If you are not yet a Cambridge school

Learn about the benefits of becoming a Cambridge school at www.cambridgeinternational.org/startcambridge. Email us at info@cambridgeinternational.org to find out how your organisation can register to become a Cambridge school.

Language

This syllabus and the associated assessment materials are available in English only.

