UNIVERSITY *of* CAMBRIDGE
International Examinations

Cambridge
International
AS & A Level

SYLLABUS

Cambridge International AS and A Level Chemistry

9701

For examination in June and November 2014

Contents

Alterations in the syllabus are indicated by black vertical lines on either side of the text.

1. Introduction

1.1 Why choose Cambridge?

University of Cambridge International Examinations is the world's largest provider of international education programmes and qualifications for 5 to 19 year olds. We are part of the University of Cambridge, trusted for excellence in education. Our qualifications are recognised by the world's universities and employers.

Recognition

A Cambridge International AS or A Level is recognised around the world by schools, universities and employers. The qualifications are accepted as proof of academic ability for entry to universities worldwide, though some courses do require specific subjects.

Cambridge International A Levels typically take two years to complete and offer a flexible course of study that gives students the freedom to select subjects that are right for them. Cambridge International AS Levels often represent the first half of an A Level course but may also be taken as a freestanding qualification. They are accepted in all UK universities and carry half the weighting of an A Level. University course credit and advanced standing is often available for Cambridge International A/AS Levels in countries such as the USA and Canada.

Learn more at **www.cie.org.uk/recognition**

Excellence in education

We understand education. We work with over 9000 schools in over 160 countries who offer our programmes and qualifications. Understanding learners' needs around the world means listening carefully to our community of schools, and we are pleased that 98 % of Cambridge schools say they would recommend us to other schools.

Our mission is to provide excellence in education, and our vision is that Cambridge learners become confident, responsible, innovative and engaged.

Cambridge programmes and qualifications help Cambridge learners to become:

- **confident** in working with information and ideas – their own and those of others
- **responsible** for themselves, responsive to and respectful of others
- **innovative** and equipped for new and future challenges
- **engaged** intellectually and socially, ready to make a difference.

Support in the classroom

We provide a world-class support service for Cambridge teachers and exams officers. We offer a wide range of teacher materials to Cambridge schools, plus teacher training (online and face-to-face), expert advice and learner-support materials. Exams officers can trust in reliable, efficient administration of exams entry and excellent, personal support from our customer services. Learn more at **www.cie.org.uk/teachers**

Not-for-profit, part of the University of Cambridge

We are a part of Cambridge Assessment, a department of the University of Cambridge and a not-for-profit organisation.

We invest constantly in research and development to improve our programmes and qualifications.

1.2 Why choose Cambridge International AS and A Level?

Cambridge International AS and A Levels have a proven reputation for preparing students well for university, employment and life. They help develop the in-depth subject knowledge and understanding which are so important to universities and employers.

You can offer almost any combination of 55 subjects. Students can specialise or study a range of subjects, ensuring breadth. Giving students the power to choose helps motivate them throughout their studies.

Cambridge International AS and A Level gives you building blocks to build an individualised curriculum that develops your learners' knowledge, understanding and skills in:

- in-depth subject content
- independent thinking
- applying knowledge and understanding to new as well as familiar situations
- handling and evaluating different types of information sources
- thinking logically and presenting ordered and coherent arguments
- making judgements, recommendations and decisions
- presenting reasoned explanations, understanding implications and communicating them clearly and logically
- working and communicating in English.

The syllabuses are international in outlook, but retain a local relevance. They have been created specifically for an international student body with content to suit a wide variety of schools and avoid cultural bias.

1.3 Why choose Cambridge International AS and A Level Chemistry?

Cambridge International AS and A Level Chemistry are accepted by universities and employers as proof of essential knowledge and ability.

This syllabus is designed:

- to stimulate students, create and sustain their interest in Chemistry, and understand its relevance to society
- to give a thorough introduction to the study of Chemistry and scientific methods
- to develop skills and abilities that are relevant to the safe practice of science and to everyday life: concern for accuracy and precision, objectivity, integrity, the skills of enquiry, initiative and insight
- to enable candidates to become confident citizens in a technological world and to take an informed interest in matters of scientific importance
- to stimulate interest in, and care for, the environment.

Chemistry is one of a number of science syllabuses which Cambridge offers – for details of other syllabuses at Cambridge IGCSE, Cambridge O Level and Cambridge International AS and A Level visit the Cambridge website at **www.cie.org.uk**

1.4 Cambridge AICE (Advanced International Certificate of Education) Diploma

Cambridge AICE (Advanced International Certificate of Education) Diploma is the group award of Cambridge International AS and A Level.

Cambridge AICE Diploma involves the selection of subjects from three curriculum groups – Mathematics and Science; Languages; Arts and Humanities.

A Cambridge International A Level counts as a double-credit qualification and a Cambridge International AS Level as a single-credit qualification within the Cambridge AICE Diploma award framework.

To be considered for an AICE Diploma, a candidate must earn the equivalent of six credits by passing a combination of examinations at either double credit or single credit, with at least one course coming from each of the three curriculum areas.

The AICE Diploma is comprised of examinations administered in May/June and October/November series each year.

Chemistry (9701) falls into Group 1, Mathematics and Science.

Learn more about the AICE Diploma at **http://www.cie.org.uk/qualifications/academic/uppersec/aice**

1.5 How can I find out more?

If you are already a Cambridge school

You can make entries for this qualification through your usual channels. If you have any questions, please contact us at **international@cie.org.uk**

If you are not yet a Cambridge school

Learn about the benefits of becoming a Cambridge school at **www.cie.org.uk/startcambridge**.
Email us at **international@cie.org.uk** to find out how your organisation can become a Cambridge school.

2. Assessment at a glance

- Candidates for Advanced Subsidiary (AS) certification will take Papers 1, 2 and 3 (either Advanced Practical Skills 1 or Advanced Practical Skills 2) at a single examination series.
- Candidates who, having received AS certification, wish to continue their studies to the full Advanced Level qualification may carry their AS marks forward and take just Papers 4 and 5 in the examination series in which they require certification.
- Candidates taking the complete Advanced Level qualification at the end of the course take all five papers in a single examination series.

Candidates may only enter for the papers in the combinations indicated above.

Candidates may not enter for single papers either on the first occasion or for re-sit purposes.

This syllabus is for:

- candidates for **AS certification only** in either 2013 or 2014,
- candidates carrying forward AS marks and taking Papers 4 and 5 to certificate their full Advanced Level qualification in 2014,
- candidates taking the complete Advanced Level qualification at the end of their course in 2014.

Paper	Type of Paper	Duration	Marks	Weighting	
				AS Level	A Level
1	Multiple Choice	1 hour	40	31%	15%
2	AS Structured Questions	1 hour 15 min	60	46%	23%
3	Advanced Practical Skills 1/2	2 hours	40	23%	12%
4	A2 Structured Questions	2 hours	100		38%
5	Planning, Analysis and Evaluation	1 hour 15 min	30		12%

Paper 1

This paper will consist of 40 questions, thirty of the direct choice type and ten of the multiple completion type, all with four options. All questions will be based on the AS syllabus. Candidates will answer all questions.

Paper 2

This paper will consist of a variable number of structured questions of variable mark value.

All questions will be based on the AS syllabus. Candidates will answer all questions. Candidates will answer on the question paper.

Paper 3 – Advanced Practical Skills 1/2

In some examination sessions, two versions of the Advanced Practical Skills paper will be available, identified as Advanced Practical Skills 1 and Advanced Practical Skills 2. In other sessions only Advanced Practical Skills 1 will be available.

These papers will be equivalent and each candidate will be required to take only one of them. This is to allow large Centres to split candidates into two groups: one group will take Advanced Practical Skills 1, the other group will take Advanced Practical Skills 2. Each of these papers will be timetabled on a different day.

Each paper will consist of two or three experiments drawn from different areas of chemistry.

The examiners will not be restricted by the subject content. Candidates will answer all questions. Candidates will answer on the question paper.

See the Practical Assessment section of the syllabus for full details.

Paper 4

This paper will consist of two sections.

Section A (70 marks) will consist of questions based on the A2 core syllabus but is not restricted to the A2 syllabus and may include material first encountered in the AS syllabus.

Section B (30 marks) will consist of questions based on the section "Applications of Chemistry" but may include material first encountered in the core (AS and A2) syllabus.

Both sections will consist of a variable number of structured and free response style questions of variable mark value. Candidates will answer all questions. Candidates will answer on the question paper.

Paper 5

This paper will consist of a variable number of questions of variable mark value based on the practical skills of planning, analysis and evaluation. The examiners will not be restricted by the subject content.

Candidates will answer all questions. Candidates will answer on the question paper.

Availability

This syllabus is examined in the May/June examination series and the October/November examination series.

This syllabus is available to private candidates. However, it is expected that private candidates learn in an environment where practical work is an integral part of the course. Candidates will not be able to perform well in this assessment or progress successfully to further study without this necessary and important aspect of science education.

Centres in the UK that receive government funding are advised to consult the Cambridge website **www.cie.org.uk** for the latest information before beginning to teach this syllabus.

Combining this with other syllabuses

Candidates can combine this syllabus in an examination series with any other Cambridge syllabus, except:

- syllabuses with the same title at the same level
- 8780 Cambridge International AS Level Physical Science

3. Syllabus aims and objectives

3.1 Aims

These are not listed in order of priority. The aims of a course based on this syllabus should be to:

1 To provide, through well designed studies of experimental and practical chemistry, a worthwhile educational experience for all students, whether or not they go on to study science beyond this level and, in particular, to enable them to acquire sufficient understanding and knowledge to
  - become confident citizens in a technological world, able to take or develop an informed interest in scientific matters
  - recognise the usefulness, and limitations, of scientific method and to appreciate its applicability in other disciplines and in everyday life
  - be suitably prepared for employment and/or further studies beyond Cambridge International A Level.

2 To develop abilities and skills that
  - are relevant to the study and practice of science
  - are useful in everyday life
  - encourage efficient and safe practice
  - encourage the presentation of information and ideas appropriate for different audiences and purposes
  - develop self motivation and the ability to work in a sustained fashion.

3 To develop attitudes relevant to science such as:
  - accuracy and precision
  - objectivity
  - integrity
  - enquiry
  - initiative
  - insight.

4 To stimulate interest in, and care for, the environment.

5 To promote an awareness that:
  - the study and practice of science are co-operative and cumulative activities, and are subject to social, economic, technological, ethical and cultural influences and limitations
  - the applications of science may be both beneficial and detrimental to the individual, the community and the environment
  - the use of information technology is important for communication, as an aid to experiments and as a tool for interpretation of experimental and theoretical results.

6 To stimulate students, create and sustain their interest in Chemistry, and understand its relevance to society.

3.2. Assessment objectives

The assessment objectives listed below reflect those parts of the Aims which will be assessed.

A Knowledge with understanding

Candidates should be able to demonstrate knowledge with understanding in relation to:

- scientific phenomena, facts, laws, definitions, concepts, theories
- scientific vocabulary, terminology, conventions (including symbols, quantities and units)
- scientific instruments and apparatus, including techniques of operation and aspects of safety
- scientific quantities and their determination
- scientific and technological applications with their social, economic and environmental implications
- present reasoned explanations for phenomena, patterns and relationships.

The subject content defines the factual knowledge that candidates may be required to recall and explain. Questions testing these objectives will often begin with one of the following words: *define, state, describe, explain* or *outline* (see Glossary of terms).

B Handling, applying and evaluating information

Candidates should be able – in words or by using symbolic, graphical and numerical forms of presentation – to:

- locate, select, organise and present information from a variety of sources
- handle information, distinguishing the relevant from the extraneous
- manipulate numerical and other data and translate information from one form to another
- analyse and evaluate information so as to identify patterns, report trends and draw inferences
- construct arguments to support hypotheses or to justify a course of action
- apply knowledge, including principles, to new situations
- evaluate information and hypotheses.

These assessment objectives cannot be precisely specified in the Subject Content because questions testing such skills may be based on information which is unfamiliar to the candidate. In answering such questions, candidates are required to use principles and concepts that are within the syllabus and apply them in a logical, reasoned or deductive manner to a new situation. Questions testing these objectives will often begin with one of the following words: *predict, suggest, construct, calculate* or *determine* (see Glossary of terms).

C Experimental skills and investigations

Students should be able to:

- plan investigations
- use techniques, apparatus and materials
- make and record observations, measurements and estimates
- interpret and evaluate observations and experimental results
- select techniques, apparatus and materials
- evaluate methods and suggest possible improvements.

3.3 Weighting of assessment objectives

The table below gives a general idea of the allocation of marks to the assessment objectives, though the balance on each paper may vary slightly.

Assessment objective	Weighting (%)	Assessment components
A: Knowledge with understanding	46*	Papers 1, 2 and 4
B: Handling information and solving problems	30	Papers 1, 2 and 4
C: Experimental skills and investigations	24	Papers 3 and 5

*Approximately 27% is allocated to recall and 19% to understanding

The overall proportion of marks allocated to physical, inorganic and organic chemistry in Papers 1 and 2, taken together, and in Section A of Paper 4 will be in the approximate ratio 3:2:3.

Teachers should note that there is a greater weighting (54%) for skills (including handling, applying and evaluating information, experimental and investigative skills) than for knowledge with understanding (46%).

Teachers' schemes of work and learning activities should reflect this.

3.4 Additional information

Data Booklet

A *Data Booklet* is available for use in Papers 1, 2 and 4. The booklet is reprinted towards the back of the syllabus. Copies of the booklet can be ordered from Cambridge Publications. Please note that changes to the *Data Booklet* were made for 2013. The new booklet will be used for the first time in the June 2013 series and Centres will be supplied with copies at this time. Further copies will be supplied as needed.

Nomenclature

The proposals in *Signs*, *Symbols and Systematics* (The Association for Science Education Companion to 16–19 Science) will generally be adopted although the traditional names sulfite, nitrite, sulfur trioxide, sulfurous acid and nitrous acid will be used in question papers. Sulfur and all compounds of sulfur will be spelled with f, not ph.

Decimal markers

In accordance with current ASE convention, decimal markers in examination papers will be a single dot on the line. Candidates are expected to follow this convention in their answers.

4. Syllabus content

4.1 Structure of the syllabus

The syllabus has been constructed with a compulsory Advanced Subsidiary core.

That part of the core syllabus which will be examined only in the full Advanced Level qualification is indicated in **bold** type.

A full Advanced Level qualification requires the study of further core material, together with section 11, Applications of Chemistry. The Applications of Chemistry section represents about 12% of the full Advanced Level course, or 23% of the A2 course.

Candidates can take the course either as a Cambridge International AS Level, Cambridge International A Level or staged assessment to Cambridge International A Level.

Practice of experimental skills

Candidates should be directed towards the practice of experimental skills throughout the whole period of their course of study. Candidates' experimental skills will be tested in Paper 3 and Paper 5.

Paper 3 is a practical examination that will test the skills of manipulation of apparatus, presentation of data, analysis and evaluation.

Paper 5 is a written examination that will test the higher-order experimental skills of planning, analysis and evaluation. It should be stressed that candidates cannot be adequately prepared for this paper without extensive laboratory work throughout the course of their study.

Section 11 Applications of Chemistry

This section of the syllabus is designed to allow candidates to use the chemical knowledge gained in the core syllabus to explore key areas of modern chemical science. The course provides opportunities to revise content from the core syllabus, as well as introducing candidates to some new chemistry. It focuses on the applications of chemistry in research, industry and everyday life, and raises awareness of the associated ethical issues. The teaching of this section will incorporate practical work.

Applications of Chemistry has three parts, all of which are compulsory:

11.1 The chemistry of life
11.2 Applications of analytical chemistry
11.3 Design and materials

Each section also covers aspects of environmental chemistry. Examination questions will focus on the chemical concepts and techniques, rather than on the recall of specific examples. All necessary information about the context will be given in the question, and candidates will be expected to apply their knowledge both from the core syllabus and from this section to new situations.

A booklet covering Applications of Chemistry can be purchased from Cambridge or obtained free of charge from Cambridge's Teacher Support site **teachers.cie.org.uk**

4.2 Subject content

The learning outcomes to be studied by all candidates are in normal type.

The **additional** learning outcomes to be studied by A2 candidates are shown in **bold** type. The A2 components will assess all learning outcomes and will not be limited to those in bold type.

Learning outcomes

In order to specify the syllabus as precisely as possible, and also to emphasise the importance of skills other than recall, learning outcomes have been used. Each part of the syllabus is specified by a brief content, followed by detailed learning outcomes. Although this format makes the syllabus a lengthier document, it will be helpful to teachers and candidates.

Teachers should incorporate social, environmental, economic and technological aspects of chemistry, where relevant, throughout the syllabus. Some examples are included in the core syllabus and in the Applications of Chemistry section, and candidates should be encouraged to apply the principles in these examples to other situations introduced during the course. Inclusion of further examples in the core of the syllabus has been avoided, as this would merely increase the amount of factual recall required.

Use of IT

Aim 5 emphasises the importance of Information Technology (IT) in this Chemistry course. Candidates should make full use of IT techniques in their practical work. Teachers may also use IT in demonstrations and simulations.

Asterisks (*) placed alongside learning outcomes indicate areas where teachers might use applications of IT. The list is not exhaustive. The Appendix contains a section Information Technology (IT) usage in Cambridge International A Level Chemistry, which suggests appropriate applications of IT to those areas

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Physical chemistry

1. Atoms, molecules and stoichiometry

Content

- I Relative masses of atoms and molecules
- II The mole, the Avogadro constant
- III The determination of relative atomic masses, A_r, and relative molecular masses, M_r, from mass spectra
- IV The calculation of empirical and molecular formulae
- V Reacting masses and volumes (of solutions and gases)

Learning outcomes

[The term relative formula mass or M_r will be used for ionic compounds.]

Candidates should be able to:

- *(a)* define and use the terms *relative atomic*, *isotopic*, *molecular* and *formula masses*, based on the ^{12}C scale
- *(b)* define and use the term *mole* in terms of the Avogadro constant
- *(c)* *analyse mass spectra in terms of isotopic abundances and **molecular fragments** [knowledge of the working of the mass spectrometer is **not** required]
- *(d)* calculate the relative atomic mass of an element given the relative abundances of its isotopes, or its mass spectrum
- *(e)* define and use the terms *empirical* and *molecular formulae*
- *(f)* calculate empirical and molecular formulae, using combustion data or composition by mass
- *(g)* *write and/or construct balanced equations
- *(h)* perform calculations, including use of the mole concept, involving:
  - (i) reacting masses (from formulae and equations)
  - (ii) volumes of gases (e.g. in the burning of hydrocarbons)
  - (iii) volumes and concentrations of solutions

  When performing calculations, candidates' answers should reflect the number of significant figures given or asked for in the question. When rounding up or down, candidates should ensure that significant figures are neither lost unnecessarily nor used beyond what is justified (see also Practical Assessment, Paper 3, Display of calculation and reasoning)
- *(i)* deduce stoichiometric relationships from calculations such as those in *(h)*

2. Atomic structure

Content

I The nucleus of the atom: neutrons and protons, isotopes, proton and nucleon numbers

II Electrons: electronic energy levels, ionisation energies, atomic orbitals, extranuclear structure

Learning outcomes

Candidates should be able to:

(a) *identify and describe protons, neutrons and electrons in terms of their relative charges and relative masses

(b) *deduce the behaviour of beams of protons, neutrons and electrons in electric fields

(c) describe the distribution of mass and charges within an atom

(d) deduce the numbers of protons, neutrons and electrons present in both atoms and ions given proton and nucleon numbers (and charge)

(e) *(i)* describe the contribution of protons and neutrons to atomic nuclei in terms of proton number and nucleon number

  (ii) distinguish between isotopes on the basis of different numbers of neutrons present

  (iii) recognise and use the symbolism ${}^{x}_{y}A$ for isotopes, where ^{x} is a the nucleon number and $_{y}$ is the proton number

(f) *describe the number and relative energies of the s, p and d orbitals for the principal quantum numbers 1, 2 and 3 and also the 4s and 4p orbitals.

(g) *describe the shapes of s and p orbitals **and d orbitals**

(h) state the electronic configuration of atoms and ions given the proton number (and charge), using the convention $1s^2 2s^2 2p^6$ etc

(i) *(i)* explain and use the terms ionisation energy **and electron affinity**

  (ii) explain the factors influencing the ionisation energies of elements

  (iii) *explain the trends in ionisation energies across a Period and down a Group of the Periodic Table (see also Section 9)

(j) deduce the electronic configurations of elements from successive ionisation energy data

(k) *interpret successive ionisation energy data of an element in terms of the position of that element within the Periodic Table

3. Chemical bonding

Content

- I Ionic (electrovalent) bonding
- II Covalent bonding and co-ordinate (dative covalent) bonding
  - (i) The shapes of simple molecules
  - (ii) Bond energies, bond lengths and bond polarities
- III Intermolecular forces, including hydrogen bonding
- IV Metallic bonding
- V Bonding and physical properties

Learning outcomes

Candidates should be able to:

- *(a)* *describe ionic (electrovalent) bonding, as in sodium chloride and magnesium oxide, including the use of ‘dot-and-cross’ diagrams
- *(b)* *describe, including the use of ‘dot-and-cross’ diagrams,
  - *(i)* covalent bonding, as in hydrogen, oxygen, chlorine, hydrogen chloride, carbon dioxide, methane, ethene
  - *(ii)* co-ordinate (dative covalent) bonding, as in the formation of the ammonium ion and in the $A\ell_2C\ell_6$ molecule
- *(c)* *explain the shapes of, and bond angles in, molecules by using the qualitative model of electron-pair repulsion (including lone pairs), using as simple examples: BF_3 (trigonal), CO_2 (linear), CH_4 (tetrahedral), NH_3 (pyramidal), H_2O (non-linear), SF_6 (octahedral), PF_5 (trigonal bipyramid))
- *(d)* *describe covalent bonding in terms of orbital overlap, giving σ and π bonds, including the concept of hybridisation to form sp, sp^2 and sp^3 orbitals
- *(e)* *explain the shape of, and bond angles in, the ethane, ethene **and benzene** molecules in terms of σ and π bonds (see also Section 10.1)
- *(f)* predict the shapes of, and bond angles in, molecules analogous to those specified in *(c)* and *(e)*
- *(g)* describe hydrogen bonding, using ammonia and water as simple examples of molecules containing N-H and O-H groups
- *(h)* understand, in simple terms, the concept of electronegativity and apply it to explain the properties of molecules such as bond polarity (3h), the dipole moments of molecules (3j), the behaviour of oxides with water (9.1j) and the acidities of chlorine-substituted ethanoic acids (10.6c)
- *(i)* explain the terms *bond energy*, *bond length* and *bond polarity* and use them to compare the reactivities of covalent bonds (see also 5b(ii))
- *(j)* *describe intermolecular forces (van der Waals’ forces), based on permanent and induced dipoles, as in $CHC\ell_3$(l); Br_2(l) and the liquid noble gases
- *(k)* describe metallic bonding in terms of a lattice of positive ions surrounded by mobile electrons
- *(l)* *describe, interpret and/or predict the effect of different types of bonding (ionic bonding, covalent bonding, hydrogen bonding, other intermolecular interactions, metallic bonding) on the physical properties of substances
- *(m)* deduce the type of bonding present from given information
- *(n)* show understanding of chemical reactions in terms of energy transfers associated with the breaking and making of chemical bonds

4. States of matter

Content

I The gaseous state:
  - (i) Ideal gas behaviour and deviations from it
  - (ii) $pV = nRT$ and its use in determining a value for M_r

II The liquid state

The kinetic concept of the liquid state and simple kinetic-molecular descriptions of changes of state

III The solid state

Lattice structures

Learning outcomes

Candidates should be able to:

- *(a)* state the basic assumptions of the kinetic theory as applied to an ideal gas
- *(b)* explain qualitatively in terms of intermolecular forces and molecular size:
  - *(i)* the conditions necessary for a gas to approach ideal behaviour
  - *(ii)* the limitations of ideality at very high pressures and very low temperatures
- *(c)* state and use the general gas equation $pV = nRT$ in calculations, including the determination of M_r
- *(d)* *describe, using a kinetic-molecular model: the liquid state, melting, vaporisation, vapour pressure
- *(e)* *describe, in simple terms, the lattice structure of a crystalline solid which is:
  - *(i)* ionic, as in sodium chloride, magnesium oxide
  - *(ii)* simple molecular, as in iodine
  - *(iii)* giant molecular, as in silicon(IV) oxide and the graphite and diamond allotropes of carbon
  - *(iv)* hydrogen-bonded, as in ice
  - *(v)* metallic, as in copper

  [the concept of the 'unit cell' is *not* required]
- *(f)* explain the strength, high melting point and electrical insulating properties of ceramics in terms of their giant molecular structure
- *(g)* relate the uses of ceramics, based on magnesium oxide, aluminium oxide and silicon(IV) oxide, to their properties (suitable examples include furnace linings, electrical insulators, glass, crockery)
- *(h)* discuss the finite nature of materials as a resource and the importance of recycling processes
- *(i)* outline the importance of hydrogen bonding to the physical properties of substances, including ice and water (for example, boiling and melting points, viscosity and surface tension)
- *(j)* suggest from quoted physical data the type of structure and bonding present in a substance

5. Chemical energetics

Content

I Enthalpy changes: ΔH of formation, combustion, hydration, solution, neutralisation and atomisation; bond energy; lattice energy; electron affinity

II Hess' Law, including Born-Haber cycles

Learning outcomes

Candidates should be able to:

(a) * explain that some chemical reactions are accompanied by energy changes, principally in the form of heat energy; the energy changes can be exothermic (ΔH, negative) or endothermic

(b) explain and use the terms:

- *(i)* *enthalpy change of reaction* and *standard conditions*, with particular reference to: formation, combustion, hydration, solution, neutralisation, atomisation
- *(ii)* *bond energy* (ΔH positive, i.e. bond breaking)
- ***(iii) lattice energy*** **(ΔH negative, i.e. gaseous ions to solid lattice)**

(c) calculate enthalpy changes from appropriate experimental results, including the use of the relationship

$$\text{enthalpy change, } \Delta H = -mc\Delta T$$

(d) **explain, in qualitative terms, the effect of ionic charge and of ionic radius on the numerical magnitude of a lattice energy**

(e) apply Hess' Law to construct simple energy cycles, and carry out calculations involving such cycles and relevant energy terms, with particular reference to:

- *(i)* determining enthalpy changes that cannot be found by direct experiment, e.g. an enthalpy change of formation from enthalpy changes of combustion
- *(ii)* average bond energies
- ***(iii)*** **the formation of a simple ionic solid and of its aqueous solution**
- ***(iv)*** **Born-Haber cycles (including ionisation energy and electron affinity)**

(f) construct and interpret a reaction pathway diagram, in terms of the enthalpy change of the reaction and of the activation energy (see Section 8)

6. Electrochemistry

Content

I Redox processes: electron transfer and changes in oxidation number (oxidation state)

II Electrode potentials
  (i) Standard electrode (redox) potentials, $E^\ominus$; the redox series
  (ii) Standard cell potentials, $E^\ominus_{cell}$, and their uses
  (iii) Batteries and fuel cells

III Electrolysis
  (i) Factors affecting the amount of substance liberated during electrolysis
  (ii) The Faraday constant: the Avogadro constant: their relationship
  (iii) Industrial uses of electrolysis

Learning outcomes

Candidates should be able to:

(a) *(i)* calculate oxidation numbers of elements in compounds and ions
  (ii) describe and explain redox processes in terms of electron transfer and/or changes in oxidation number (oxidation state)
  (iii) use changes in oxidation numbers to help balance chemical equations

(b) explain, including the electrode reactions, the industrial processes of:
  (i) the electrolysis of brine, using a diaphragm cell
  (ii) the extraction of aluminium from molten aluminium oxide/cryolite
  (iii) the electrolytic purification of copper

(c) **define the terms:**
  (i) ***standard electrode (redox) potential***
  (ii) ***standard cell potential***

(d) **describe the standard hydrogen electrode**

(e) **describe methods used to measure the standard electrode potentials of:**
  (i) **metals or non-metals in contact with their ions in aqueous solution**
  (ii) **ions of the same element in different oxidation states**

(f) **calculate a standard cell potential by combining two standard electrode potentials**

(g) **use standard cell potentials to:**
  (i) **explain/deduce the direction of electron flow from a simple cell**
  (ii) ***predict the feasibility of a reaction**

(h) **construct redox equations using the relevant half-equations (see also Section 9.5)**

(i) **predict qualitatively how the value of an electrode potential varies with the concentration of the aqueous ion**

(j) **state the possible advantages of developing other types of cell, e.g. the H_2/O_2 fuel cell and improved batteries (as in electric vehicles) in terms of smaller size, lower mass and higher voltage**

(k) **state the relationship, $F = Le$, between the Faraday constant, the Avogadro constant and the charge on the electron**

(l) **predict the identity of the substance liberated during electrolysis from the state of electrolyte (molten or aqueous), position in the redox series (electrode potential) and concentration**

(m) calculate:

- **(i) the quantity of charge passed during electrolysis**
- **(ii) the mass and/or volume of substance liberated during electrolysis, including those in the electrolysis of H_2SO_4(aq), Na_2SO_4(aq)**

(n) describe the determination of a value of the Avogadro constant by an electrolytic method

7. Equilibria

Content

- I Chemical equilibria: reversible reactions; dynamic equilibrium
  - (i) Factors affecting chemical equilibria
  - (ii) Equilibrium constants
  - (iii) The Haber process; the Contact process
- II Ionic equilibria
  - (i) Brønsted-Lowry theory of acids and bases
  - (ii) Acid dissociation constants, K_a and the use of pK_a
  - (iii) The ionic product of water, K_w
  - (iv) pH: choice of pH indicators
  - (v) Buffer solutions
  - (vi) Solubility product; the common ion effect

Learning outcomes

Candidates should be able to:

(a) *explain, in terms of rates of the forward and reverse reactions, what is meant by a *reversible reaction* and *dynamic equilibrium*

(b) *state Le Chatelier's Principle and apply it to deduce qualitatively (from appropriate information) the effects of changes in temperature, concentration or pressure, on a system at equilibrium

(c) state whether changes in concentration, pressure or temperature or the presence of a catalyst affect the value of the equilibrium constant for a reaction

(d) deduce expressions for equilibrium constants in terms of concentrations, K_c, and partial pressures, K_p

[treatment of the relationship between K_p and K_c is *not* required]

(e) calculate the values of equilibrium constants in terms of concentrations or partial pressures from appropriate data

(f) calculate the quantities present at equilibrium, given appropriate data (such calculations will *not* require the solving of quadratic equations)

(g) describe and explain the conditions used in the Haber process and the Contact process, as examples of the importance of an understanding of chemical equilibrium in the chemical industry (see also Section 9.6)

(h) show understanding of, and use, the Brønsted-Lowry theory of acids and bases, including the use of the acid-I, base-II concept

(i) explain qualitatively the differences in behaviour between strong and weak acids and bases and the pH values of their aqueous solutions in terms of the extent of dissociation

***(j)* explain the terms pH, K_a, pK_a, K_w and use them in calculations**

***(k)* calculate [H^+(aq)] and pH values for strong and weak acids and strong bases**

***(l)* explain the choice of suitable indicators for acid-base titrations, given appropriate data**

***(m)* *describe the changes in pH during acid-base titrations and explain these changes in terms of the strengths of the acids and bases**

***(n)* *(i)* explain how buffer solutions control pH**

***(ii)* describe and explain their uses, including the role of HCO_3^- in controlling pH in blood**

***(o)* calculate the pH of buffer solutions, given appropriate data**

***(p)* show understanding of, and use, the concept of solubility product, K_{sp}**

(q)* calculate K_{sp} from concentrations and *vice versa

***(r)* show understanding of the common ion effect**

8. Reaction kinetics

Content

I Simple rate equations; orders of reaction; rate constants

II Effect of temperature on rate constants; the concept of activation energy

III Homogeneous and heterogeneous catalysis

Learning outcomes

Candidates should be able to:

(a) explain and use the terms: *rate of reaction, activation energy, catalysis,* ***rate equation, order of reaction, rate constant, half-life of a reaction, rate-determining step***

(b) *explain qualitatively, in terms of collisions, the effect of concentration changes on the rate of a reaction

(c) *show understanding, including reference to the Boltzmann distribution, of what is meant by the term activation energy

(d) *explain qualitatively, in terms both of the Boltzmann distribution and of collision frequency, the effect of temperature change on the rate of a reaction

(e) (i)* explain that, in the presence of a catalyst, a reaction has a different mechanism, i.e. one of lower activation energy

- *(ii)* interpret this catalytic effect in terms of the Boltzmann distribution

(f) describe enzymes as biological catalysts (proteins) which may have specific activity

(g) **construct and use rate equations of the form rate = $k[A]^m[B]^n$ (limited to simple cases of single step reactions and of multi-step processes with a rate-determining step, for which *m* and *n* are 0, 1 or 2), including:**

- ***(i)*** **deducing the order of a reaction from concentration-time graphs, by the initial rates method and half-life methods**
- ***(ii)*** **deducing, for zero- and first-order reactions, the order of reaction from concentration-time graphs**
- ***(iii) verifying*** **that a suggested reaction mechanism is consistent with the observed kinetics**
- ***(iv) predicting*** **the order that would result from a given reaction mechanism (and *vice versa*)**
- ***(v) calculating*** **an initial rate using concentration data [integrated forms of rate equations are not required]**

(h) (i) **show understanding that the half-life of a first-order reaction is independent of concentration**

- ***(ii)*** **use the half-life of a first-order reaction in calculations**

(i) **calculate a rate constant, for example by using the initial rates or half-life method**

(j) **devise a suitable experimental technique for studying the rate of a reaction, from given information**

(k) **outline the different modes of action of homogeneous and heterogeneous catalysis, including:**

- ***(i)*** ***the Haber process**
- ***(ii)*** **the catalytic removal of oxides of nitrogen in the exhaust gases from car engines (see also Section 10.2)**
- ***(iii)*** **the catalytic role of atmospheric oxides of nitrogen in the oxidation of atmospheric sulfur dioxide**
- ***(iv)*** **catalytic role of Fe^{3+} in the $I^-/S_2O_8^{2-}$ reaction**

9. Inorganic chemistry

Statement of Aims

It is intended that the study should:

- be concerned primarily with aspects of selected ranges of elements and their compounds
- be based on a study of the patterns:

  across the third period of the Periodic Table

  in the two Groups II and VII
- introduce, with examples, the transition elements and their compounds
- introduce the more important everyday aspects of nitrogen, sulfur and their compounds
- apply unifying themes to inorganic chemistry, such as structure (Section 2), chemical bonding (Section 3), redox (Section 6), the reactions of ions, acid-base behaviour, precipitation (Section 7) and complexing behaviour (Section 9.5), where appropriate
- include:

  the representation of reactions by means of balanced equations (molecular and/or ionic equations, together with state symbols)

  the interpretation of redox reactions in terms of changes in oxidation state of the species involved

  the prediction of the feasibility of reactions from $E^{\ominus}$ values

  the interpretation of chemical reactions in terms of ionic equilibria

  the interpretation of chemical reactions in terms of the formation of complex ions

9.1 The periodic table: chemical periodicity

Content

I Periodicity of physical properties of the elements: variation with proton number across the third period (sodium to argon) of:
  - (i) atomic radius and ionic radius
  - (ii) melting point
  - (iii) electrical conductivity
  - (iv) ionisation energy

II Periodicity of chemical properties of the elements in the third period
  - (i) Reaction of the elements with oxygen, chlorine and water
  - (ii) Variation in oxidation number of the oxides (sodium to sulfur only) and of the chlorides (sodium to phosphorus only)
  - (iii) Reactions of these oxides and chlorides with water
  - (iv) Acid/base behaviour of these oxides and the corresponding hydroxides

Learning outcomes

Candidates should, for the third period (sodium to argon), be able to:

(a) *describe qualitatively (and indicate the periodicity in) the variations in atomic radius, ionic radius, melting point and electrical conductivity of the elements (see the *Data Booklet*)

(b) explain qualitatively the variation in atomic radius and ionic radius

(c) interpret the variation in melting point and in electrical conductivity in terms of the presence of simple molecular, giant molecular or metallic bonding in the elements

(d) explain the variation in first ionisation energy

(e) describe the reactions, if any, of the elements with oxygen (to give Na_2O, MgO, $A\ell_2O_3$, P_4O_{10}, SO_2, SO_3), chlorine (to give $NaC\ell$, $MgC\ell_2$, $A\ell_2C\ell_6$, $SiC\ell_4$, $PC\ell_5$) and water (Na and Mg only)

(f) state and explain the variation in oxidation number of the oxides and chlorides in terms of their valance shell electrons

(g) describe the reactions of the oxides with water

[treatment of peroxides and superoxides is *not* required]

(h) describe and explain the acid/base behaviour of oxides and hydroxides including, where relevant, amphoteric behaviour in reaction with sodium hydroxide (only) and acids

(i) describe and explain the reactions of the chlorides with water

(j) interpret the variations and trends in *(f)*, *(g)*, *(h)*, and *(i)* in terms of bonding and electronegativity

(k) suggest the types of chemical bonding present in chlorides and oxides from observations of their chemical and physical properties

In addition, candidates should be able to:

(l) predict the characteristic properties of an element in a given group by using knowledge of chemical periodicity

(m) deduce the nature, possible position in the Periodic Table, and identity of unknown elements from given information about physical and chemical properties

9.2 Group II

Content

I Similarities and trends in the properties of the Group II metals magnesium to barium and their compounds

II Some uses of Group II compounds

Learning outcomes

Candidates should be able to:

(a) describe the reactions of the elements with oxygen, water and dilute acids

(b) describe the behaviour of the oxides, hydroxides and carbonates with water and with dilute acids

(c) describe the thermal decomposition of the nitrates and carbonates

(d) interpret, and make predictions from, the trends in physical and chemical properties of the elements and their compounds

(e) explain the use of magnesium oxide as a refractory lining material

(f) describe and explain the use of lime in agriculture

(g) **interpret and explain qualitatively the trend in the thermal stability of the nitrates and carbonates in terms of the charge density of the cation and the polarisability of the large anion**

(h) **interpret and explain qualitatively the variation in solubility of the sulfates in terms of relative magnitudes of the enthalpy change of hydration and the corresponding lattice energy**

9.3 Group IV

The elements carbon to lead as a group in which the physical and chemical properties of the elements change with increase in proton number from non-metals through metalloids to metals and their compounds.

Content

- I The variation in melting points and electrical conductivities of the elements
- II The bonding, molecular shape, volatility and hydrolysis of the tetrachlorides
- III The bonding, acid/base nature and thermal stability of the oxides of oxidation states II and IV
- IV The relative stability of higher and lower oxidation states for the elements in their oxides and aqueous cations

Learning outcomes

Candidates should be able to:

- *(a)* **outline the variation in melting point and in electrical conductivity of the elements and interpret them in terms of structure and bonding**
- *(b)* **describe and explain the bonding in, molecular shape and volatility of the tetrachlorides**
- *(c)* **describe and explain the reactions of the tetrachlorides with water in terms of structure and bonding**
- *(d)* **describe and explain the bonding, acid-base nature and thermal stability of the oxides of oxidation states II and IV**
- *(e)* **describe and explain the relative stability of higher and lower oxidation states of the elements in their oxides and aqueous cations including, where relevant, $E^\ominus$ values**

9.4 Group VII

The similarities and trends in the physical and chemical properties of chlorine, bromine and iodine.

Content

- I Characteristic physical properties
- II The relative reactivity of the elements as oxidising agents
- III Some reactions of the halide ions
- IV The manufacture of chlorine
- V The reactions of chlorine with aqueous sodium hydroxide
- VI The important uses of the halogens and of halogen compounds (see also Section 10.3)

Learning outcomes

Candidates should be able to:

- *(a)* describe the colours of, and the trend in volatility of chlorine, bromine and iodine
- *(b)* interpret the volatility of the elements in terms of van der Waals' forces
- *(c)* describe **and deduce from $E^{\ominus}$ values** the relative reactivity of the elements as oxidising agents
- *(d)* describe and explain the reactions of the elements with hydrogen
- *(e)* *(i)* describe and explain the relative thermal stabilities of the hydrides
  - *(ii)* interpret these relative stabilities in terms of bond energies
- *(f)* describe and explain the reactions of halide ions with
  - *(i)* aqueous silver ions followed by aqueous ammonia
  - *(ii)* concentrated sulfuric acid
- *(g)* outline a method for the manufacture of chlorine from brine by a diaphragm cell (see also Section 6)
- *(h)* describe and interpret in terms of changes of oxidation number the reaction of chlorine with cold, and with hot, aqueous sodium hydroxide
- *(i)* explain the use of chlorine in water purification
- *(j)* state the industrial importance and environmental significance of the halogens and their compounds (e.g. for bleaches, PVC, halogenated hydrocarbons as solvents, refrigerants and in aerosols) (see also Section 10.3)

9.5 An introduction to the chemistry of transition elements

Content

I General physical and characteristic chemical properties of the first set of transition elements, titanium to copper

II Colour of complexes

Learning outcomes

Candidates should be able to:

(a) **explain what is meant by a *transition element*, in terms of d-block elements forming one or more stable ions with incomplete d orbitals**

(b) ***state the electronic configuration of a first row transition element and of its ions**

(c) ***contrast, qualitatively, the melting points and densities of the transition elements with those of calcium as a typical s-block element**

(d) **describe the tendency of transition elements to have variable oxidation states**

(e) **predict from a given electronic configuration, the likely oxidation states of a transition element**

(f) **describe and explain the use of Fe^{3+}/Fe^{2+}, MnO_4^-/Mn^{2+} and $Cr_2O_7^{2-}/Cr^{3+}$ as examples of redox systems (see also Section 6)**

(g) **predict, using $E^\ominus$ values, the likelihood of redox reactions**

(h) ***explain the reactions of transition elements with ligands to form complexes, including the complexes of copper(II) ions with water, hydroxide, ammonia and chloride ions**

(i) *(i)* **define the term *ligand* as a species that contains a lone pair of electrons that forms a dative bond to a central metal atom/ion.**

  (ii) **define the term *complex* as a molecule or ion formed by a central metal atom/ion surrounded by one or more ligands**

  (iii) **describe transition metal complexes as linear, octahedral, tetrahedral or square planar**

(j) **explain qualitatively that ligand exchange may occur, including the complexes of copper(II) ions with water, hydroxide, ammonia and chloride ions**

(k) **describe the shape and symmetry of the d orbitals, and the splitting of degenerate d orbitals into two energy levels in octahedral complexes using the complexes of copper(II) ions with water and ammonia as examples**

(l) **explain the origin of colour in transition element complexes resulting from the absorption of light energy as an electron moves between two non-degenerate d orbitals**

(m) **describe, in qualitative terms, the effects of different ligands on absorption, and hence colour, using the complexes of copper(II) ions with water, hydroxide, ammonia and chloride ions as examples**

(n) **apply the above ideas of ligands and complexes to other metals, given information**

9.6 Nitrogen and sulfur

Content

- I Nitrogen
  - (i) Its unreactivity
  - (ii) Ammonia, the ammonium ion, nitric acid and fertilisers
  - (iii) The environmental impact of nitrogen oxides and nitrates
- II Sulfur
  - (i) The formation of atmospheric sulfur dioxide, its role in acid rain formation, the use of sulfur dioxide in food preservation
  - (ii) Sulfuric acid

Learning outcomes

Candidates should be able to:

- *(a)* explain the lack of reactivity of nitrogen
- *(b)* describe and explain:
  - *(i)* the basicity of ammonia (see Section 7)
  - *(ii)* the structure of the ammonium ion and its formation by an acid-base reaction
  - *(iii)* the displacement of ammonia from its salts
- *(c)* describe the Haber process for the manufacture of ammonia from its elements, giving essential operating conditions, and interpret these conditions (qualitatively) in terms of the principles of kinetics and equilibria (see also Sections 7 and 8)
- *(d)* state the industrial importance of ammonia and nitrogen compounds derived from ammonia
- *(e)* state and explain the environmental consequences of the uncontrolled use of nitrate fertilisers
- *(f)* state and explain the natural and man-made occurrences of oxides of nitrogen and their catalytic removal from the exhaust gases of internal combustion engines
- *(g)* explain why atmospheric oxides of nitrogen are pollutants, including their catalytic role in the oxidation of atmospheric sulfur dioxide
- *(h)* describe the formation of atmospheric sulfur dioxide from the combustion of sulfur contaminated carbonaceous fuels
- *(i)* state the role of sulfur dioxide in the formation of acid rain and describe the main environmental consequences of acid rain
- *(j)* state the main details of the Contact process for sulfuric acid production
- *(k)* describe the use of sulfur dioxide in food preservation

10. Organic chemistry

Statement of Aims

Although there are features of organic chemistry topics that are distinctive, it is intended that appropriate cross-references with other sections/topics in the syllabus should be made.

When describing preparative reactions, candidates will be expected to quote the reagents (e.g. aqueous NaOH), the essential practical conditions (e.g. reflux) and the identity of each of the major products. Detailed knowledge of practical procedures is *not* required; however, candidates may be expected to suggest (from their knowledge of the reagents, essential conditions and products) what steps may be needed to purify/extract a required product from the reaction mixture. In equations for organic redox reactions, the symbols [O] and [H] are acceptable.

10.1 Introductory topics

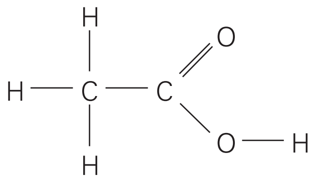
In each of the sections below, 10.1 to 10.8, candidates will be expected to be able to predict the reaction products of a given compound in reactions that are chemically similar to those specified.

Structural formulae:

In candidates' answers, an acceptable response to a request for a structural formula will be to give the minimal detail, using conventional groups, for an unambiguous structure, e.g. $CH_3CH_2CH_2OH$ for propan-1-ol, **not** C_3H_7OH and $CH_3CH{=}CHCH_3$ or $CH_3CHCHCH_3$ for butene, **not** C_4H_8.

Displayed formulae

A displayed formula should show both the relative placing of atoms and the number of bonds between them, e.g.

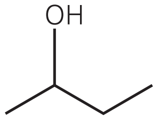


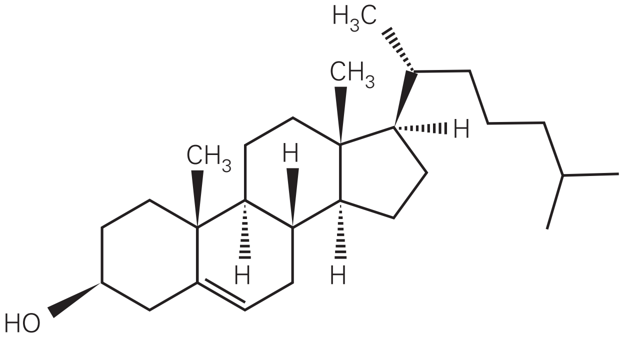
for ethanoic acid.

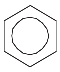
Skeletal formulae

A skeletal formula is a simplified representation of an organic formula. It is derived from the structural formula by removing hydrogen atoms (and their associated bonds) and carbon atoms from alkyl chains, leaving just the carbon-carbon bonds in the carbon skeleton and the associated functional groups.

Skeletal or partial-skeletal representations may be used in question papers and are acceptable in candidates' answers where they are unambiguous. The skeletal formula for butan-2-ol and a partial-skeletal formula for cholesterol are shown below.

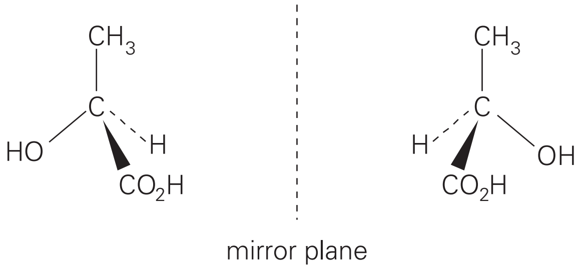




The  convention for representing the aromatic ring is preferred.

Optical Isomers

When drawing a pair of optical isomers, candidates should indicate the three-dimensional structures according to the convention used in the example below.



Content

- I Empirical, molecular, structural, displayed and skeletal formulae
- II Functional groups and the naming of organic compounds
- III Characteristic organic reactions
- IV Shapes of organic molecules; σ and π bonds
- V Isomerism: structural and stereoisomerism

Learning outcomes

Candidates should be able to:

(a) *interpret, and use the general, structural, displayed and skeletal formulae of the following classes of compound:
- *(i)* alkanes, alkenes **and arenes**
- *(ii)* halogenoalkanes **and halogenoarenes**
- *(iii)* alcohols (including primary, secondary and tertiary) **and phenols**
- *(iv)* aldehydes and ketones
- *(v)* carboxylic acids, esters **and acyl chlorides**
- *(vi)* amines (primary only), nitriles, **amides and amino acids**

[Candidates will be expected to recognise the shape of the benzene ring when it is present in organic compounds. Knowledge of benzene or its compounds is *not* required for AS.]

(b) interpret, and use the following terminology associated with organic reactions:
- *(i)* functional group
- *(ii)* homolytic and heterolytic fission
- *(iii)* free radical, initiation, propagation, termination
- *(iv)* nucleophile, electrophile
- *(v)* addition, substitution, elimination, hydrolysis
- *(vi)* oxidation and reduction

[in equations for organic redox reactions, the symbols [O] and [H] are acceptable]

(c) *(i)* *describe the shapes of the ethane, ethene **and benzene** molecules

(ii) *predict the shapes of other related molecules

(d) *explain the shapes of the ethane, ethene **and benzene** molecules in terms of σ and π carbon-carbon bonds

(e) describe structural isomerism, and its division into chain, positional and functional group isomerism

(f) describe stereoisomerism, and its division into geometrical (cis-trans) and optical isomerism

(g) describe *cis-trans* isomerism in alkenes, and explain its origin in terms of restricted rotation due to the presence of π bonds

(h) *explain what is meant by a *chiral centre* and that such a centre gives rise to optical isomerism

(i) identify chiral centres and/or *cis-trans* isomerism in a molecule of given structural formula

(j) deduce the possible isomers for an organic molecule of known molecular formula

(k) deduce the molecular formula of a compound, given its structural, displayed or skeletal formula (see Section 1)

10.2 Hydrocarbons

Content

- I Alkanes (exemplified by ethane)
  - (i) Free-radical reactions
  - (ii) Crude oil and 'cracking'
- II Alkenes (exemplified by ethene)
  - (i) Addition and oxidation reactions
  - (ii) Industrial importance
- III Arenes (exemplified by benzene and methylbenzene)
  - (i) Influence of delocalised π electrons on structure and properties
  - (ii) Substitution reactions with electrophiles
  - (iii) Oxidation of side-chain
- IV Hydrocarbons as fuels

Learning outcomes

Candidates should be able to:

- *(a)* show awareness of the general unreactivity of alkanes, including towards polar reagents
- *(b)* describe the chemistry of alkanes as exemplified by the following reactions of ethane:
  - *(i)* combustion
  - *(ii)* substitution by chlorine and by bromine
- *(c)* *describe the mechanism of free-radical substitution at methyl groups with particular reference to the initiation, propagation and termination reactions
- *(d)* describe the chemistry of alkenes as exemplified, where relevant, by the following reactions of ethene and propene (including the Markovnikov addition of asymmetric electrophiles to propene):
  - *(i)* *addition of hydrogen, steam, hydrogen halides and halogens
  - *(ii)* *oxidation by cold, dilute, acidified manganate(VII) ions to form the diol
  - *(iii)* oxidation by hot, concentrated, acidified manganate(VII) ions leading to the rupture of the carbon-to-carbon double bond in order to determine the position of alkene linkages in larger molecules
  - *(iv)* polymerisation (see also Section 10.8)
- *(e)* *describe the mechanism of electrophilic addition in alkenes, using bromine/ethene and hydrogen bromide/propene as examples
- *(f)* explain the use of crude oil as a source of both aliphatic and aromatic hydrocarbons
- *(g)* suggest how 'cracking' can be used to obtain more useful alkanes and alkenes of lower M_r from larger hydrocarbon molecules
- *(h)* describe and explain how the combustion reactions of alkanes lead to their use as fuels in industry, in the home and in transport
- *(i)* recognise the environmental consequences of:
  - *(i)* carbon monoxide, oxides of nitrogen and unburnt hydrocarbons arising from the internal combustion engine and of their catalytic removal
  - *(ii)* gases that contribute to the enhanced greenhouse effect

(j) **describe the chemistry of arenes as exemplified by the following reactions of benzene and methylbenzene:**

  (i) ***substitution reactions with chlorine and with bromine**

  (ii) **nitration**

  (iii) **complete oxidation of the side-chain to give a benzoic acid**

  (iv) **hydrogenation of the benzene ring to form a cyclohexane ring**

(k) ***(i)*** ***describe the mechanism of electrophilic substitution in arenes, as exemplified by the formation of nitrobenzene and bromobenzene**

  (ii) **suggest the mechanism of other electrophilic substitution reactions, given data**

  (iii) **describe the effect of the delocalisation of electrons in arenes in such reactions**

(l) **predict whether halogenation will occur in the side-chain or aromatic nucleus in arenes depending on reaction conditions**

(m) **apply the knowledge of positions of substitution in the electrophilic substitution of arenes**

10.3 Halogen derivatives

Content

I Halogenoalkanes and halogenoarenes

  (i) Nucleophilic substitution

  (ii) Hydrolysis

  (iii) Formation of nitriles, primary amines

  (iv) Elimination

II Relative strength of the C-Hal bond

Learning outcomes

Candidates should be able to:

(a) recall the chemistry of halogenoalkanes as exemplified by

  (i) the following nucleophilic substitution reactions of bromoethane: hydrolysis, formation of nitriles, formation of primary amines by reaction with ammonia

  (ii) the elimination of hydrogen bromide from 2-bromopropane

(b) *describe the mechanism of nucleophilic substitution (by both S_N1 and S_N2 mechanisms) in halogenoalkanes

(c) interpret the different reactivities of halogenoalkanes **and chlorobenzene** (with particular reference to hydrolysis and to the relative strengths of the C-Hal bonds)

(d) explain the uses of fluoroalkanes and fluorohalogenoalkanes in terms of their relative chemical inertness

(e) recognise the concern about the effect of chlorofluoroalkanes on the ozone layer

10.4 Hydroxy compounds

Content

- I Alcohols (exemplified by ethanol)
  - (i) Formation of halogenoalkanes
  - (ii) Reaction with sodium; oxidation; dehydration; esterification; acylation
  - (iii) The tri-iodomethane test
- II Phenol
  - (i) Its acidity; reaction with sodium
  - (ii) Nitration of, and bromination of, the aromatic ring

Learning outcomes

Candidates should be able to:

- *(a)* recall the chemistry of alcohols, exemplified by ethanol:
  - *(i)* combustion
  - *(ii)* substitution to give halogenoalkanes
  - *(iii)* reaction with sodium
  - *(iv)* oxidation to carbonyl compounds and carboxylic acids
  - *(v)* dehydration to alkenes
  - *(vi)* formation of esters by esterification with carboxylic acids **and acylation with acyl chlorides**
- *(b)* *(i)* classify hydroxy compounds into primary, secondary and tertiary alcohols
  - *(ii)* suggest characteristic distinguishing reactions, e.g. mild oxidation
- ***(c)*** **deduce the presence of a $CH_3CH(OH)$– group in an alcohol from its reaction with alkaline aqueous iodine to form tri-iodomethane**
- ***(d)*** **recall the chemistry of phenol, as exemplified by the following reactions:**
  - ***(i)*** **with bases**
  - ***(ii)*** **with sodium**
  - ***(iii)*** **with diazonium salts (Section 10.7)**
  - ***(iv)*** **nitration of, and bromination of, the aromatic ring**
- ***(e)*** **describe and explain the relative acidities of water, phenol and ethanol**

10.5 Carbonyl compounds

Content

- I Aldehydes (exemplified by ethanal)
  - (i) Oxidation to carboxylic acids
  - (ii) Reaction with hydrogen cyanide
  - (iii) Characteristic tests for aldehydes
- II Ketones (exemplified by propanone and phenylethanone)
  - (i) Reaction with hydrogen cyanide
  - (ii) Characteristic tests for ketones

Learning outcomes

Candidates should be able to:

- *(a)* describe
  - *(i)* the formation of aldehydes and ketones from primary and secondary alcohols respectively using $Cr_2O_7^{2-}/H^+$
  - *(ii)* the reduction of aldehydes and ketones e.g. using $NaBH_4$ or $LiA\ell H_4$
  - *(iii)* the reaction of aldehydes and ketones with HCN and NaCN
- *(b)* *describe the mechanism of the nucleophilic addition reactions of hydrogen cyanide with aldehydes and ketones
- *(c)* describe the use of 2,4-dinitrophenylhydrazine (2,4-DNPH) reagent to detect the presence of carbonyl compounds
- *(d)* deduce the nature (aldehyde or ketone) of an unknown carbonyl compound from the results of simple tests (i.e. Fehling's and Tollens' reagents; ease of oxidation)
- ***(e)*** **describe the reaction of CH_3CO– compounds with alkaline aqueous iodine to give tri-iodomethane**

10.6 Carboxylic acids and derivatives

Content

I Carboxylic acids (exemplified by ethanoic acid and benzoic acid)
  - (i) Formation from primary alcohols and nitriles
  - (ii) Salt, ester and acyl chloride formation

II Acyl chlorides (exemplified by ethanoyl chloride)
  - (i) Ease of hydrolysis compared with alkyl and aryl chlorides
  - (ii) Reaction with alcohols, phenols and primary amines

III Esters (exemplified by ethyl ethanoate and phenyl benzoate)
  - (i) Formation from carboxylic acids and from acyl chlorides
  - (ii) Hydrolysis (under acidic and under basic conditions)
  - (iii) Uses of esters

Learning outcomes

Candidates should be able to:

(a) describe the formation of carboxylic acids from alcohols, aldehydes and nitriles

(b) describe the reactions of carboxylic acids in the formation of
  - *(i)* salts, by the use of reactive metals, alkalis or carbonates
  - *(ii)* esters
  - *(iii)* acyl chlorides

***(c)* explain the acidity of carboxylic acids and of chlorine-substituted ethanoic acids in terms of their structures**

***(d)* describe the hydrolysis of acyl chlorides**

***(e)* describe the reactions of acyl chlorides with alcohols, phenols and primary amines**

***(f)* explain the relative ease of hydrolysis of acyl chlorides, alkyl chlorides and aryl chlorides**

(g) describe the formation of esters from carboxylic acids **or acyl chlorides**, using ethyl ethanoate and **phenyl benzoate** as examples

(h) *describe the acid and base hydrolysis of esters

***(i)* describe the formation of polyesters (see also Section 10.8)**

(j) state the major commercial uses of esters e.g. solvents, perfumes, flavourings

10.7 Nitrogen compounds

Content

- I Primary amines (exemplified by ethylamine and phenylamine)
  - (i) Formation
  - (ii) Salt formation
  - (iii) Other reactions of phenylamine
- II Amides (exemplified by ethanamide)
  - (i) Formation from acyl chlorides
  - (ii) Hydrolysis
  - (iii) Reduction
- III Amino acids (exemplified by aminoethanoic acid)
  - (i) Acid and base properties
  - (ii) Zwitterion formation
- IV Proteins
  - (i) Structure, based on the peptide linkage
  - (ii) Hydrolysis of proteins

Learning outcomes

Candidates should be able to:

- ***(a)*** **describe the formation of alkyl amines such as ethylamine (by the reaction of ammonia with halogenoalkanes; the reduction of amides with $LiAlH_4$; the reduction of nitriles with $LiAlH_4$ or H_2/Ni) and of phenylamine (by the reduction of nitrobenzene with tin/concentrated HCl)**
- ***(b)*** **describe and explain the basicity of amines**
- ***(c)*** **explain the relative basicities of ammonia, ethylamine and phenylamine in terms of their structures**
- ***(d)*** **describe the reaction of phenylamine with:**
  - ***(i)*** **aqueous bromine**
  - ***(ii)*** **nitrous acid to give the diazonium salt and phenol**
- ***(e)*** **describe the coupling of benzenediazonium chloride and phenol and the use of similar reactions in the formation of dyestuff**
- *(f)* describe the formation of amides from the reaction between RNH_2 and R'COCl
- ***(g)*** **recognise that amides are neutral**
- *(h)* *(i)* describe amide hydrolysis on treatment with aqueous alkali or acid
  - ***(ii)*** **describe the reduction of amides with $LiAlH_4$**
- ***(i)*** **describe the acid/base properties of amino acids and the formation of zwitterions**
- ***(j)*** **describe the formation of peptide bonds between amino acids and, hence, explain protein formation**
- ***(k)*** **describe the hydrolysis of proteins**
- ***(l)*** **describe the formation of polyamides (see also Section 10.8)**

10.8 Polymerisation

Content

I Addition polymerisation

II Condensation polymerisation

Learning outcomes

Candidates should be able to:

(a) describe the characteristics of addition polymerisation as exemplified by poly(ethene) and PVC

(b) *recognise the difficulty of the disposal of poly(alkene)s, i.e. non-biodegradability and harmful combustion products

(c) **describe the characteristics of condensation polymerisation**

- ***(i)*** **in polyesters as exemplified by *Terylene***
- ***(ii)*** **in polyamides as exemplified by peptides, proteins, nylon 6 and nylon 6,6**

(d) **predict the type of polymerisation reaction for a given monomer or pair of monomers**

(e) **deduce the repeat unit of a polymer obtained from a given monomer or pair of monomers**

(f) **deduce the type of polymerisation reaction which produces a given section of a polymer molecule**

(g) **identify the monomer(s) present in a given section of a polymer molecule**

11. Applications of chemistry

Key concepts

- Chemistry is fundamental to understanding biological systems and processes and to modern medicine.
- Novel chemistry can provide both the means of monitoring, and solutions to, environmental problems.
- The chemist is a designer, both of methods of analysis and of novel molecules and materials.
- The applications of chemistry have both positive and negative impacts on society and can be used to address the issues of pollution, disease and resources.

Teachers will find it helpful to refer to Cambridge's *Applications of Chemistry* book when teaching this section. This is available from the Cambridge Teacher Support website and from Cambridge Publications, and provides a guide to the level of detail required. The Applications of Chemistry section of the syllabus forms approximately one-eighth of the A Level material examined.

11.1 The chemistry of life

At the end of this course candidates should be aware of the diverse variety of roles played by proteins. These will be illustrated by examples in this section and in sections 11.2 and 11.3. The recall of specific examples will not be tested but candidates will be expected to discuss the chemistry of given examples.

Content

I Protein chemistry
II Genetic information
III Energy
IV Metals in biological systems

Learning outcomes

Candidates should be able to:

(a) **recall that proteins are condensation polymers formed from amino acid monomers and recognise and describe the generalised structure of amino acids (link to core syllabus, sections 10.7 and 10.8)**

(b) **explain the importance of amino acid sequence (primary structure) in determining the properties of proteins**

(c) **distinguish between the primary, secondary (α-helix and β-sheet) and tertiary structures of proteins and explain the stabilisation of secondary (through hydrogen bonding between C=O and N-H bonds of peptide groups) and tertiary (through interactions between R-groups) structure using the chemistry learnt in the core syllabus, sections 3 and 10.7**

(d) **describe and explain the characteristics of enzyme catalysis, including**

  (i) **specificity (using a simple lock and key model) and the idea of competitive inhibition**

  (ii) **structural integrity in relation to denaturation and non-competitive inhibition**

(e) **given information, use core chemistry to explain how small molecules interact with proteins and how they can modify the structure and function of biological systems (for example, as enzyme inhibitors or cofactors, disrupting protein-protein interactions, blocking ion channels) (link to 11.3 (a))**

- **(f) describe the double helical structure of DNA in terms of a sugar-phosphate backbone and attached bases (Candidates will be expected to know the general structure in terms of a block diagram but will not be expected to recall the detailed structures of the components involved. Where these are required they will be given in the question paper.)**
- **(g) explain the significance of hydrogen-bonding in the pairing of bases in DNA in relation to the replication of genetic information**
- **(h) explain in outline how DNA encodes for the amino acid sequence of proteins with reference to mRNA, tRNA and the ribosome in translation and transcription**
- **(i) explain the chemistry of DNA mutation from provided data**
- **(j) discuss the genetic basis of disease (for example, sickle cell anaemia) in terms of altered base sequence, causing alterations in protein structure and function**
- **(k) explain how modification to protein/enzyme primary structure can result in new structure and/or function**
- **(l) outline, in terms of the hydrolysis of ATP to ADP + P_i, the provision of energy for the cell**
- **(m) understand why some metals are essential to life and, given information and with reference to the chemistry of the core syllabus, be able to explain the chemistry involved (for example, iron in haemoglobin (section 9.5 (g) and 11.1(e) and (j)), sodium and potassium in transmission of nerve impulses (section 3, ion solvation and section 5, energetics), zinc as an enzyme cofactor (section 10.1, nucleophilic attack, 11.1(e)))**
- **(n) recognise that some metals are toxic and discuss, in chemical terms, the problems associated with heavy metals in the environment entering the food chain, for example mercury (development of methods to detect and address these problems will be discussed in 11.2(i) and 11.3(f))**

11.2 Applications of analytical chemistry

Questions in this section will focus on the techniques involved rather than the recall of examples. All necessary information about the context will be given in the question and candidates will be expected to apply their knowledge.

Content

I Methods of detection and analysis

II Applications in chemistry and society

Learning outcomes

Candidates should be able to:

(a) **describe simply the process of electrophoresis and the effect of pH, using peptides and amino acids as examples (link to 11.1 (a))**

(b) **explain, in simple terms, the technique of DNA fingerprinting and its applications in forensic science, archaeology and medicine**

(c) **describe the importance to modern medicine, and the challenges, of separating and characterising the proteins in cells (link to 11.1)**

(d) **outline in simple terms the principles of nuclear magnetic resonance in ^{1}H and be able to interpret simple NMR spectra, using chemical shift values, splitting patterns and the effect of adding D_2O to a sample**

(e) **show awareness of the use of NMR and X-ray crystallography in determining the structure of macromolecules and in understanding their function (link to 11.1 (c) and 11.2 (c))**

(f) **state what is meant by partition coefficient and calculate a partition coefficient for a system in which the solute is in the same molecular state in the two solvents**

(g) **understand qualitatively paper, high performance liquid, thin layer and gas/liquid chromatography in terms of adsorption and/or partition and be able to interpret data from these techniques**

(h) **explain the concept of mass spectroscopy, deduce the number of carbon atoms in a compound using the M+1 peak and the presence of bromine and chlorine atoms using the M+2 peak and suggest the identity of molecules formed by simple fragmentation in a given mass spectrum (see also core syllabus, section 1 (c) and (d))**

(i) **draw conclusions given appropriate information and data from environmental monitoring (for example, PCBs in the atmosphere, isotopic ratios in ice cores)**

11.3 Design and materials

Candidates will not be expected to recall specific examples but to use and explain material given in the question paper.

Content

I Medicinal chemistry and drug delivery
II Properties of polymers
III Nanotechnology
IV Environment and energy

Learning outcomes

Candidates should be able to use the concepts and knowledge from the core syllabus and sections 11.1 and 11.2 to:

(a) **discuss the challenges of drug design and explain in simple terms how molecules may be identified and developed to overcome these problems**
(b) **discuss the challenges of drug delivery and explain in simple terms how materials may be developed to overcome these problems**
(c) **discuss the properties and structure of polymers based on their methods of formation (addition or condensation, link to core syllabus, section 10.8)**
(d) **discuss how the presence of side-chains and intermolecular forces affect the properties of polymeric materials (for example, spider silk)**
(e) **show awareness of nanotechnology and, given information and data, be able to discuss the chemistry involved with reference to the core syllabus**
(f) **discuss how a knowledge of chemistry can be used to overcome environmental problems (for example, ground water contamination, oil spillage, CFCs)**
(g) **discuss how a knowledge of chemistry can be used to extend the life of existing resources, to identify alternative resources and to improve the efficiency of energy production and use**

5. Practical assessment

5.1 Introduction

Teachers should ensure that candidates practise experimental skills throughout the whole period of their course of study. As a guide, candidates should expect to spend at least 20% of their time doing practical work individually or in small groups. This 20% does not include the time spent observing teacher demonstrations of experiments.

The practical work that candidates do during their course should aim to:

- provide learning opportunities so that candidates develop the skills they need to carry out experimental and investigative work
- reinforce the learning of the theoretical subject content of the syllabus
- instil an understanding of the interplay of experiment and theory in scientific method
- prove enjoyable, contributing to the motivation of candidates

Candidates' experimental skills will be assessed in Paper 3 (Advanced Practical Skills 1/2) and Paper 5. In each of these papers, the examiners will not be strictly bound by the subject content of the syllabus in finding contexts for setting questions. Where appropriate, candidates will be told exactly what to do and how to do it: only knowledge of theory and experimental skills within the syllabus will be expected.

Cambridge booklets of practical exercises
To support the teaching of practical skills, Cambridge has produced two booklets totalling almost 200 pages. Each booklet contains 30 practical exercises, of which at least 10 are presented in detail, with lesson plans, student worksheets and useful information for teachers and technical support staff. The other 20 are presented in outline, for Centres to develop, learning from the experience. The booklets are:

- *Teaching AS Chemistry Practical Skills* (PSAS97010105)
- *Teaching A2 Chemistry Practical Skills* (PSA297010105)

They are available from Cambridge publications, 1 Hills Road, Cambridge, CB1 2EU, UK, phone +44 (0) 1223 553553, fax +44 (0) 1223 553558, e-mail **international@cie.org.uk**

Guidance on making measurements and on error analysis may be found on the following websites.

www.chemistry-react.org/go/Tutorial/Tutorial_4428.html

www.chemsoc.org/networks/LearnNet/RSCmeasurements.htm

See also the Resources section.

5.2 Paper 3 – Advanced Practical Skills 1/2

In some examination sessions, two versions of the Advanced Practical Skills paper will be available, identified as Advanced Practical Skills 1 and Advanced Practical Skills 2. In other sessions only Advanced Practical Skills 1 will be available.

Paper 3 (Advanced Practical Skills 1/2) will be a timetabled, laboratory-based practical paper focussing on the following experimental skills:

- manipulation of apparatus
- presentation of data
- analysis and evaluation

Each paper will consist of two or three questions, totalling 40 marks.

One question will be an observational problem in which the candidate will be asked to investigate by specified experiments, an unknown substance or substances. Candidates will be expected to draw up tables to record their observations, to analyse their results and to draw appropriate conclusions. The substances may be elements, compounds or mixtures.

The other question or questions will be quantitative: either volumetric analysis or measurement of some quantity e.g. the enthalpy change of a reaction. Candidates will be expected to draw up tables, graphs and other appropriate means of presenting the data, to analyse it and perform calculations and to draw appropriate conclusions.

One or more of the questions will require candidates to identify sources of error and make suggestions for change.

The two Advanced Practical Skills papers will contain different questions, but will be equivalent in the skills assessed and in the level of demand. Each candidate should take one of these papers.

Some Centres may wish to divide their candidates, so that some are entered for Advanced Practical Skills 1 and the others are entered for Advanced Practical Skills 2; other Centres may wish to enter all of their candidates for the same paper.

Apparatus requirements for Paper 3 (Advanced Practical Skills 1/2)

The apparatus requirements for Advanced Practical Skills 1/2 will vary from paper to paper. A complete list of apparatus and materials required will be issued in the Confidential Instructions. The Confidential Instructions should be followed very carefully. If there is any doubt about how the practical examinations should be set up or if a particular chemical is impossible to obtain, it is vital that Centres contact Cambridge as soon as possible.

The list of practical apparatus and materials at the end of this section gives details of the requirements that are frequently required. Centres should keep these in stock and candidates should be accustomed to using these. To provide some variation in the questions set, some additional items of equipment or materials may be required.

Guidance for the preparation of reagents for qualitative analysis and titration indicators is given at the end of this section. These instructions will **not** be repeated in the Confidential Instructions; Supervisors will be referred to the syllabus.

Mark scheme for Paper 3 (Advanced Practical Skills 1/2)

Paper 3 will be marked using the generic mark scheme below. The expectations for each mark category are listed in the sections that follow.

Skill	Minimum mark allocation*	Breakdown of skills	Minimum mark allocation*
Manipulation, measurement and observation	12 marks	Successful collection of data and observations	8 marks
		Quality of measurements or observations	2 marks
		Decisions relating to measurements or observations	2 marks
Presentation of data and observations	6 marks	Recording data and observations	2 marks
		Display of calculation and reasoning	2 marks
		Data layout	2 marks
Analysis, conclusions and evaluation	10 marks	Interpretation of data or observations and identifying sources of error	4 marks
		Drawing conclusions	5 marks
		Suggesting improvements	1 marks

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

Expectations for each mark category (Paper 3)

Manipulation, measurement and observation

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.

Systematic analysis and a knowledge of traditional methods of separation will not be required. It will be assumed that candidates will be familiar with

(i) 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+}, Pb^{2+}

(ii) the reactions of the following anions: CO_3^{2-}, NO_3^-, NO_2^-, SO_4^{2-}, SO_3^{2-}, Cl^-, Br^-, I^-, CrO_4^{2-}

(iii) tests for the following gases: NH_3, CO_2, Cl_2, H_2, O_2, SO_2, as detailed in the qualitative analysis notes which will be included with the question paper and are reproduced at the end of the section.

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.

Exercises requiring a knowledge of simple organic reactions e.g. test-tube reactions indicating the presence of unsaturated, alcoholic and carboxylic groups may also be set, but this would be for the testing of observation skills and drawing general conclusions only.

A knowledge of the following volumetric determinations will be assumed: acids and alkalis using suitable indicators; iron(II), 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.

Quality of measurements or observations

Candidates should be able to:

- 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. The 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.

Decisions relating to measurements or observations

Candidates should be able to:

- decide how many tests or observations to perform
- make measurements that span a range and have a distribution appropriate to the experiment
- decide how long to leave experiments running before making readings
- identify where repeated readings or observations are appropriate
- replicate readings or observations as necessary
- identify where confirmatory tests are appropriate and the nature of such tests
- 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 will be expected to identify appropriate confirmatory tests.

Presentation of data and observations

Recording data or observations

Candidates should be able to:

- present numerical data, values or observations in a single table of results
- draw up the table in advance of taking readings/making observations so that they do not have to copy up their 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 volume in a column of raw data is given as 0.06 cm^3, then all the volumes in that column should be given to the nearest 0.01 cm^3. The degree of precision used should be compatible with the measuring instrument used: it would be inappropriate to record a volume measured on a cm^3 scale as '10 mm^3'. Where the calibration marks on a measuring instrument are widely spaced, it may be appropriate to interpolate between the marks, but 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' or 'paler green than at 0.2 mol dm^{-3}, but darker than at 0.4 mol dm^{-3}'.

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 four significant figures e.g. 23.45 cm^3, then the corresponding molar concentration should be given to four significant figures e.g. 1.305 mol dm^{-3} or 0.9876 mol dm^{-3}.

Data layout
Candidates should be able to:

- choose a suitable and clear method of presenting the data, e.g. tabulations, graph or 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 predict values outside the range of the experiment.

Analysis, conclusions and evaluation

Interpretation of data or observations and identifying sources of error

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 co-ordinates 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
- evaluate the effectiveness of control variables
- 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 actual or percentage error
- show an understanding of the distinction between systematic errors and random errors

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, and 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.

Candidates should be used to looking at experiments and assessing the relative importance of errors in measurement or in making observations so that they can judge which sources of error are most important. Candidates should be familiar with simple means of estimating error, such as the errors intrinsic in measuring devices or in the observer's ability to observe, 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 express these errors in standard forms such as length = 73 mm ± 1mm, or temperature increase = 14 °C ± 4 °C. 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 candidates who read 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.

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

Hypotheses that are being tested in AS practical papers will be given, although hypothesis formulation is in skill B, and thus may be tested in the theory components. 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 the candidates will be expected to refer to knowledge and understanding gained in their theory part of the course in order to provide explanations of their practical conclusions.

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 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 identified by the candidate or to other sources of error. Extensions of the investigation should only be proposed specifically to permit the answering of a specified new question.

5.3 Paper 5

Paper 5 will be a timetabled, written paper focussing on the following higher-order experimental skills:

- planning
- analysis and evaluation

This examination paper will not require laboratory facilities.

It should be stressed that candidates cannot be adequately prepared for this paper without extensive laboratory work during their course of study.

In particular, candidates cannot be taught to plan experiments effectively unless, on a number of occasions, they are required:

- to plan an experiment
- to perform the experiment according to their plan
- to evaluate what they have done.

This requires many hours of laboratory-based work, and it also requires careful supervision from teachers to ensure that experiments are performed with due regard to safety.

Paper 5 will consist of two or more questions totalling 30 marks.

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

Candidates may be asked to express a prediction in the form of a written hypothesis linking independent and dependent variables, or in the form of a graph showing the expected outcome.

There will be activities in which candidates will be given some experimental data and will be required to analyse, evaluate and draw conclusions from it. These questions also will not be highly structured: candidates will be expected to decide for themselves the means that should be used to analyse, evaluate and conclude.

Some questions on this paper 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 the syllabus. Information that candidates are not expected to know will be provided in the examination paper.

Mark scheme for Paper 5

Paper 5 will be marked using the generic mark scheme below. The expectations for each mark category are listed in the sections that follow.

Skill		Approximate breakdown of marks	
Planning	15 marks	Defining the problem	5 marks
		Methods	10 marks
Analysis, conclusions and evaluation	15 marks	Dealing with data	8 marks
		Evaluation	4 marks
		Conclusion	3 marks

Expectations for each mark category (Paper 5)

Planning

Defining the problem
Candidates should be able to:

- identify the independent variable in the experiment or investigation
- identify the dependent variable in the experiment or investigation
- express the aim in terms of a prediction or hypothesis, and express this in words or in the form of a predicted graph
- identify the variables that are to be controlled

Candidates will be provided with information about the aims of the investigation or experiment, and some background information relating to it. They should be able to make use of this information to identify the key variables in the investigation, and to make a quantitative, testable, falsifiable prediction of the likely outcome, based on the information given and their knowledge and understanding of the topic under consideration.

Candidates may be asked to express their prediction in the form of a sketch graph showing the expected outcome. A list of key variables to control in order to test the hypothesis effectively is required, and should include variables that might be expected to have some effect on the material involved (e.g. temperature), but not those likely to have a trivial effect (e.g. using the same test-tube).

Methods
Candidates should be able to:

- describe the method to be used to vary the independent variable, and the means that they will propose to ensure that they have measured its values accurately
- describe how the dependent variable is to be measured
- describe how each of the other key variables is to be controlled
- explain how any control experiments will be used to verify that it is the independent variable that is affecting the dependent variable and not some other factor
- describe the arrangement of apparatus and the steps in the procedure to be followed
- suggest appropriate volumes and concentrations of reagents
- assess the risks of their proposed methods
- describe precautions that should be taken to keep risks to a minimum
- draw up tables for data that they might wish to record
- describe how the data might be used in order to reach a conclusion

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. The measuring instruments chosen should measure the correct quantity to a suitable precision. Control experiments may be of the type where all factors are identical to the experimental treatment, except that the value of the independent variable is zero, or they may be of the type used to confirm that, for example, it is a catalyst that is causing a particular effect, where the catalyst is omitted or inactivated.

Candidates should be able to carry out a simple risk assessment of their plan, identifying the areas where accident or injury is most likely and areas where it would be most serious. They should be able to use this to propose appropriate safety precautions specifically related to the risks that they have identified e.g. the experiment gives off NO_2 fumes and should be carried out in a fume hood.

Candidates should be able to describe the main steps that they would use in order to get to the point of being able to draw conclusions, including, as appropriate, preparation of results tables, proposed graphs to plot, key points to consider in any evaluation of the method and results, and reference back to the hypothesis.

Analysis, conclusions and evaluation

Dealing with data

Candidates should be able to:

- identify the calculations and means of presentation of data that are necessary to be able to draw conclusions from provided data
- use calculations to enable simplification or explanation of data
- 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, and fulfilling the criteria laid out in the AS section above.

Evaluation

Candidates should be able to:

- identify anomalous values in provided data and suggest appropriate means of dealing with such anomalies
- within familiar contexts, suggest possible explanations for anomalous readings
- identify the extent to which provided readings have been adequately replicated, and describe the adequacy of the range of data provided
- use provided information to assess the extent to which selected variables have been effectively controlled
- use these evaluations and provided information to make informed judgements on the confidence with which conclusions may be drawn

In a table or graph of data, candidates should be able to identify values which are clearly anomalous, and suggest strategies for dealing with such anomalies, including repeating the experiment or omitting the affected replicate. Where investigations are set in familiar contexts, which it is expected that candidates will have explored during the course, candidates may be asked to suggest possible causes for such anomalies (above and beyond 'investigator error'), and will be rewarded for answers derived from their own experience of problems intrinsic in the particular investigation. Candidates will be expected to have a knowledge of the advantages of replication of data, and the practical limitations. Candidates will be expected to be able to identify instances where it would have been sensible for the investigator to take readings at lower or higher values of the independent variable in order to give a complete range of values, and also situations where there are gaps in the range that reduce the information that can be provided from the investigation (e.g. around a key turning point). Candidates may be provided with information that will permit them to assess the extent to which particular variable have been effectively controlled (e.g. the temperature recorded within each of a number of samples in which it is supposed to be the same). Candidates will be expected to be able to draw together all of this information to permit them to make judgements about the reliability of the investigation and the trustworthiness of its outcomes. They should be able to state if the data will permit strong or weak support for or against, or indeed, proof or refutation of, a hypothesis, or is of such poor quality that it cannot successfully be used to test the hypothesis.

Conclusions

Candidates should be able to:

- draw conclusions from an investigation, providing a detailed description of the key features of the data and analyses, and considering whether experimental data supports a given hypothesis
- make detailed scientific explanations of the data, analyses and conclusions that they have described
- make further predictions, ask informed and relevant questions and suggest improvements

Key points of the raw data, graphical representations of it and calculated values should be given, leading to a clear indication of the strength or weakness of any support for or against the hypothesis, or indeed, its proof or refutation. Detailed scientific explanations form a part of such conclusions and therefore form a part of this higher-order practical skill assessment, in which the candidates will be expected to refer to knowledge and understanding gained in their theory part of the course in order to provide explanations of their practical conclusions, for example making detailed reference to the rate of effective collisions between particles and substrates in explaining the conclusions made about a reaction-rate hypothesis. Where appropriate, candidates may be given the opportunity to ask questions based on their conclusions and thus to derive further predictions and hypotheses. Within familiar contexts and 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 drawing conclusions.

5.4 Apparatus and materials list

This list given below has been drawn up in order to give guidance to schools concerning the apparatus that is expected to be generally available for examination purposes (Paper 3 Advanced Practical Skills 1 and Advanced Practical Skills 2). The list is not intended to be exhaustive: in particular, items (such as Bunsen burners, tripods, glass-tubing) that are commonly regarded as standard equipment in a chemical laboratory are not included. Unless otherwise stated, the rate of allocation is 'per candidate'.

Glassware should where possible conform to the quality specifications given, or Supervisors should otherwise satisfy themselves that the glassware used is of an appropriate accuracy.

Two burettes, 50 cm^3 (ISO385 or grade B)
Two pipettes, 25 cm^3 (ISO648 or grade B)
One pipette, 10 cm^3 (ISO648 or grade B)
Teat/squeeze/dropping pipettes
One pipette filler
Conical flasks: three within range 150 cm^3 to 250 cm^3
One-mark graduated volumetric flask, 250 cm^3 (ISO1042 or grade B)
Measuring cylinders, 25 cm^3 and 50 cm^3 (ISO6706 or ISO4788 or grade B)
Wash bottle
Two filter funnels
Porcelain crucible, approximately 15 cm^3, with lid
Evaporating basin, at least 30 cm^3
Beakers, squat form with lip: 100 cm^3, 250 cm^3
Thermometers: –10 °C to +110 °C at 1 °C
Plastic beaker, e.g. polystyrene, of approximate capacity 150 cm^3
Test-tubes (some of which should be Pyrex or hard glass) approximately 125 mm × 16 mm
Boiling tubes, approximately 150 mm × 25 mm
Clocks (or wall-clock) to measure to an accuracy of about 1s (Where clocks are specified, candidates may use their own wrist watches if they prefer.)
Balance, single-pan, direct reading, minimum accuracy 0.1 g (1 per 8–12 candidates) weighing to 300 g

It is suggested that the following chemicals be used in the Centre as part of the practical course. These chemicals 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
phenolphthalein indicator
methyl orange or screened methyl orange indicator or bromophenol blue indicator

Permanganate titration

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

Iodine/thiosulfate titration

potassium manganate(VII)
potassium dichromate(VI)
hydrogen peroxide
potassium iodate(V)
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 potassium dichromate(VI) (approximately 0.5 mol dm^{-3})
aqueous barium nitrate or aqueous barium chloride (approximately 0.1 mol dm^{-3})
aqueous lead(II) nitrate (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
red and blue litmus paper
splints and a Bunsen burner
aluminium foil

For 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

For organic analysis

the reagents necessary to perform the reactions of alcohols (primary, secondary, tertiary), aldehydes, ketones, carboxylic acids and esters listed in the theory syllabus
N.B. Tests for aldehydes may be performed by substituting glucose for the aldehyde.
2,4-dinitrophenylhydrazine reagent (Brady's reagent) is available from some suppliers (e.g. Sigma-Aldrich).

Preparation for the examination (Paper 3 – Advanced Practical Skills 1/2)

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. These instructions also contain advice about colour-blind candidates. Centres should contact the Despatch Department at Cambridge if they believe the *Confidential Instructions* have not been received.

It is essential that absolute confidentiality be maintained in advance of the examination date: the contents of the *Confidential Instructions* must not be revealed either directly or indirectly to candidates.

Supervisors are reminded of their responsibilities for supplying the examiners with the information specified in the Confidential Instructions. Failure to supply such information may cause candidates to be unavoidably penalised.

The attention of Centres is drawn to the *Cambridge Handbook* which contains a section on Science Syllabuses that includes information about arrangements for practical examinations.

If there is any doubt about the interpretation of *Confidential Instructions* document or the suitability of the apparatus available, enquiries should be sent to the Product Manger for Chemistry at Cambridge, using either e-mail (**international@cie.org.uk**), fax (+44 1223 553558) or telephone (+44 1223 553554).

Detailed guidance on preparing the standard bench reagents and indicators will **not** be given in the Confidential Instructions. The Confidential Instructions will refer Supervisors to the following guidance notes in this syllabus document. The following hazard codes are used where relevant:

C = corrosive substance
H = harmful or irritating substance
T = toxic substance
F = highly flammable substance
O = oxidising substance
N = dangerous for the environment

The attention of Centres is drawn to any local regulations relating to safety, first-aid and disposal of chemicals. “Hazard Data Sheets” should be available from your chemical supplier.

Guidance for the preparation of reagents for qualitative analysis and indicators

Hazard	Label	Identity	Instructions
[H]	**dilute hydrochloric acid**	2.0 mol dm^{-3} HCl	Dilute 170 cm^3 of concentrated (35–37%; approximately 11 mol dm^{-3}) acid **[C]** to 1 dm^3.
[C]	**dilute nitric acid**	2.0 mol dm^{-3} HNO_3	Dilute 128 cm^3 of concentrated (70% w/v) acid **[C] [O]** to 1 dm^3.
[H]	**dilute sulfuric acid**	1.0 mol dm^{-3} H_2SO_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.*
[H]	**aqueous ammonia**	2.0 mol dm^{-3} NH_3	Dilute 112 cm^3 of concentrated (35%) ammonia **[C] [N]** to 1 dm^3.
[C]	**aqueous sodium hydroxide**	2.0 mol dm^{-3} 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.*
[H]	**0.1 mol dm^{-3} barium chloride** **[or 0.1 mol dm^{-3} barium nitrate]**	0.1 mol dm^{-3} barium chloride [or 0.1 mol dm^{-3} barium nitrate]	Dissolve 24.4 g of $BaCl_2.2H_2O$ **[T]** (or 26.1 g of $Ba(NO_3)_2$ **[H] [O]**) in each dm^3 of solution.
[H] [N]	**0.05 mol dm^{-3} silver nitrate**	0.05 mol dm^{-3} silver nitrate	Dissolve 8.5 g of $AgNO_3$ **[C] [N]** in each dm^3 of solution.
[T] [N]	**0.1 mol dm^{-3} lead(II) nitrate**	0.1 mol dm^{-3} lead(II) nitrate	Dissolve 33.1 g of $Pb(NO_3)_2$ **[T] [O] [N]** in each dm^3 of solution.
[H]	**limewater**	saturated aqueous calcium hydroxide, $Ca(OH)_2$	Prepare fresh limewater by leaving distilled water to stand over solid calcium hydroxide **[H]** for several days, shaking occasionally. Decant or filter the solution.
[T] [N]	**acidified aqueous potassium dichromate(VI)**	0.05 mol dm^{-3} $K_2Cr_2O_7$, 0.05 mol dm^{-3} H_2SO_4	Dissolve 14.8 g of $K_2Cr_2O_7$ **[T] [N]** in 50 cm^3 of 1 mol dm^{-3} sulfuric acid **[H]**. Make the solution up to 1 dm^3 with distilled water. *The use of plastic gloves may be considered to prevent contact with skin.*
	0.1 mol dm^{-3} potassium iodide	0.1 mol dm^{-3} KI	Dissolve 16.6 g of KI **[H]** in each dm^3 of solution.

[N]	**0.02 mol dm^{-3} potassium manganate(VII)**	0.02 mol dm^{-3} $KMnO_4$	Dissolve 3.16 g of $KMnO_4$ **[N] [O] [H]** 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).
	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 **[H]** in 200 cm^3 of ethanol (IMS) **[F]** and make up to 1 dm^3 with distilled water.
	bromophenol blue indicator	bromophenol blue indicator (pH range 3.0 to 4.5)	Dissolve 0.4 g of the solid indicator **[H]** in 200 cm^3 of ethanol (IMS) **[F]** and make up to 1 dm^3 with distilled water.
[F]	**phenolphthalein indicator**	phenolphthalein indicator (pH range 8.0 to 10.0)	Dissolve 1.0 g of the solid indicator **[H]** in 600 cm^3 of ethanol (IMS) **[F]** and make up to 1 dm^3 with distilled water.

5.5 Qualitative analysis notes

[Key: ppt. = precipitate]

1 Reactions of aqueous cations

cation	**reaction with**	
	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
lead(II), Pb^{2+}(aq)	white ppt. soluble in excess	white 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

[Lead(II) ions can be distinguished from aluminium ions by the insolubility of lead(II) chloride.]

2 Reactions of anions

ion	reaction
carbonate, CO_3^{2-}	CO_2 liberated by dilute acids
chromate(VI), CrO_4^{2-}(aq)	yellow solution turns orange with H^+(aq); gives yellow ppt. with Ba^{2+}(aq); gives bright yellow ppt. with Pb^{2+}(aq)
chloride, Cl^-(aq)	gives white ppt. with Ag^+(aq) (soluble in NH_3(aq)); gives white ppt. with Pb^{2+}(aq)
bromide, Br^-(aq)	gives cream ppt. with Ag^+(aq) (partially soluble in NH_3(aq)); gives white ppt. with Pb^{2+}(aq)
iodide, I^-(aq)	gives yellow ppt. with Ag^+(aq) (insoluble in NH_3(aq)); gives yellow ppt. with Pb^{2+}(aq)
nitrate, NO_3^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil
nitrite, NO_2^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil; NO liberated by dilute acids (colourless NO → (pale) brown NO_2 in air)
sulfate, SO_4^{2-}(aq)	gives white ppt. with Ba^{2+}(aq) or with Pb^{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

gas	test and test result
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 aqueous potassium dichromate(VI) from orange to green

6. Appendix

6.1 Safety in the laboratory

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

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.secmbfr.htm

Websites

www.chemsoc.org/networks/learnnet/Safety.htm
www.ncbe.reading.ac.uk/NCBE/SAFETY/menu.html
www.microbiologyonline.org.uk/safety.html
www.ase.org.uk

Publications

Safeguards in the School Laboratory, ASE, 11th Edition, 2006
Topics in Safety, ASE, 3rd Edition, 2001
CLEAPSS Laboratory Handbook, updated annually (available to CLEAPSS members only)
CLEAPSS Hazcards, updated annually (available to CLEAPSS members only)
Safety in Science Education, DfES, HMSO, 1996, (available from **www.ase.org.uk/htm/teacher_zone/safety_in_science_education.php**)
Hazardous Chemicals, an interactive manual for science education, SSERC, 2002 (CD)

UK Regulations

Control of Substances Hazardous to Health Regulations (COSHH) 2002,
www.opsi.gov.uk/SI/si2002/20022677.htm
A brief guide may be found at:
www.hse.gov.uk/pubns/indg136.pdf

6.2 Summary of key quantities and units

The list below is intended as a guide to the more important quantities which might be encountered in teaching and used in question papers. The list is not exhaustive.

Quantity	Usual symbols	SI unit
Base quantities		
mass	m	kg, g
length	l	m
time	t	s
electric current	I	A
thermodynamic temperature	T	K
amount of substance	n	mol
Other quantities		
temperature	θ, t	°C
volume	V, v	m^3, dm^3
density	ρ	kg m^{-3}, g dm^{-3}, g cm^{-3}
pressure	p	Pa
frequency	v, f	Hz
wavelength	λ	m, mm, nm
speed of electromagnetic waves	c	m s^{-1}
Planck constant	h	J s
electric potential difference	V	V
(standard) electrode redox } potential	$(E^{\ominus})$ E	V
electromotive force	E	V
molar gas constant	R	J K^{-1} mol^{-1}
half-life	$T_{½}$, $t_{½}$	s
atomic mass	m_a	kg
relative { atomic isotopic } mass	A_r	–
molecular mass	m	kg
relative molecular mass	M_r	–
molar mass	M	kg mol^{-1}
nucleon number	A	–
proton number	Z	–
neutron number	N	–
number of molecules	N	–

Quantity	**Usual symbols**	**SI unit**
number of molecules per unit volume	n	m^{-3}
Avogadro constant	L	mol^{-1}
Faraday constant	F	$C\ mol^{-1}$
enthalpy change of reaction	ΔH	J, kJ
standard enthalpy change of reaction	$\Delta H^{\ominus}$	$J\ mol^{-1}$, $kJ\ mol^{-1}$
ionisation energy	I	$kJ\ mol^{-1}$
lattice energy	–	$kJ\ mol^{-1}$
bond energy	–	$kJ\ mol^{-1}$
electron affinity	–	$kJ\ mol^{-1}$
rate constant	k	as appropriate
equilibrium constant	K, K_p, K_c	as appropriate
acid dissociation constant	K_a	as appropriate
order of reaction	n, m	–
mole fraction	x	–
concentration	c	$mol\ dm^{-3}$
partition coefficient	K	–
ionic product, solubility product	K, K_{sp}	as appropriate
ionic product of water	K_w	$mol^2\ dm^{-6}$
pH	pH	–

6.3 Mathematical requirements

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

(a) make calculations involving addition, subtraction, multiplication and division of quantities

(b) make approximate evaluations of numerical expressions

(c) express small fractions as percentages, and *vice versa*

(d) calculate an arithmetic mean

(e) transform decimal notation to power of ten notation (standard form)

(f) use tables or calculators to evaluate logarithms (for pH calculations), squares, square roots, and reciprocals

(g) change the subject of an equation (most such equations involve only the simpler operations but may include positive and negative indices and square roots)

(h) substitute physical quantities into an equation using consistent units so as to calculate one quantity; check the dimensional consistency of such calculations, e.g. the units of a rate constant *k*

(i) solve simple algebraic equations

(j) comprehend and use the symbols/notations $<$, $>$, $\approx$, $/$, Δ, $\equiv$, $\overline{x}$ (or $<x>$)

(k) test tabulated pairs of values for direct proportionality by a graphical method or by constancy of ratio

(l) select appropriate variables and scales for plotting a graph, especially to obtain a linear graph of the form $y = mx + c$

(m) determine and interpret the slope and intercept of a linear graph

(n) choose by inspection a straight line that will serve as the 'least bad' linear model for a set of data presented graphically

(o) understand

  i. the slope 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. Boltzmann distribution curves

(p) comprehend how to handle numerical work so that significant figures are neither lost unnecessarily nor used beyond what is justified

(q) estimate orders of magnitude

(r) formulate simple algebraic equations as mathematical models, e.g. construct a rate equation, and identify 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, $\lg x$. A memory function may be useful but is not essential.

6.4 Information technology (IT) usage in Cambridge International A Level Chemistry

The power of IT can be harnessed in Chemistry education by developing and extending candidates' capabilities and enhancing the understandings of Chemistry concepts and processes. The following areas are ones where it might be useful for students to gain exposure to the use of IT in Chemistry:

1 Data acquisition (hardware)

Sensors and data loggers can be used in experiments to measure and store the variations of physical quantities with time or with each other. Sensors and data loggers are invaluable where the timescales of the experiments are either very long or very short, or when multiple data have to be acquired simultaneously. The use of an appropriate combination of sensors and data loggers to collect the required data and the use of real time graphing of the collected data allows students to spent more time on the analysis and evaluation of the data. In the case of chemistry, data loggers and sensors could be used for experiments such as those involving measurement of temperature, pH, pressure or transmittance of light through solutions.

The following are some examples of the use of sensors and data loggers in standard Cambridge International A Level Chemistry experiments:

- the variation of pH during an acid-base titration
- the variation of temperature in a thermometric titration e.g. heat of neutralisation
- the variation of light transmittance through solutions in the investigation of effects of concentration on rate of reaction
- the variation of pressure during a chemical reaction where one of the products is a gas

2 Data analysis (software)

A spreadsheet is the most commonly available application software suitable for the analysis of data. The data may be added manually via the keyboard or imported from files. One of the most important uses of a spreadsheet is that it allows its data to be analysed graphically. Two or more sets of corresponding data can be plotted as histograms or as simple line graphs. For example, students can plot graphs on the variations of physical properties of elements against the atomic number using the spreadsheet. This is useful for students in visualising the trends present in periods and groups in the Periodic Table. Spreadsheets can also be used to help students investigate graphically the effects of concentration of reactants on the rate of reaction. Simple modelling of chemical systems, for example, on chemical equilibrium, can be carried out using the spreadsheet. Students can explore 'what-if' situations in such cases.

3 Teaching aids and resources

Many multimedia software titles, CD-ROMs and Internet resources are available to assist in the teaching of Chemistry. Some of this software can be used for self-paced learning for individual students while others can be used for classroom demonstrations and lectures. The use of digitised images, digital video and three dimensional computer models produces great realism in the visualisation of chemical reactions, concepts and phenomena which are both visually stimulating and dynamic for the learners and can greatly enhance the level of retention. Use of simulations programs encourages the explorations of 'what-if' situations, which can precipitate a better understanding of the interdependence of factors influencing a chemical process.

Learning outcomes

Certain learning outcomes have been marked in the Syllabus section with an asterisk (*) to indicate the possibility of the application of IT. A brief commentary on some of these objectives follows. References in the notes below are to learning outcomes.

Syllabus section	IT application
1. Atoms, molecules and stoichiometry	1*(c)* offers an opportunity for the use of computer software to simulate the effect on the mass spectra due to the presence of isotopes. 1*(g)* allows the use of computer software to help students to check whether an equation is balanced.
2. Atomic structure	Computer software can be used to illustrate the nature and simulate the behaviours of the fundamental particles in electric and magnetic fields {2*(a)* and *(b)*}. Computer graphics and models can be used in the visualisation of the shapes and relative energies of orbitals {2*(f)* and *(g)*}. {2*(i)(iii)* and *(k)*} allows the use of a spreadsheet to analyse and visualise the trends in ionisation energies
3. Chemical bonding	Computer software can be used effectively to help students to visualise the bondings, structures, bond angles, orbital overlaps, σ and π bonds and shapes of molecules {3*(a)*, *(b)*, *(c)*, *(d)* and *(e)*}. Computer animation can be used to illustrate intermolecular forces {3*(i)* and *(k)*}.
4. States of matter	3-dimensional computer models can be used to illustrate structure of liquids and crystalline solids {4*(d)* and *(e)*}.
5. Chemical energetics	Sensors and data loggers can be used to investigate the heat changes during a chemical reaction {5*(a)*}. The experimental results can be studied using spreadsheets and graphical displays. Computer simulation can be used to illustrate the effects of bond enthalpy on the ΔH of reaction. Computer animations can be used to illustrate the process of dissolving.
6. Electrochemistry	Computer simulation can be used to model a simple cell and study its feasibility based on $E^{\ominus}$ values {6*(g)(ii)*} and also to illustrate electrolysis.
7. Equilibria	Computer simulation software and spreadsheet programs can be used to model a reversible reaction at equilibrium {7*(a)*}, and investigate the effects of changing the reaction conditions {7*(b)*}. Computer simulations of acid-base titrations and titration curves can be used to illustrate the effects of the strength of the acid/base used {7*(m)*}.
8. Reaction kinetics	Sensors and data loggers can be used to study the rate of reaction {8*(b)*}. Spreadsheets and graphical displays can be used effectively to help students in interpreting experimental data concerned with rate of reaction. Computer software can be used to model the effects of concentration changes on the rate of reaction {8*(b)*}. The Boltzmann distribution {8*(c)*} and the effect of temperature {8*(d)*} can be modelled using simulation software or spreadsheet programs. Computer animations can be used to illustrate catalysis {8*(e)(i)*}.

9.1 The periodic table: chemical periodicity	Spreadsheets and graphical displays can be used to investigate the trends and variations of properties within the groups and across the third period of the Periodic Table {9.1*(a)*}.
9.5 Introduction to the chemistry of transition elements	Computer software can be used to illustrate the electronic configurations {9.5*(b)*} and shapes of complexes, d orbital splitting and change in colour of complexes as a result of ligand change. Spreadsheets and graphical displays can be used to illustrate the trends in the variation of some properties of transition metals {9.5*(d)*}. Electronic periodic table can be used to provide physical and chemical data of elements. Digital video can be used to show reactions that are difficult or dangerous to conduct in the school laboratory.
10. Organic chemistry	Molecular visualisation software can be used to help students in visualising the bonding types, molecular shapes and structures of alkanes, alkenes, alcohols, organic acids and their derivatives, carbonyl compounds, amines, and macromolecules. A good collection of three-dimensional simple organic as well as complex biochemical molecular models is available on the Internet in the *PDB* (**P**rotein **D**ata **B**ank) format. The VRML (**V**irtual **R**eality **M**odeling **L**anguage) format allows the visualisation of 3-D molecular models as well as molecular dynamics. These two formats can be easily viewed using standard web browsers with the appropriate plug-ins. Limited user interactions with models in these two formats are possible. Pre-rendered, non-interactive animation movies on various topics such as organic reaction mechanism are also available on the Internet, mainly in the form of digital movie. Some common formats are *AVI* (**A**udio **V**ideo **I**nterleave), *QT* (**Q**uick**T**ime) and *MPG* (a highly compressed digital video as in Video CD). *Shockwave* movies are also available which can be interactive.
10.1 Introductory topics	Computer software can be used to help students in learning the nomenclature and general formula of organic compound {10.1*(a)*}. Computer programs/graphics can be used to illustrate the shapes of molecules {10.1*(c)* and *(d)*}. Three-dimensional molecular models can be used to illustrate the concept of chirality and optical isomerism {10.1*(g)*}.
10.2 Hydrocarbons	Computer animations can be used to illustrate the various organic chemistry reaction mechanisms {10.2*(c)*, *(d)(i)*, *(d)(ii)*, *(e)*, *(j)(i)* and *(k)(i)*}.
10.3 Halogen derivatives	Computer animations can be used to illustrate the mechanism of nucleophilic substitution {10.3*(b)*}.
10.5 Carbonyl compounds	Computer animations can be used to illustrate the mechanism of nucleophilic addition {10.5*(b)*}.
10.6 Carboxylic acids and derivatives	Computer animations can be used to illustrate the hydrolysis of esters {10.6*(h)*}.
10.8 Polymerisation	Internet resources can be used to provide current information on issues related to disposal of plastics {10.8*(b)*} and background information and examples on addition and condensation polymers.

6.5 Glossary of terms used in Science papers

It is hoped that the glossary (which is relevant only to science subjects) will prove helpful to candidates as a guide, i.e. it is neither exhaustive nor definitive. The glossary has been deliberately kept brief not only with respect to the number of terms included but also to the descriptions of their meanings. Candidates should appreciate that the meaning of a term must depend in part on its context.

1. *Define (the term(s)...)* is intended literally. Only a formal statement or equivalent paraphrase is required.
2. *What do you understand by/What is meant by (the term(s)...)* normally implies that a definition should be given, together with some relevant comment on the significance or context of the term(s) concerned, especially where two or more terms are included in the question. The amount of supplementary comment intended should be interpreted in the light of the indicated mark value.
3. *State* implies a concise answer with little or no supporting argument, e.g. a numerical answer that can be obtained 'by inspection'.
4. *List* requires a number of points, generally each of one word, with no elaboration. Where a given number of points is specified, this should not be exceeded.
5. *Explain* may imply reasoning or some reference to theory, depending on the context.
6. *Describe* requires candidates to state in words (using diagrams where appropriate) the main points of the topic. It is often used with reference either to particular phenomena or to particular experiments. In the former instance, the term usually implies that the answer should include reference to (visual) observations associated with the phenomena.

   In other contexts, *describe and give an account of* should be interpreted more generally, i.e. the candidate has greater discretion about the nature and the organisation of the material to be included in the answer. *Describe and explain* may be coupled in a similar way to *state and explain*.
7. *Discuss* requires candidates to give a critical account of the points involved in the topic.
8. *Outline* implies brevity, i.e. restricting the answer to giving essentials.
9. *Predict* or *deduce* implies that the candidate is not expected to produce the required answer by recall but by making a logical connection between other pieces of information. Such information may be wholly given in the question or may depend on answers extracted in an early part of the question.
10. *Comment* is intended as an open-ended instruction, inviting candidates to recall or infer points of interest relevant to the context of the question, taking account of the number of marks available.
11. *Suggest* is used in two main contexts, i.e. either to imply that there is no unique answer (e.g. in chemistry, two or more substances may satisfy the given conditions describing an 'unknown'), or to imply that candidates are expected to apply their general knowledge to a 'novel' situation, one that may be formally 'not in the syllabus'.
12. *Find* is a general term that may variously be interpreted as calculate, measure, determine etc.
13. *Calculate* is used when a numerical answer is required. In general, working should be shown, especially where two or more steps are involved.
14. *Measure* implies that the quantity concerned can be directly obtained from a suitable measuring instrument, e.g. length, using a rule, or angle, using a protractor.
15. *Determine* often implies that the quantity concerned cannot be measured directly but is obtained by calculation, substituting measured or known values of other quantities into a standard formula, e.g. relative molecular mass.
16. *Estimate* implies a reasoned order of magnitude statement or calculation of the quantity concerned, making such simplifying assumptions as may be necessary about points of principle and about the values of quantities not otherwise included in the question.

17. *Sketch*, when applied to graph work, implies that the shape and/or position of the curve need only be qualitatively correct, but candidates should be aware that, depending on the context, some quantitative aspects may be looked for, e.g. passing through the origin, having an intercept, asymptote or discontinuity at a particular value.

    In diagrams, *sketch* implies that a simple, freehand drawing is acceptable: nevertheless, care should be taken over proportions and the clear exposition of important details.
18. *Construct* is often used in relation to chemical equations where a candidate is expected to write a balanced equation, not by factual recall but by analogy or by using information in the question.
19. *Compare* requires candidates to provide both the similarities and differences between things or concepts.
20. *Classify* requires candidates to group things based on common characteristics.

Special Note
Units, significant figures. Candidates should be aware that misuse of units and/or significant figures, i.e. failure to quote units where necessary, the inclusion of units in quantities defined as ratios or quoting answers to an inappropriate number of significant figures, is liable to be penalised.

Data Booklet

Chemistry Advanced Subsidiary and Advanced Level

for use from 2013 in all papers for the above syllabus, except practical examinations

UNIVERSITY *of* CAMBRIDGE
International Examinations

Tables of Chemical Data

Important values, constants and standards

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	$L = 6.02 \text{ x } 10^{23} \text{ mol}^{-1}$
the Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$
speed of light in a vacuum	$c = 3.00 \times 10^{8} \text{ m s}^{-1}$
rest mass of proton, ${}^{1}_{1}\text{H}$	$m_p = 1.67 \times 10^{-27} \text{ kg}$
rest mass of neutron, ${}^{1}_{0}\text{n}$	$m_n = 1.67 \times 10^{-27} \text{ kg}$
rest mass of electron, ${}^{0}_{-1}\text{e}$	$m_e = 9.11 \times 10^{-31} \text{ kg}$
electronic charge	$e = -1.60 \times 10^{-19} \text{ C}$
molar volume of gas	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p $V_m = 24 \text{ dm}^3 \text{ mol}^{-1}$ under room conditions (where s.t.p. is expressed as 101 kPa, approximately, and 273 K (0 °C))
ionic product of water	$K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K [25 °C])
specific heat capacity of water	$= 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ $(= 4.18 \text{ J g}^{-1} \text{ K}^{-1})$

Ionisation energies (1st, 2nd, 3rd and 4th) of selected elements, in kJ mol^{-1}

	Proton number	First	Second	Third	Fourth
H	1	1310	–	–	–
He	2	2370	5250	–	–
Li	3	519	7300	11800	–
Be	4	900	1760	14800	21000
B	5	799	2420	3660	25000
C	6	1090	2350	4610	6220
N	7	1400	2860	4590	7480
O	8	1310	3390	5320	7450
F	9	1680	3370	6040	8410
Ne	10	2080	3950	6150	9290
Na	11	494	4560	6940	9540
Mg	12	736	1450	7740	10500
Al	13	577	1820	2740	11600
Si	14	786	1580	3230	4360
P	15	1060	1900	2920	4960
S	16	1000	2260	3390	4540
Cl	17	1260	2300	3850	5150
Ar	18	1520	2660	3950	5770
K	19	418	3070	4600	5860
Ca	20	590	1150	4940	6480
Sc	21	632	1240	2390	7110
Ti	22	661	1310	2720	4170
V	23	648	1370	2870	4600
Cr	24	653	1590	2990	4770
Mn	25	716	1510	3250	5190
Fe	26	762	1560	2960	5400
Co	27	757	1640	3230	5100
Ni	28	736	1750	3390	5400
Cu	29	745	1960	3350	5690
Zn	30	908	1730	3828	5980
Ga	31	577	1980	2960	6190
Ge	32	762	1540	3300	4390

	Proton number	First	Second	Third	Fourth
Br	35	1140	2080	3460	4850
Sr	38	548	1060	4120	5440
Sn	50	707	1410	2940	3930
I	53	1010	1840	2040	4030
Ba	56	502	966	3390	–
Pb	82	716	1450	3080	4080

Bond energies

(a) Diatomic molecules

Bond	Energy/kJ mol^{-1}
H—H	436
D—D	442
N≡N	944
O=O	496
F—F	158
Cl—Cl	242
Br—Br	193
I—I	151
H—F	562
H—Cl	431
H—Br	366
H—I	299

(b) Polyatomic molecules

Bond	Energy/kJ mol^{-1}
C—C	350
C=C	610
C≡C	840
C⋯C (benzene)	520
C—H	410
C—Cl	340
C—Br	280
C—I	240
C—O	360
C=O	740
C—N	305
C=N	610
C≡N	890
N—H	390
N—N	160
N=N	410
O—H	460
O—O	150
Si—Cl	359
Si—H	320
Si—O	444
Si—Si	222
S—Cl	250
S—H	347
S—S	264

Standard electrode potential and redox potentials, $E^\ominus$ at 298 K (25 °C)

For ease of reference, two tables are given:

(a) an extended list in alphabetical order;

(b) a shorter list in decreasing order of magnitude, i.e. a redox series.

(a) $E^\ominus$ in alphabetical order

Electrode reaction			$E^\ominus/V$
$Ag^+ + e^-$	$\rightleftharpoons$	Ag	+0.80
$Al^{3+} + 3e^-$	$\rightleftharpoons$	Al	–1.66
$Ba^{2+} + 2e^-$	$\rightleftharpoons$	Ba	–2.90
$Br_2 + 2e^-$	$\rightleftharpoons$	$2Br^-$	+1.07
$Ca^{2+} + 2e^-$	$\rightleftharpoons$	Ca	–2.87
$Cl_2 + 2e^-$	$\rightleftharpoons$	$2Cl^-$	+1.36
$2HOCl + 2H^+ + 2e^-$	$\rightleftharpoons$	$Cl_2 + 2H_2O$	+1.64
$Co^{2+} + 2e^-$	$\rightleftharpoons$	Co	–0.28
$Co^{3+} + e^-$	$\rightleftharpoons$	Co^{2+}	+1.82
$[Co(NH_3)_6]^{2+} + 2e^-$	$\rightleftharpoons$	$Co + 6NH_3$	–0.43
$Cr^{2+} + 2e^-$	$\rightleftharpoons$	Cr	–0.91
$Cr^{3+} + 3e^-$	$\rightleftharpoons$	Cr	–0.74
$Cr^{3+} + e^-$	$\rightleftharpoons$	Cr^{2+}	–0.41
$Cr_2O_7^{2-} + 14H^+ + 6e^-$	$\rightleftharpoons$	$2Cr^{3+} + 7H_2O$	+1.33
$Cu^+ + e^-$	$\rightleftharpoons$	Cu	+0.52
$Cu^{2+} + 2e^-$	$\rightleftharpoons$	Cu	+0.34
$Cu^{2+} + e^-$	$\rightleftharpoons$	Cu^+	+0.15
$[Cu(NH_3)_4]^{2+} + 2e^-$	$\rightleftharpoons$	$Cu + 4NH_3$	–0.05
$F_2 + 2e^-$	$\rightleftharpoons$	$2F^-$	+2.87
$Fe^{2+} + 2e^-$	$\rightleftharpoons$	Fe	–0.44
$Fe^{3+} + 3e^-$	$\rightleftharpoons$	Fe	–0.04
$Fe^{3+} + e^-$	$\rightleftharpoons$	Fe^{2+}	+0.77
$[Fe(CN)_6]^{3-} + e^-$	$\rightleftharpoons$	$[Fe(CN)_6]^{4-}$	+0.36
$Fe(OH)_3 + e^-$	$\rightleftharpoons$	$Fe(OH)_2 + OH^-$	–0.56
$2H^+ + 2e^-$	$\rightleftharpoons$	H_2	0.00
$I_2 + 2e^-$	$\rightleftharpoons$	$2I^-$	+0.54
$K^+ + e^-$	$\rightleftharpoons$	K	–2.92
$Li^+ + e^-$	$\rightleftharpoons$	Li	–3.04

Electrode reaction			$E^\ominus$/V
$Mg^{2+} + 2e^-$	$\rightleftharpoons$	Mg	–2.38
$Mn^{2+} + 2e^-$	$\rightleftharpoons$	Mn	–1.18
$Mn^{3+} + e^-$	$\rightleftharpoons$	Mn^{2+}	+1.49
$MnO_2 + 4H^+ + 2e^-$	$\rightleftharpoons$	$Mn^{2+} + 2H_2O$	+1.23
$MnO_4^- + e^-$	$\rightleftharpoons$	MnO_4^{2-}	+0.56
$MnO_4^- + 4H^+ + 3e^-$	$\rightleftharpoons$	$MnO_2 + 2H_2O$	+1.67
$MnO_4^- + 8H^+ + 5e^-$	$\rightleftharpoons$	$Mn^{2+} + 4H_2O$	+1.52
$NO_3^- + 2H^+ + e^-$	$\rightleftharpoons$	$NO_2 + H_2O$	+0.81
$NO_3^- + 3H^+ + 2e^-$	$\rightleftharpoons$	$HNO_2 + H_2O$	+0.94
$NO_3^- + 10H^+ + 8e^-$	$\rightleftharpoons$	$NH_4^+ + 3H_2O$	+0.87
$Na^+ + e^-$	$\rightleftharpoons$	Na	–2.71
$Ni^{2+} + 2e^-$	$\rightleftharpoons$	Ni	–0.25
$[Ni(NH_3)_6]^{2+} + 2e^-$	$\rightleftharpoons$	$Ni + 6NH_3$	–0.51
$H_2O_2 + 2H^+ + 2e^-$	$\rightleftharpoons$	$2H_2O$	+1.77
$O_2 + 4H^+ + 4e^-$	$\rightleftharpoons$	$2H_2O$	+1.23
$O_2 + 2H_2O + 4e^-$	$\rightleftharpoons$	$4OH^-$	+0.40
$O_2 + 2H^+ + 2e^-$	$\rightleftharpoons$	H_2O_2	+0.68
$2H_2O + 2e^-$	$\rightleftharpoons$	$H_2 + 2OH^-$	–0.83
$Pb^{2+} + 2e^-$	$\rightleftharpoons$	Pb	–0.13
$Pb^{4+} + 2e^-$	$\rightleftharpoons$	Pb^{2+}	+1.69
$PbO_2 + 4H^+ + 2e^-$	$\rightleftharpoons$	$Pb^{2+} + 2H_2O$	+1.47
$SO_4^{2-} + 4H^+ + 2e^-$	$\rightleftharpoons$	$SO_2 + 2H_2O$	+0.17
$S_2O_8^{2-} + 2e^-$	$\rightleftharpoons$	$2SO_4^{2-}$	+2.01
$S_4O_6^{2-} + 2e^-$	$\rightleftharpoons$	$2S_2O_3^{2-}$	+0.09
$Sn^{2+} + 2e^-$	$\rightleftharpoons$	Sn	–0.14
$Sn^{4+} + 2e^-$	$\rightleftharpoons$	Sn^{2+}	+0.15
$V^{2+} + 2e^-$	$\rightleftharpoons$	V	–1.20
$V^{3+} + e^-$	$\rightleftharpoons$	V^{2+}	–0.26
$VO^{2+} + 2H^+ + e^-$	$\rightleftharpoons$	$V^{3+} + H_2O$	+0.34
$VO_2^+ + 2H^+ + e^-$	$\rightleftharpoons$	$VO^{2+} + H_2O$	+1.00
$VO_3^- + 4H^+ + e^-$	$\rightleftharpoons$	$VO^{2+} + 2H_2O$	+1.00
$Zn^{2+} + 2e^-$	$\rightleftharpoons$	Zn	–0.76

All ionic states refer to aqueous ions but other state symbols have been omitted.

(b) $E^\ominus$ in decreasing order of oxidising power

(see also the extended alphabetical list on the previous pages)

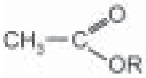
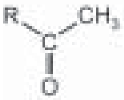
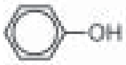
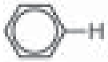
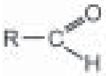
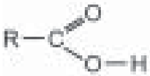
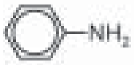
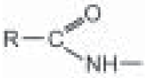
Electrode reaction	$E^\ominus/V$
$F_2 + 2e^- \rightleftharpoons 2F^-$	+2.87
$S_2O_8^{2-} + 2e^- \rightleftharpoons 2SO_4^{2-}$	+2.01
$H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O$	+1.77
$MnO_4^- + 8H^+ + 5e^- \rightleftharpoons Mn^{2+} + 4H_2O$	+1.52
$PbO_2 + 4H^+ + 2e^- \rightleftharpoons Pb^{2+} + 2H_2O$	+1.47
$Cl_2 + 2e^- \rightleftharpoons 2Cl^-$	+1.36
$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O$	+1.33
$Br_2 + 2e^- \rightleftharpoons 2Br^-$	+1.07
$NO_3^- + 2H^+ + e^- \rightleftharpoons NO_2 + H_2O$	+0.81
$Ag^+ + e^- \rightleftharpoons Ag$	+0.80
$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$	+0.77
$I_2 + 2e^- \rightleftharpoons 2I^-$	+0.54
$O_2 + 2H_2O + 4e^- \rightleftharpoons 4OH^-$	+0.40
$Cu^{2+} + 2e^- \rightleftharpoons Cu$	+0.34
$SO_4^{2-} + 4H^+ + 2e^- \rightleftharpoons SO_2 + 2H_2O$	+0.17
$Sn^{4+} + 2e^- \rightleftharpoons Sn^{2+}$	+0.15
$S_4O_6^{2-} + 2e^- \rightleftharpoons 2S_2O_3^{2-}$	+0.09
$2H^+ + 2e^- \rightleftharpoons H_2$	0.00
$Pb^{2+} + 2e^- \rightleftharpoons Pb$	–0.13
$Sn^{2+} + 2e^- \rightleftharpoons Sn$	–0.14
$Fe^{2+} + 2e^- \rightleftharpoons Fe$	–0.44
$Zn^{2+} + 2e^- \rightleftharpoons Zn$	–0.76
$Mg^{2+} + 2e^- \rightleftharpoons Mg$	–2.38
$Ca^{2+} + 2e^- \rightleftharpoons Ca$	–2.87
$K^+ + e^- \rightleftharpoons K$	–2.92

Atomic and ionic radii

(a) Period 3	**atomic/nm**		**ionic/nm**	
metallic	Na	0.186	Na^+	0.095
	Mg	0.160	Mg^{2+}	0.065
	Al	0.143	Al^{3+}	0.050
single covalent	Si	0.117	Si^{4+}	0.041
	P	0.110	P^{3-}	0.212
	S	0.104	S^{2-}	0.184
	Cl	0.099	Cl^-	0.181
van der Waals	Ar	0.192		
(b) Group II				
metallic	Be	0.112	Be^{2+}	0.031
	Mg	0.160	Mg^{2+}	0.065
	Ca	0.197	Ca^{2+}	0.099
	Sr	0.215	Sr^{2+}	0.113
	Ba	0.217	Ba^{2+}	0.135
	Ra	0.220	Ra^{2+}	0.140
(c) Group IV				
single covalent	C	0.077		
	Si	0.117	Si^{4+}	0.041
	Ge	0.122	Ge^{2+}	0.093
metallic	Sn	0.162	Sn^{2+}	0.112
	Pb	0.175	Pb^{2+}	0.120
(d) Group VII				
single covalent	F	0.072	F^-	0.136
	Cl	0.099	Cl^-	0.181
	Br	0.114	Br^-	0.195
	I	0.133	I^-	0.216
	At	0.140		

(e) First row transition elements				
single covalent	Sc	0.144	Sc^{3+}	0.081
	Ti	0.132	Ti^{2+}	0.090
	V	0.122	V^{3+}	0.074
	Cr	0.117	Cr^{3+}	0.069
	Mn	0.117	Mn^{2+}	0.080
	Fe	0.116	Fe^{2+}	0.076
			Fe^{3+}	0.064
	Co	0.116	Co^{2+}	0.078
	Ni	0.115	Ni^{2+}	0.078
	Cu	0.117	Cu^{2+}	0.069
	Zn	0.125	Zn^{2+}	0.074

Typical proton chemical shift value (δ) relative to T.M.S.=0

Type of proton	*Chemical shift (ppm)*
$R-CH_3$	0.9
$R-CH_2-R$	1.3
R_3CH	1.4–1.7
	2.0
	2.1
	2.3
$R-C\equiv C-H$	1.8–3.1
$R-CH_2-Hal$	3.2–3.7
$R-O-CH_3$	3.3–4.0
$R-O-H$	0.5–6.0*
$R_2C=CH-$	4.5–6.0
	4.5–7.0*
	6.0–9.0
	9.0–10.0
	9.0–13.0*
$R-NH_2$	1.0–5.0*
	3.0–6.0*
	5.0–12.0*

*Sensitive to solvent, concentration

The Periodic Table of the Elements

Group																	
I	II											III	IV	V	VI	VII	0
				Key			1.0 H hydrogen 1										4.0 He helium 2
6.9 Li lithium 3	9.0 Be beryllium 4			relative atomic mass atomic symbol name atomic number								10.8 B boron 5	12.0 C carbon 6	14.0 N nitrogen 7	16.0 O oxygen 8	19.0 F fluorine 9	20.2 Ne neon 10
23.0 Na sodium 11	24.3 Mg magnesium 12											27.0 Al aluminium 13	28.1 Si silicon 14	31.0 P phosphorus 15	32.1 S sulfur 16	35.5 Cl chlorine 17	39.9 Ar argon 18
39.1 K potassium 19	40.1 Ca calcium 20	45.0 Sc scandium 21	47.9 Ti titanium 22	50.9 V vanadium 23	52.0 Cr chromium 24	54.9 Mn manganese 25	55.8 Fe iron 26	58.9 Co cobalt 27	58.7 Ni nickel 28	63.5 Cu copper 29	65.4 Zn zinc 30	69.7 Ga gallium 31	72.6 Ge germanium 32	74.9 As arsenic 33	79.0 Se selenium 34	79.9 Br bromine 35	83.8 Kr krypton 36
85.5 Rb rubidium 37	87.6 Sr strontium 38	88.9 Y yttrium 39	91.2 Zr zirconium 40	92.9 Nb niobium 41	95.9 Mo molybdenum 42	– Tc technetium 43	101 Ru ruthenium 44	103 Rh rhodium 45	106 Pd palladium 46	108 Ag silver 47	112 Cd cadmium 48	115 In indium 49	119 Sn tin 50	122 Sb antimony 51	128 Te tellurium 52	127 I iodine 53	131 Xe xenon 54
133 Cs caesium 55	137 Ba barium 56	139 La lanthanum 57 *	178 Hf hafnium 72	181 Ta tantalum 73	184 W tungsten 74	186 Re rhenium 75	190 Os osmium 76	192 Ir iridium 77	195 Pt platinum 78	197 Au gold 79	201 Hg mercury 80	204 Tl thallium 81	207 Pb lead 82	209 Bi bismuth 83	– Po polonium 84	– At astatine 85	– Rn radon 86
– Fr francium 87	– Ra radium 88	– Ac actinium 89 * *	– Rf rutherfordium 104	– Db dubnium 105	– Sg seaborgium 106	– Bh bohrium 107	– Hs hassium 108	– Mt meitnerium 109	– Uun ununnilium 110	– Uuu unununium 111	– Uub ununbium 112		– Uuq ununquadium 114		– Uuh ununhexium 116		– Uuo ununoctium 118

anthanides *	140 Ce cerium 58	141 Pr praseodymium 59	144 Nd neodymium 60	– Pm promethium 61	150 Sm samarium 62	152 Eu europium 63	157 Gd gadolinium 64	159 Tb terbium 65	163 Dy dysprosium 66	165 Ho holmium 67	167 Er erbium 68	169 Tm thulium 69	173 Yb ytterbium 70	175 Lu lutetium 71
actinides * *	– Th thorium 90	– Pa protactinium 91	– U uranium 92	– Np neptunium 93	– Pu plutonium 94	– Am americium 95	– Cm curium 96	– Bk berkelium 97	– Cf californium 98	– Es einsteinium 99	– Fm fermium 100	– Md mendelevium 101	– No nobelium 102	– Lr lawrencium 103

7. Additional information

7.1 Guided learning hours

Cambridge International A Level syllabuses are designed on the assumption that candidates have about 360 guided learning hours per subject over the duration of the course. Cambridge International AS Level syllabuses are designed on the assumption that candidates have about 180 guided learning hours per subject over the duration of the course. ('Guided learning hours' include direct teaching and any other supervised or directed study time. They do not include private study by the candidate.)

However, these figures are for guidance only, and the number of hours required may vary according to local curricular practice and the candidates' prior experience of the subject.

7.2 Recommended prior learning

We recommend that candidates who are beginning this course should have previously completed a Cambridge O Level or Cambridge IGCSE course, or the equivalent, in Chemistry or in Coordinated Science.

7.3 Progression

Cambridge International A Level Chemistry provides a suitable foundation for the study of Chemistry or related courses in higher education. Equally it is suitable for candidates intending to pursue careers or further study in the Chemical Sciences, or as part of a course of general education.

Cambridge International AS Level Chemistry constitutes the first half of the Cambridge International A Level course in Chemistry and therefore provides a suitable foundation for the study of Chemistry at Cambridge International A Level and thence for related courses in higher education. Depending on local university entrance requirements, it may permit or assist progression directly to university courses in Chemistry or some other subjects. It is also suitable for candidates intending to pursue careers or further study in science, or as part of a course of general education.

7.4 Component codes

Because of local variations, in some cases component codes will be different in instructions about making entries for examinations and timetables from those printed in this syllabus, but the component names will be unchanged to make identification straightforward.

7.5 Grading and reporting

Cambridge International A Level results are shown by one of the grades A*, A, B, C, D or E indicating the standard achieved, Grade A* being the highest and Grade E the lowest. 'Ungraded' indicates that the candidate has failed to reach the standard required for a pass at either Cambridge International AS Level or A Level. 'Ungraded' will be reported on the statement of results but not on the certificate.

If a candidate takes a Cambridge International A Level and fails to achieve grade E or higher, a Cambridge International AS Level grade will be awarded if both of the following apply:

- the components taken for the Cambridge International A Level by the candidate in that series included all the components making up a Cambridge International AS Level
- the candidate's performance on these components was sufficient to merit the award of a Cambridge International AS Level grade.

For languages other than English, Cambridge also reports separate speaking endorsement grades (Distinction, Merit and Pass), for candidates who satisfy the conditions stated in the syllabus.

Percentage uniform marks are also provided on each candidate's statement of results to supplement their grade for a syllabus. They are determined in this way:

- A candidate who obtains…
  … the minimum mark necessary for a Grade A* obtains a percentage uniform mark of 90%.
  … the minimum mark necessary for a Grade A obtains a percentage uniform mark of 80%.
  … the minimum mark necessary for a Grade B obtains a percentage uniform mark of 70%.
  … the minimum mark necessary for a Grade C obtains a percentage uniform mark of 60%.
  … the minimum mark necessary for a Grade D obtains a percentage uniform mark of 50%.
  … the minimum mark necessary for a Grade E obtains a percentage uniform mark of 40%.
  … no marks receives a percentage uniform mark of 0%.

Candidates whose mark is none of the above receive a percentage mark in between those stated according to the position of their mark in relation to the grade 'thresholds' (i.e. the minimum mark for obtaining a grade). For example, a candidate whose mark is halfway between the minimum for a Grade C and the minimum for a Grade D (and whose grade is therefore D) receives a percentage uniform mark of 55%.

The percentage uniform mark is stated at syllabus level only. It is not the same as the 'raw' mark obtained by the candidate, since it depends on the position of the grade thresholds (which may vary from one series to another and from one subject to another) and it has been turned into a percentage.

Cambridge International AS Level results are shown by one of the grades a, b, c, d or e indicating the standard achieved, Grade a being the highest and Grade e the lowest. 'Ungraded' indicates that the candidate has failed to reach the standard required for a pass at Cambridge International AS Level. 'Ungraded' will be reported on the statement of results but not on the certificate.

For languages other than English, Cambridge will also report separate speaking endorsement grades (Distinction, Merit and Pass) for candidates who satisfy the conditions stated in the syllabus.

The content and difficulty of a Cambridge International AS Level examination is equivalent to the first half of a corresponding Cambridge International A Level.

Percentage uniform marks are also provided on each candidate's statement of results to supplement their grade for a syllabus. They are determined in this way:

- A candidate who obtains…
  … the minimum mark necessary for a Grade a obtains a percentage uniform mark of 80%.
  … the minimum mark necessary for a Grade b obtains a percentage uniform mark of 70%.
  … the minimum mark necessary for a Grade c obtains a percentage uniform mark of 60%.
  … the minimum mark necessary for a Grade d obtains a percentage uniform mark of 50%.
  … the minimum mark necessary for a Grade e obtains a percentage uniform mark of 40%.
  … no marks receives a percentage uniform mark of 0%.

Candidates whose mark is none of the above receive a percentage mark in between those stated according to the position of their mark in relation to the grade 'thresholds' (i.e. the minimum mark for obtaining a grade). For example, a candidate whose mark is halfway between the minimum for a Grade c and the minimum for a Grade d (and whose grade is therefore d) receives a percentage uniform mark of 55%.

The percentage uniform mark is stated at syllabus level only. It is not the same as the 'raw' mark obtained by the candidate, since it depends on the position of the grade thresholds (which may vary from one series to another and from one subject to another) and it has been turned into a percentage.

7.6 Access

Reasonable adjustments are made for disabled candidates in order to enable them to access the assessments and to demonstrate what they know and what they can do. For this reason, very few candidates will have a complete barrier to the assessment. Information on reasonable adjustments is found in the *Cambridge Handbook* which can be downloaded from the website **www.cie.org.uk**

Candidates who are unable to access part of the assessment, even after exploring all possibilities through reasonable adjustments, may still be able to receive an award based on the parts of the assessment they have taken.

7.7 Resources

Copies of syllabuses, the most recent question papers and Principal Examiners' reports for teachers are on the Syllabus and Support Materials CD-ROM, which we send to all Cambridge International Schools. They are also on our public website – go to **www.cie.org.uk/alevel**. Click the Subjects tab and choose your subject. For resources, click 'Resource List'.

You can use the 'Filter by' list to show all resources or only resources categorised as 'Endorsed by Cambridge'. Endorsed resources are written to align closely with the syllabus they support. They have been through a detailed quality-assurance process. As new resources are published, we review them against the syllabus and publish their details on the relevant resource list section of the website.

Additional syllabus-specific support is available from our secure Teacher Support website **http://teachers.cie.org.uk** which is available to teachers at registered Cambridge schools. It provides past question papers and examiner reports on previous examinations, as well as any extra resources such as schemes of work or examples of candidate responses. You can also find a range of subject communities on the Teacher Support website, where Cambridge teachers can share their own materials and join discussion groups.

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