Cambridge Assessment International Education

Syllabus

Cambridge International AS & A Level Chemistry 9701

Use this syllabus for exams in 2025, 2026 and 2027.
Exams are available in the June and November series.
Also available for examination in March 2025, 2026 and 2027 for India.

Version 2

For the purposes of screen readers, any mention in this document of Cambridge IGCSE refers to Cambridge International General Certificate of Secondary Education.

Cambridge Pathway

Why choose Cambridge International?

Cambridge International prepares school students for life, helping them develop an informed curiosity and a lasting passion for learning. We are part of Cambridge University Press & Assessment, which is a department of the University of Cambridge.

Our Cambridge Pathway gives students a clear path for educational success from age 5 to 19. Schools can shape the curriculum around how they want students to learn – with a wide range of subjects and flexible ways to offer them. It helps students discover new abilities and a wider world, and gives them the skills they need for life, so they can achieve at school, university and work.

Our programmes and qualifications set the global standard for international education. They are created by subject experts, rooted in academic rigour and reflect the latest educational research. They provide a strong platform for students to progress from one stage to the next, and are well supported by teaching and learning resources.

We review all our syllabuses regularly, so they reflect the latest research evidence and professional teaching practice – and take account of the different national contexts in which they are taught.

We consult with teachers to help us design each syllabus around the needs of their learners. Consulting with leading universities has helped us make sure our syllabuses encourage students to master the key concepts in the subject and develop the skills necessary for success in higher education.

Our mission is to provide educational benefit through provision of international programmes and qualifications for school education and to be the world leader in this field. Together with schools, we develop Cambridge learners who are confident, responsible, reflective, innovative and engaged – equipped for success in the modern world.

Every year, nearly a million Cambridge students from 10 000 schools in 160 countries prepare for their future with the Cambridge Pathway.

School feedback: 'We think the Cambridge curriculum is superb preparation for university.'

Feedback from: Christoph Guttentag, Dean of Undergraduate Admissions, Duke University, USA

Quality management

Cambridge International is committed to providing exceptional quality. In line with this commitment, our quality management system for the provision of international qualifications and education programmes for students aged 5 to 19 is independently certified as meeting the internationally recognised standard, ISO 9001:2015. Learn more at **www.cambridgeinternational.org/ISO9001**

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Important: Changes to this syllabus

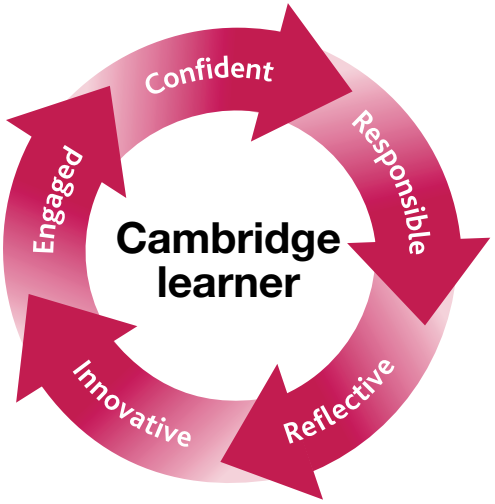
For information about changes to this syllabus for 2025, 2026 and 2027, go to page 97.

Any textbooks endorsed to support the syllabus for examination from 2022 are still suitable for use with this syllabus.

1 Why choose this syllabus?

Key benefits

The best motivation for a student is a real passion for the subject they're learning. By offering students a variety of Cambridge International AS & A Levels, you can give them the greatest chance of finding the path of education they most want to follow. With over 50 subjects to choose from, students can select the ones they love and that they're best at, which helps motivate them throughout their studies.



Following a Cambridge International AS & A Level programme helps students develop abilities which universities value highly, including:

- a deep understanding of their subjects
- higher order thinking skills – analysis, critical thinking, problem solving
- presenting ordered and coherent arguments
- independent learning and research.

Cambridge International AS & A Level Chemistry develops a set of transferable skills including handling data, practical problem-solving and applying the scientific method. Learners develop relevant attitudes, such as concern for accuracy and precision, objectivity, integrity, enquiry, initiative and inventiveness. They acquire the essential scientific skills required for progression to further studies or employment.

Our approach in Cambridge International AS & A Level Chemistry encourages learners to be:

confident, secure in their knowledge, keen to explore further and able to communicate effectively through the language of science

responsible, developing efficient and safe scientific practices and working collaboratively with others

reflective, able to evaluate evidence to draw informed and appropriate conclusions and recognising that the applications of science have the potential to affect the individual, the community and the environment

innovative, applying problem-solving skills to novel situations and engaging with new tools and techniques, including information technology, to develop successful approaches

engaged, developing an enquiring mind, keen to apply scientific skills in everyday life.

School feedback: 'Cambridge students develop a deep understanding of subjects and independent thinking skills.'

Feedback from: Principal, Rockledge High School, USA

Key concepts

Key concepts are essential ideas that help students develop a deep understanding of their subject and make links between different aspects. Key concepts may open up new ways of thinking about, understanding or interpreting the important things to be learned.

Good teaching and learning will incorporate and reinforce a subject's key concepts to help students gain:

- a greater depth as well as breadth of subject knowledge
- confidence, especially in applying knowledge and skills in new situations
- the vocabulary to discuss their subject conceptually and show how different aspects link together
- a level of mastery of their subject to help them enter higher education.

The key concepts identified below, carefully introduced and developed, will help to underpin the course you will teach. You may identify additional key concepts which will also enrich teaching and learning.

The key concepts for Cambridge International AS & A Level Chemistry are:

- **Atoms and forces**
  Matter is built from atoms interacting and bonding through electrostatic forces. The structure of matter affects its physical and chemical properties, and influences how substances react chemically.
- **Experiments and evidence**
  Chemists use evidence gained from observations and experiments to build models and theories of the structure and reactivity of materials. Theories are tested by further experiments and an appreciation of accuracy and reliability is gained.
- **Patterns in chemical behaviour and reactions**
  Patterns in chemical behaviour can be identified and used to predict the properties of substances. By applying these patterns, useful new substances can be designed and synthetic routes created.
- **Chemical bonds**
  The understanding of how chemical bonds are made and broken by the movement of electrons allows us to predict patterns of reactivity. Appreciation of the strength of chemical bonds leads to the understanding of a material's properties and its uses.
- **Energy changes**
  The energy changes that take place during chemical reactions can be used to predict the extent, feasibility and rate of such reactions. An understanding is gained of why and how chemical reactions happen.

International recognition and acceptance

Our expertise in curriculum, teaching and learning, and assessment is the basis for the recognition of our programmes and qualifications around the world. Every year thousands of students with Cambridge International AS & A Levels gain places at leading universities worldwide. Our programmes and qualifications are valued by top universities around the world including those in the UK, US (including Ivy League universities), Europe, Australia, Canada and New Zealand.

UK NARIC*, the national agency in the UK for the recognition and comparison of international qualifications and skills, has carried out an independent benchmarking study of Cambridge International AS & A Level and found it to be comparable to the standard of AS & A Level in the UK. This means students can be confident that their Cambridge International AS & A Level qualifications are accepted as equivalent, grade for grade, to UK AS & A Levels by leading universities worldwide.

Cambridge International AS Level Chemistry makes up the first half of the Cambridge International A Level course in Chemistry and provides a foundation for the study of Chemistry at Cambridge International A Level. Depending on local university entrance requirements, students may be able to use it to progress directly to university courses in Chemistry or some other subjects. It is also suitable as part of a course of general education.

Cambridge International A Level Chemistry provides a foundation for the study of Chemistry or related courses in higher education. Equally it is suitable as part of a course of general education.

For more information about the relationship between the Cambridge International AS Level and Cambridge International A Level see the 'Assessment overview' section of the Syllabus overview.

We recommend learners check the Cambridge recognition database and university websites to find the most up-to-date entry requirements for courses they wish to study.

* Due to the United Kingdom leaving the European Union, the UK NARIC national recognition agency function was re-titled as UK ENIC on 1 March 2021, operated and managed by Ecctis Limited. From 1 March 2021, international benchmarking findings are published under the Ecctis name.

Learn more at **www.cambridgeinternational.org/recognition**

School feedback: 'The depth of knowledge displayed by the best A Level students makes them prime targets for America's Ivy League universities.'

Feedback from: Yale University, USA

Supporting teachers

We provide a wide range of resources, detailed guidance, innovative training and professional development so that you can give your students the best possible preparation for Cambridge International AS & A Level. To find out which resources are available for each syllabus go to **www.cambridgeinternational.org/support**

The School Support Hub is our secure online site for Cambridge teachers where you can find the resources you need to deliver our programmes. You can also keep up to date with your subject and the global Cambridge community through our online discussion forums.

Find out more at **www.cambridgeinternational.org/support**

Support for Cambridge International AS & A Level			
Planning and preparation • Schemes of work • Specimen papers • Syllabuses • Teacher guides	**Teaching and assessment** • Endorsed resources • Online forums • Support for coursework and speaking tests	**Learning and revision** • Example candidate responses • Past papers and mark schemes • Specimen paper answers	**Results** • Candidate Results Service • Principal examiner reports for teachers

Sign up for email notifications about changes to syllabuses, including new and revised products and services at **www.cambridgeinternational.org/syllabusupdates**

Professional development

We support teachers through:

- Introductory Training – face-to-face or online
- Extension Training – face-to-face or online
- Enrichment Professional Development – face-to-face or online

Find out more at **www.cambridgeinternational.org/events**

- Cambridge Professional Development Qualifications

Find out more at **www.cambridgeinternational.org/profdev**

Supporting exams officers

We provide comprehensive support and guidance for all Cambridge exams officers.
Find out more at: **www.cambridgeinternational.org/eoguide**

2 Syllabus overview

Aims

The aims describe the purposes of a course based on this syllabus.

The aims are to enable students to:

- acquire knowledge and understanding and develop practical skills, including efficient, accurate and safe scientific practices
- learn to apply the scientific method, while developing an awareness of the limitations of scientific theories and models
- develop skills in data analysis, evaluation and drawing conclusions, cultivating attitudes relevant to science such as objectivity, integrity, enquiry, initiative and inventiveness
- develop effective scientific communication skills, using appropriate terminology and scientific conventions
- understand their responsibility to others/society and to care for the environment
- enjoy science and develop an informed interest in the subject that may lead to further study.

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

Content overview

AS Level subject content

Candidates for Cambridge International AS Level Chemistry study the following topics:

Physical chemistry

1 Atomic structure
2 Atoms, molecules and stoichiometry
3 Chemical bonding
4 States of matter
5 Chemical energetics
6 Electrochemistry
7 Equilibria
8 Reaction kinetics

Inorganic chemistry

9 The Periodic Table: chemical periodicity
10 Group 2
11 Group 17
12 Nitrogen and sulfur

Organic chemistry

13 An introduction to AS Level organic chemistry
14 Hydrocarbons
15 Halogen compounds
16 Hydroxy compounds
17 Carbonyl compounds
18 Carboxylic acids and derivatives
19 Nitrogen compounds
20 Polymerisation
21 Organic synthesis

Analysis

22 Analytical techniques

AS Level candidates also study practical skills.

A Level subject content

Candidates for Cambridge International A Level Chemistry study the AS topics and the following topics:

Physical chemistry

23 Chemical energetics
24 Electrochemistry
25 Equilibria
26 Reaction kinetics

Inorganic chemistry

27 Group 2
28 Chemistry of transition elements

Organic chemistry

29 An introduction to A Level organic chemistry
30 Hydrocarbons
31 Halogen compounds
32 Hydroxy compounds
33 Carboxylic acids and derivatives
34 Nitrogen compounds
35 Polymerisation
36 Organic synthesis

Analysis

37 Analytical techniques

A Level candidates also study practical skills.

School feedback: 'Cambridge International AS & A Levels prepare students well for university because they've learnt to go into a subject in considerable depth. There's that ability to really understand the depth and richness and the detail of a subject. It's a wonderful preparation for what they are going to face at university.'

Feedback from: US Higher Education Advisory Council

Assessment overview

Paper 1

Multiple Choice

1 hour 15 minutes

40 marks

40 multiple-choice questions

Questions are based on the AS Level syllabus content.

Externally assessed

31% of the AS Level

15.5% of the A Level

Paper 2

AS Level Structured Questions

1 hour 15 minutes

60 marks

Structured questions

Questions are based on the AS Level syllabus content.

Externally assessed

46% of the AS Level

23% of the A Level

Paper 3

Advanced Practical Skills

2 hours

40 marks

Practical work and structured questions

Questions are based on the experimental skills in the Practical assessment section of the syllabus.

Externally assessed

23% of the AS Level

11.5% of the A Level

Paper 4

A Level Structured Questions

2 hours

100 marks

Structured questions

Questions are based on the A Level syllabus content; knowledge of material from the AS Level syllabus content will be required.

Externally assessed

38.5% of the A Level

Paper 5

Planning, Analysis and Evaluation

1 hour 15 minutes

30 marks

Questions are based on the experimental skills of planning, analysis and evaluation.

The context of the questions may be outside the syllabus content.

Externally assessed

11.5% of the A Level

Information on availability is in the **Before you start** section.

There are three routes for Cambridge International AS & A Level Chemistry:

	Route	Paper 1	Paper 2	Paper 3	Paper 4	Paper 5
1	**AS Level only** (Candidates take all AS components in the same exam series)	yes	yes	yes		
2	**A Level** (staged over two years) Year 1 AS Level*	yes	yes	yes		
	Year 2 Complete the A Level				yes	yes
3	**A Level** (Candidates take all components in the same exam series)	yes	yes	yes	yes	yes

* Candidates carry forward their AS Level result subject to the rules and time limits described in the *Cambridge Handbook*. See **Making entries** for more information on carry forward of results.

Candidates following an AS Level route are eligible for grades a–e. Candidates following an A Level route are eligible for grades A*–E.

Assessment objectives

The assessment objectives (AOs) are:

AO1 Knowledge and understanding

Candidates should be able to demonstrate knowledge and understanding of:

- scientific phenomena, facts, laws, definitions, concepts and theories
- scientific vocabulary, terminology and 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
- reasoned explanations for phenomena, patterns and relationships.

AO2 Handling, applying and evaluating information

Candidates should be able to handle, apply and evaluate information in words or using other forms of presentation (e.g. symbols, graphical or numerical) to:

- locate, select, organise and present information from a variety of sources
- translate information from one form to another
- manipulate numerical and other data
- use information to identify patterns, report trends and draw conclusions
- give reasoned explanations for phenomena, patterns and relationships
- make predictions and construct arguments to support hypotheses
- make sense of new situations
- evaluate hypotheses
- demonstrate an awareness of the limitations of chemical theories and models
- solve problems.

AO3 Experimental skills and investigations

Candidates should be able to:

- plan experiments and investigations
- collect, record and present observations, measurements and estimates
- analyse and interpret experimental data to reach conclusions
- evaluate methods and quality of experimental data, and suggest improvements to experiments.

Weighting for assessment objectives

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

Assessment objectives as a percentage of each qualification

Assessment objective	Weighting in AS Level %	Weighting in A Level %
AO1 Knowledge and understanding	40	40
AO2 Handling, applying and evaluating information	40	40
AO3 Experimental skills and investigations	20	20
Total	100	100

Assessment objectives as a percentage of each component

Assessment objective	Weighting in components %				
	Paper 1	Paper 2	Paper 3	Paper 4	Paper 5
AO1 Knowledge and understanding	50	50	0	50	0
AO2 Handling, applying and evaluating information	50	50	0	50	0
AO3 Experimental skills and investigations	0	0	100	0	100
Total	100	100	100	100	100

3 Subject content

Candidates for Cambridge International AS Level should study topics 1–22.

Candidates for Cambridge International A Level should study all topics.

The content of the AS Level learning outcomes is assumed knowledge for the A Level components.

Teachers should refer to the social, environmental, economic and technological aspects of chemistry wherever possible throughout the syllabus. Some examples are included in the syllabus and teachers should encourage learners to apply the principles of these examples to other situations introduced during the course.

The syllabus content for practical skills is in the Practical assessment section.

Teachers should ensure that candidates are prepared for the assessment of both theory learning outcomes and practical expectations.

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

Nomenclature

Symbols, signs and abbreviations used in examination papers will follow the recommendations made in the ASE publication *Signs, Symbols and Systematics* (The ASE Companion to 16–19 Science, 2000) although the traditional names sulfite, nitrite, sulfur trioxide, sulfurous acid and nitrous acid will be used. 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.

Units

In practical work, candidates will be expected to use SI units or, where appropriate, units approved by the BIPM for use with the SI (e.g. minute). A list of SI units and units approved for use with the SI may be found in the SI brochure at **www.bipm.org**

The use of imperial/customary units such as the inch and degree Fahrenheit is not acceptable and should be discouraged. In all examinations, where data are supplied for use in questions, candidates will be expected to use units that are consistent with the units supplied, and should not attempt conversion to other systems of units unless this is a requirement of the question.

Special note regarding units and 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 in the assessments.

AS Level subject content

Physical chemistry

1 Atomic structure

1.1 Particles in the atom and atomic radius

Learning outcomes

Candidates should be able to:

1 understand that atoms are mostly empty space surrounding a very small, dense nucleus that contains protons and neutrons; electrons are found in shells in the empty space around the nucleus

2 identify and describe protons, neutrons and electrons in terms of their relative charges and relative masses

3 understand the terms atomic and proton number; mass and nucleon number

4 describe the distribution of mass and charge within an atom

5 describe the behaviour of beams of protons, neutrons and electrons moving at the same velocity in an electric field

6 determine the numbers of protons, neutrons and electrons present in both atoms and ions given atomic or proton number, mass or nucleon number and charge

7 state and explain qualitatively the variations in atomic radius and ionic radius across a period and down a group

1.2 Isotopes

Learning outcomes

Candidates should be able to:

1 define the term isotope in terms of numbers of protons and neutrons

2 understand the notation ${}^{x}_{y}A$ for isotopes, where ^{x} is the mass or nucleon number and ${}_{y}$ is the atomic or proton number

3 state that and explain why isotopes of the same element have the same chemical properties

4 state that and explain why isotopes of the same element have different physical properties, limited to mass and density

1.3 Electrons, energy levels and atomic orbitals

In 1.3 each atom or ion described will be in the ground state. Only the elements hydrogen to krypton will be assessed.

Learning outcomes

Candidates should be able to:

1 understand the terms:
- shells, sub-shells and orbitals
- principal quantum number (n)
- ground state, limited to electronic configuration

2 describe the number of orbitals making up s, p and d sub-shells, and the number of electrons that can fill s, p and d sub-shells

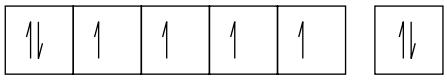
3 describe the order of increasing energy of the sub-shells within the first three shells and the 4s and 4p sub-shells

4 describe the electronic configurations to include the number of electrons in each shell, sub-shell and orbital

5 explain the electronic configurations in terms of energy of the electrons and inter-electron repulsion

6 determine the electronic configuration of atoms and ions given the atomic or proton number and charge, using either of the following conventions:
e.g. for Fe: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$ (full electronic configuration)
or [Ar] $3d^6 4s^2$ (shorthand electronic configuration)

7 understand and use the electrons in boxes notation

e.g. for Fe: [Ar] 

8 describe and sketch the shapes of s and p orbitals

9 describe a free radical as a species with one or more unpaired electrons

1.4 Ionisation energy

In 1.4 each atom or ion described will be in the ground state. Only the elements hydrogen to krypton will be assessed.

Learning outcomes

Candidates should be able to:

1 define and use the term first ionisation energy, IE

2 construct equations to represent first, second and subsequent ionisation energies

3 identify and explain the trends in ionisation energies across a period and down a group of the Periodic Table

4 identify and explain the variation in successive ionisation energies of an element

5 understand that ionisation energies are due to the attraction between the nucleus and the outer electron

6 explain the factors influencing the ionisation energies of elements in terms of nuclear charge, atomic/ionic radius, shielding by inner shells and sub-shells and spin-pair repulsion

7 deduce the electronic configurations of elements using successive ionisation energy data

8 deduce the position of an element in the Periodic Table using successive ionisation energy data

2 Atoms, molecules and stoichiometry

2.1 Relative masses of atoms and molecules

Learning outcomes

Candidates should be able to:

1 define the unified atomic mass unit as one twelfth of the mass of a carbon-12 atom

2 define relative atomic mass, A_r, relative isotopic mass, relative molecular mass, M_r, and relative formula mass in terms of the unified atomic mass unit

2.2 The mole and the Avogadro constant

Learning outcomes

Candidates should be able to:

1 define and use the term mole in terms of the Avogadro constant

2.3 Formulas

Learning outcomes

Candidates should be able to:

1 write formulas of ionic compounds from ionic charges and oxidation numbers (shown by a Roman numeral), including:

(a) the prediction of ionic charge from the position of an element in the Periodic Table

(b) recall of the names and formulas for the following ions: NO_3^-, CO_3^{2-}, SO_4^{2-}, OH^-, NH_4^+, Zn^{2+}, Ag^+, HCO_3^-, PO_4^{3-}

2 (a) write and construct equations (which should be balanced), including ionic equations (which should not include spectator ions)

(b) use appropriate state symbols in equations

3 define and use the terms empirical and molecular formula

4 understand and use the terms anhydrous, hydrated and water of crystallisation

5 calculate empirical and molecular formulas, using given data

2.4 Reacting masses and volumes (of solutions and gases)

Learning outcomes

Candidates should be able to:

1 perform calculations including use of the mole concept, involving:

(a) reacting masses (from formulas and equations) including percentage yield calculations

(b) volumes of gases (e.g. in the burning of hydrocarbons)

(c) volumes and concentrations of solutions

(d) limiting reagent and excess reagent

(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 Mathematical requirements section).)

(e) deduce stoichiometric relationships from calculations such as those in 2.4.1(a)–(d)

3 Chemical bonding

3.1 Electronegativity and bonding

Learning outcomes

Candidates should be able to:

1 define electronegativity as the power of an atom to attract electrons to itself

2 explain the factors influencing the electronegativities of the elements in terms of nuclear charge, atomic radius and shielding by inner shells and sub-shells

3 state and explain the trends in electronegativity across a period and down a group of the Periodic Table

4 use the differences in Pauling electronegativity values to predict the formation of ionic and covalent bonds (the presence of covalent character in some ionic compounds will not be assessed) (Pauling electronegativity values will be given where necessary)

3.2 Ionic bonding

Learning outcomes

Candidates should be able to:

1 define ionic bonding as the electrostatic attraction between oppositely charged ions (positively charged cations and negatively charged anions)

2 describe ionic bonding including the examples of sodium chloride, magnesium oxide and calcium fluoride

3.3 Metallic bonding

Learning outcomes

Candidates should be able to:

1 define metallic bonding as the electrostatic attraction between positive metal ions and delocalised electrons

3.4 Covalent bonding and coordinate (dative covalent) bonding

Learning outcomes

Candidates should be able to:

1 define covalent bonding as electrostatic attraction between the nuclei of two atoms and a shared pair of electrons

(a) describe covalent bonding in molecules including:

- hydrogen, H_2
- oxygen, O_2
- nitrogen, N_2
- chlorine, Cl_2
- hydrogen chloride, HCl
- carbon dioxide, CO_2
- ammonia, NH_3
- methane, CH_4
- ethane, C_2H_6
- ethene, C_2H_4

(b) understand that elements in period 3 can expand their octet including in the compounds sulfur dioxide, SO_2, phosphorus pentachloride, PCl_5, and sulfur hexafluoride, SF_6

(c) describe coordinate (dative covalent) bonding, including in the reaction between ammonia and hydrogen chloride gases to form the ammonium ion, NH_4^+, and in the Al_2Cl_6 molecule

2 (a) describe covalent bonds in terms of orbital overlap giving σ and π bonds:

- σ bonds are formed by direct overlap of orbitals between the bonding atoms
- π bonds are formed by the sideways overlap of adjacent p orbitals above and below the σ bond

(b) describe how the σ and π bonds form in molecules including H_2, C_2H_6, C_2H_4, HCN and N_2

(c) use the concept of hybridisation to describe sp, sp^2 and sp^3 orbitals

3 (a) define the terms:

- bond energy as the energy required to break one mole of a particular covalent bond in the gaseous state
- bond length as the internuclear distance of two covalently bonded atoms

(b) use bond energy values and the concept of bond length to compare the reactivity of covalent molecules

3.5 Shapes of molecules

Learning outcomes

Candidates should be able to:

1 state and explain the shapes of, and bond angles in, molecules by using VSEPR theory, including as simple examples:
- BF_3 (trigonal planar, 120°)
- CO_2 (linear, 180°)
- CH_4 (tetrahedral, 109.5°)
- NH_3 (pyramidal, 107°)
- H_2O (non-linear, 104.5°)
- SF_6 (octahedral, 90°)
- PF_5 (trigonal bipyramidal, 120° and 90°)

2 predict the shapes of, and bond angles in, molecules and ions analogous to those specified in 3.5.1

3.6 Intermolecular forces, electronegativity and bond properties

Learning outcomes

Candidates should be able to:

1 (a) describe hydrogen bonding, limited to molecules containing N–H and O–H groups, including ammonia and water as simple examples

(b) use the concept of hydrogen bonding to explain the anomalous properties of H_2O (ice and water):
- its relatively high melting and boiling points
- its relatively high surface tension
- the density of the solid ice compared with the liquid water

2 use the concept of electronegativity to explain bond polarity and dipole moments of molecules

3 (a) describe van der Waals' forces as the intermolecular forces between molecular entities other than those due to bond formation, and use the term van der Waals' forces as a generic term to describe all intermolecular forces

(b) describe the types of van der Waals' forces:
- instantaneous dipole–induced dipole (id-id) forces, also called London dispersion forces
- permanent dipole–permanent dipole (pd-pd) forces, including hydrogen bonding

(c) describe hydrogen bonding and understand that hydrogen bonding is a special case of permanent dipole–permanent dipole forces between molecules where hydrogen is bonded to a highly electronegative atom

4 state that, in general, ionic, covalent and metallic bonding are stronger than intermolecular forces

3.7 Dot-and-cross diagrams

Learning outcomes

Candidates should be able to:

1 use dot-and-cross diagrams to illustrate ionic, covalent and coordinate bonding including the representation of any compounds stated in 3.4 and 3.5 (dot-and-cross diagrams may include species with atoms which have an expanded octet or species with an odd number of electrons)

4 States of matter

4.1 The gaseous state: ideal and real gases and *pV* = *nRT*

Learning outcomes

Candidates should be able to:

1 explain the origin of pressure in a gas in terms of collisions between gas molecules and the wall of the container

2 understand that ideal gases have zero particle volume and no intermolecular forces of attraction

3 state and use the ideal gas equation $pV = nRT$ in calculations, including in the determination of M_r

4.2 Bonding and structure

Learning outcomes

Candidates should be able to:

1 describe, in simple terms, the lattice structure of a crystalline solid which is:

(a) giant ionic, including sodium chloride and magnesium oxide

(b) simple molecular, including iodine, buckminsterfullerene C_{60} and ice

(c) giant molecular, including silicon(IV) oxide, graphite and diamond

(d) giant metallic, including copper

2 describe, interpret and predict the effect of different types of structure and bonding on the physical properties of substances, including melting point, boiling point, electrical conductivity and solubility

3 deduce the type of structure and bonding present in a substance from given information

5 Chemical energetics

5.1 Enthalpy change, ΔH

Learning outcomes

Candidates should be able to:

1 understand that chemical reactions are accompanied by enthalpy changes and these changes can be exothermic (ΔH is negative) or endothermic (ΔH is positive)

2 construct and interpret a reaction pathway diagram, in terms of the enthalpy change of the reaction and of the activation energy

3 define and use the terms:

(a) standard conditions (this syllabus assumes that these are 298 K and 101 kPa) shown by $^{\ominus}$.

(b) enthalpy change with particular reference to: reaction, ΔH_r, formation, ΔH_f, combustion, ΔH_c, neutralisation, ΔH_{neut}

4 understand that energy transfers occur during chemical reactions because of the breaking and making of chemical bonds

5 use bond energies (ΔH positive, i.e. bond breaking) to calculate enthalpy change of reaction, ΔH_r

6 understand that some bond energies are exact and some bond energies are averages

7 calculate enthalpy changes from appropriate experimental results, including the use of the relationships $q = mc\Delta T$ and $\Delta H = -mc\Delta T/_n$

5.2 Hess's law

Learning outcomes

Candidates should be able to:

1 apply Hess's law to construct simple energy cycles

2 carry out calculations using cycles and relevant energy terms, including:

(a) determining enthalpy changes that cannot be found by direct experiment

(b) use of bond energy data

6 Electrochemistry

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

Learning outcomes

Candidates should be able to:

1 calculate oxidation numbers of elements in compounds and ions

2 use changes in oxidation numbers to help balance chemical equations

3 explain and use the terms redox, oxidation, reduction and disproportionation in terms of electron transfer and changes in oxidation number

4 explain and use the terms oxidising agent and reducing agent

5 use a Roman numeral to indicate the magnitude of the oxidation number of an element

7 Equilibria

7.1 Chemical equilibria: reversible reactions, dynamic equilibrium

Learning outcomes

Candidates should be able to:

1 (a) understand what is meant by a reversible reaction
   (b) understand what is meant by dynamic equilibrium in terms of the rate of forward and reverse reactions being equal and the concentration of reactants and products remaining constant
   (c) understand the need for a closed system in order to establish dynamic equilibrium
2 define Le Chatelier's principle as: if a change is made to a system at dynamic equilibrium, the position of equilibrium moves to minimise this change
3 use Le Chatelier's principle to deduce qualitatively (from appropriate information) the effects of changes in temperature, concentration, pressure or presence of a catalyst on a system at equilibrium
4 deduce expressions for equilibrium constants in terms of concentrations, K_c
5 use the terms mole fraction and partial pressure
6 deduce expressions for equilibrium constants in terms of partial pressures, K_p (use of the relationship between K_p and K_c is not required)
7 use the K_c and K_p expressions to carry out calculations (such calculations will not require the solving of quadratic equations)
8 calculate the quantities present at equilibrium, given appropriate data
9 state whether changes in temperature, concentration or pressure or the presence of a catalyst affect the value of the equilibrium constant for a reaction
10 describe and explain the conditions used in the Haber process and the Contact process, as examples of the importance of an understanding of dynamic equilibrium in the chemical industry and the application of Le Chatelier's principle

7.2 Brønsted–Lowry theory of acids and bases

Learning outcomes

Candidates should be able to:

1 state the names and formulas of the common acids, limited to hydrochloric acid, HC*l*, sulfuric acid, H_2SO_4, nitric acid, HNO_3, ethanoic acid, CH_3COOH
2 state the names and formulas of the common alkalis, limited to sodium hydroxide, NaOH, potassium hydroxide, KOH, ammonia, NH_3
3 describe the Brønsted–Lowry theory of acids and bases
4 describe strong acids and strong bases as fully dissociated in aqueous solution and weak acids and weak bases as partially dissociated in aqueous solution
5 appreciate that water has pH of 7, acid solutions pH of below 7 and alkaline solutions pH of above 7
6 explain qualitatively the differences in behaviour between strong and weak acids including the reaction with a reactive metal and difference in pH values by use of a pH meter, universal indicator or conductivity
7 understand that neutralisation reactions occur when $H^+(aq)$ and $OH^-(aq)$ form $H_2O(l)$
8 understand that salts are formed in neutralisation reactions
9 sketch the pH titration curves of titrations using combinations of strong and weak acids with strong and weak alkalis
10 select suitable indicators for acid-alkali titrations, given appropriate data (pK_a values will not be used)

8 Reaction kinetics

8.1 Rate of reaction

Learning outcomes

Candidates should be able to:

1 explain and use the term rate of reaction, frequency of collisions, effective collisions and non-effective collisions

2 explain qualitatively, in terms of frequency of effective collisions, the effect of concentration and pressure changes on the rate of a reaction

3 use experimental data to calculate the rate of a reaction

8.2 Effect of temperature on reaction rates and the concept of activation energy

Learning outcomes

Candidates should be able to:

1 define activation energy, E_A, as the minimum energy required for a collision to be effective

2 sketch and use the Boltzmann distribution to explain the significance of activation energy

3 explain qualitatively, in terms both of the Boltzmann distribution and of frequency of effective collisions, the effect of temperature change on the rate of a reaction

8.3 Homogeneous and heterogeneous catalysts

Learning outcomes

Candidates should be able to:

1 explain and use the terms catalyst and catalysis:

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

(b) explain this catalytic effect in terms of the Boltzmann distribution

(c) construct and interpret a reaction pathway diagram, for a reaction in the presence and absence of an effective catalyst

Inorganic chemistry

9 The Periodic Table: chemical periodicity

9.1 Periodicity of physical properties of the elements in Period 3

Learning outcomes

Candidates should be able to:

1 describe qualitatively (and indicate the periodicity in) the variations in atomic radius, ionic radius, melting point and electrical conductivity of the elements

2 explain the variation in melting point and electrical conductivity in terms of the structure and bonding of the elements

9.2 Periodicity of chemical properties of the elements in Period 3

Learning outcomes

Candidates should be able to:

1 describe, and write equations for, the reactions of the elements with oxygen (to give Na_2O, MgO, Al_2O_3, P_4O_{10}, SO_2), chlorine (to give NaCl, $MgCl_2$, $AlCl_3$, $SiCl_4$, PCl_5) and water (Na and Mg only)

2 state and explain the variation in the oxidation number of the oxides (Na_2O, MgO, Al_2O_3, P_4O_{10}, SO_2 and SO_3 only) and chlorides (NaCl, $MgCl_2$, $AlCl_3$, $SiCl_4$, PCl_5 only) in terms of their outer shell (valence shell) electrons

3 describe, and write equations for, the reactions, if any, of the oxides Na_2O, MgO, Al_2O_3, SiO_2, P_4O_{10}, SO_2 and SO_3 with water including the likely pHs of the solutions obtained

4 describe, explain, and write equations for, the acid/base behaviour of the oxides Na_2O, MgO, Al_2O_3, P_4O_{10}, SO_2 and SO_3 and the hydroxides NaOH, $Mg(OH)_2$ and $Al(OH)_3$ including, where relevant, amphoteric behaviour in reactions with acids and bases (sodium hydroxide only)

5 describe, explain, and write equations for, the reactions of the chlorides NaCl, $MgCl_2$, $Al\,Cl_3$, $SiCl_4$, PCl_5 with water including the likely pHs of the solutions obtained

6 explain the variations and trends in 9.2.2, 9.2.3, 9.2.4 and 9.2.5 in terms of bonding and electronegativity

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

9.3 Chemical periodicity of other elements

Learning outcomes

Candidates should be able to:

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

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

10 Group 2

10.1 Similarities and trends in the properties of the Group 2 metals, magnesium to barium, and their compounds

Learning outcomes

Candidates should be able to:

1 describe, and write equations for, the reactions of the elements with oxygen, water and dilute hydrochloric and sulfuric acids

2 describe, and write equations for, the reactions of the oxides, hydroxides and carbonates with water and dilute hydrochloric and sulfuric acids

3 describe, and write equations for, the thermal decomposition of the nitrates and carbonates, to include the trend in thermal stabilities

4 describe, and make predictions from, the trends in physical and chemical properties of the elements involved in the reactions in 10.1.1 and the compounds involved in 10.1.2, 10.1.3 and 10.1.5

5 state the variation in the solubilities of the hydroxides and sulfates

11 Group 17

11.1 Physical properties of the Group 17 elements

Learning outcomes

Candidates should be able to:

1 describe the colours and the trend in volatility of chlorine, bromine and iodine

2 describe and explain the trend in the bond strength of the halogen molecules

3 interpret the volatility of the elements in terms of instantaneous dipole–induced dipole forces

11.2 The chemical properties of the halogen elements and the hydrogen halides

Learning outcomes

Candidates should be able to:

1 describe the relative reactivity of the elements as oxidising agents

2 describe the reactions of the elements with hydrogen and explain their relative reactivity in these reactions

3 describe the relative thermal stabilities of the hydrogen halides and explain these in terms of bond strengths

11.3 Some reactions of the halide ions

Learning outcomes

Candidates should be able to:

1 describe the relative reactivity of halide ions as reducing agents

2 describe and explain the reactions of halide ions with:

(a) aqueous silver ions followed by aqueous ammonia (the formation and formula of the $[Ag(NH_3)_2]^+$ complex is not required)

(b) concentrated sulfuric acid, to include balanced chemical equations

11.4 The reactions of chlorine

Learning outcomes

Candidates should be able to:

1 describe and interpret, in terms of changes in oxidation number, the reaction of chlorine with cold and with hot aqueous sodium hydroxide and recognise these as disproportionation reactions

2 explain, including by use of an equation, the use of chlorine in water purification to include the production of the active species HOC*l* and C*l*O$^-$ which kill bacteria

12 Nitrogen and sulfur

12.1 Nitrogen and sulfur

Learning outcomes

Candidates should be able to:

1 explain the lack of reactivity of nitrogen, with reference to triple bond strength and lack of polarity

2 describe and explain:

(a) the basicity of ammonia, using the Brønsted–Lowry theory

(b) the structure of the ammonium ion and its formation by an acid–base reaction

(c) the displacement of ammonia from ammonium salts by an acid–base reaction

3 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

4 understand that atmospheric oxides of nitrogen (NO and NO_2) can react with unburned hydrocarbons to form peroxyacetyl nitrate, PAN, which is a component of photochemical smog

5 describe the role of NO and NO_2 in the formation of acid rain both directly and in their catalytic role in the oxidation of atmospheric sulfur dioxide

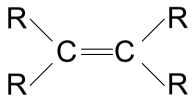
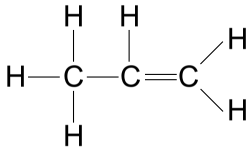
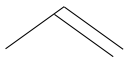
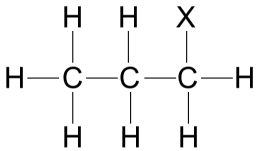
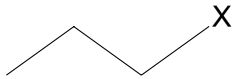
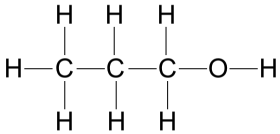
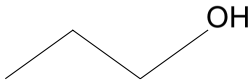
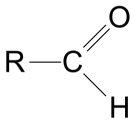
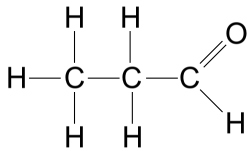
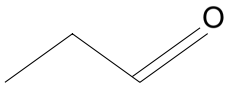
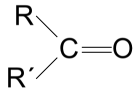
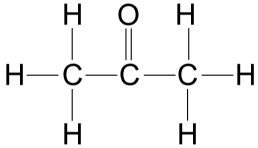
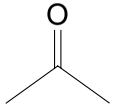
Organic chemistry

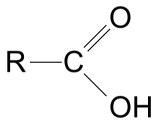
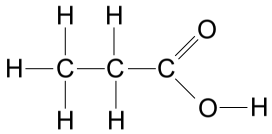
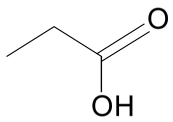
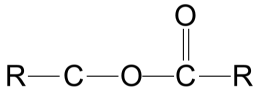
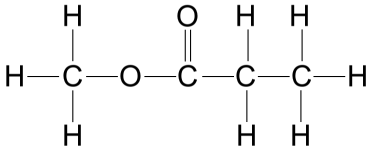
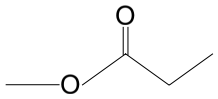
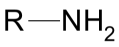
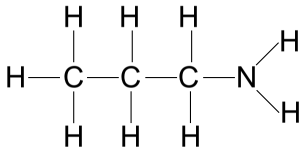
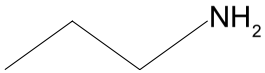
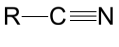
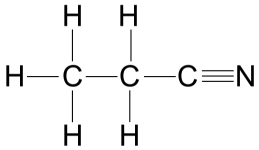
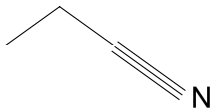
13 An introduction to AS Level organic chemistry

In this syllabus the following conventions are used:

X to represent a halogen atom

R and R′ to represent alkyl groups (or in some circumstances a hydrogen atom); R and R′ can be the same or different depending on the molecule.

homologous series	name of functional group	structural formula of functional group	displayed formula	skeletal formula	name
alkene	C=C bond				propene
halogenoalkane (primary, secondary and tertiary)	halogen				1-chloropropane (when X is chlorine)
alcohol (primary, secondary and tertiary)	hydroxyl				propan-1-ol
aldehyde	carbonyl				propanal
ketone	carbonyl				propanone

homologous series	name of functional group	structural formula of functional group	displayed formula	skeletal formula	name
carboxylic acid	carboxyl				propanoic acid
ester	ester				methyl propanoate
amine (primary only)	amine				propylamine
nitrile	nitrile				propanenitrile

13.1 Formulas, functional groups and the naming of organic compounds

Learning outcomes

Candidates should be able to:

1 define the term hydrocarbon as a compound made up of C and H atoms only
2 understand that alkanes are simple hydrocarbons with no functional group
3 understand that the compounds in the table on pages 29 and 30 contain a functional group which dictates their physical and chemical properties
4 interpret and use the general, structural, displayed and skeletal formulas of the classes of compound stated in the table on pages 29 and 30
5 understand and use systematic nomenclature of simple aliphatic organic molecules with functional groups detailed in the table on pages 29 and 30, up to six carbon atoms (six plus six for esters, straight chains only for esters and nitriles)
6 deduce the molecular and/or empirical formula of a compound, given its structural, displayed or skeletal formula

13.2 Characteristic organic reactions

Learning outcomes

Candidates should be able to:

1 interpret and use the following terminology associated with types of organic compounds and reactions:
   (a) homologous series
   (b) saturated and unsaturated
   (c) homolytic and heterolytic fission
   (d) free radical, initiation, propagation, termination
   (e) nucleophile, electrophile, nucleophilic, electrophilic
   (f) addition, substitution, elimination, hydrolysis, condensation
   (g) oxidation and reduction

   (in equations for organic redox reactions, the symbol [O] can be used to represent one atom of oxygen from an oxidising agent and the symbol [H] to represent one atom of hydrogen from a reducing agent)
2 understand and use the following terminology associated with types of organic mechanisms:
   (a) free-radical substitution
   (b) electrophilic addition
   (c) nucleophilic substitution
   (d) nucleophilic addition

   (in organic reaction mechanisms, the use of curly arrows to represent movement of electron pairs is expected; the arrow should begin at a bond or a lone pair of electrons)

13.3 Shapes of organic molecules; σ and π bonds

Learning outcomes

Candidates should be able to:

1 describe organic molecules as either straight-chained, branched or cyclic

2 describe and explain the shape of, and bond angles in, molecules containing sp, sp^2 and sp^3 hybridised atoms

3 describe the arrangement of σ and π bonds in molecules containing sp, sp^2 and sp^3 hybridised atoms

4 understand and use the term planar when describing the arrangement of atoms in organic molecules, for example ethene

13.4 Isomerism: structural isomerism and stereoisomerism

Learning outcomes

Candidates should be able to:

1 describe structural isomerism and its division into chain, positional and functional group isomerism

2 describe stereoisomerism and its division into geometrical (cis/trans) and optical isomerism (use of E/Z nomenclature is acceptable but is not required)

3 describe geometrical (cis/trans) isomerism in alkenes, and explain its origin in terms of restricted rotation due to the presence of π bonds

4 explain what is meant by a chiral centre and that such a centre gives rise to two optical isomers (enantiomers)

(Candidates should appreciate that compounds can contain more than one chiral centre, but knowledge of meso compounds, or nomenclature such as diastereoisomers is **not** required.)

5 identify chiral centres and geometrical (cis/trans) isomerism in a molecule of given structural formula including cyclic compounds

6 deduce the possible isomers for an organic molecule of known molecular formula

14 Hydrocarbons

14.1 Alkanes

Learning outcomes

Candidates should be able to:

1 recall the reactions (reagents and conditions) by which alkanes can be produced:
   (a) addition of hydrogen to an alkene in a hydrogenation reaction, $H_2(g)$ and Pt/Ni catalyst and heat
   (b) cracking of a longer chain alkane, heat with Al_2O_3
2 describe:
   (a) the complete and incomplete combustion of alkanes
   (b) the free-radical substitution of alkanes by Cl_2 or Br_2 in the presence of ultraviolet light, as exemplified by the reactions of ethane
3 describe the mechanism of free-radical substitution with reference to the initiation, propagation and termination steps
4 suggest how cracking can be used to obtain more useful alkanes and alkenes of lower M_r from heavier crude oil fractions
5 understand the general unreactivity of alkanes, including towards polar reagents in terms of the strength of the C–H bonds and their relative lack of polarity
6 recognise the environmental consequences of carbon monoxide, oxides of nitrogen and unburnt hydrocarbons arising from the combustion of alkanes in the internal combustion engine and of their catalytic removal

14.2 Alkenes

Learning outcomes

Candidates should be able to:

1 recall the reactions (including reagents and conditions) by which alkenes can be produced:
   (a) elimination of HX from a halogenoalkane by ethanolic NaOH and heat
   (b) dehydration of an alcohol, by using a heated catalyst (e.g. Al_2O_3) or a concentrated acid (e.g. concentrated H_2SO_4)
   (c) cracking of a longer chain alkane
2 describe the following reactions of alkenes:
   (a) the electrophilic addition of
      (i) hydrogen in a hydrogenation reaction, $H_2(g)$ and Pt/Ni catalyst and heat
      (ii) steam, $H_2O(g)$ and H_3PO_4 catalyst
      (iii) a hydrogen halide, HX(g), at room temperature
      (iv) a halogen, X_2
   (b) the oxidation by cold dilute acidified $KMnO_4$ to form the diol
   (c) the oxidation by hot concentrated acidified $KMnO_4$ leading to the rupture of the carbon–carbon double bond and the identities of the subsequent products to determine the position of alkene linkages in larger molecules
   (d) addition polymerisation exemplified by the reactions of ethene and propene

14.2 Alkenes (continued)

3 describe the use of aqueous bromine to show the presence of a C=C bond

4 describe the mechanism of electrophilic addition in alkenes, using bromine/ethene and hydrogen bromide/propene as examples

5 describe and explain the inductive effects of alkyl groups on the stability of primary, secondary and tertiary cations formed during electrophilic addition (this should be used to explain Markovnikov addition)

15 Halogen compounds

15.1 Halogenoalkanes

Learning outcomes

Candidates should be able to:

1 recall the reactions (reagents and conditions) by which halogenoalkanes can be produced:
   (a) the free-radical substitution of alkanes by Cl_2 or Br_2 in the presence of ultraviolet light, as exemplified by the reactions of ethane
   (b) electrophilic addition of an alkene with a halogen, X_2, or hydrogen halide, HX(g), at room temperature
   (c) substitution of an alcohol, e.g. by reaction with HX(g); or with KC*l* and concentrated H_2SO_4 or concentrated H_3PO_4; or with PCl_3 and heat; or with PCl_5; or with $SOCl_2$

2 classify halogenoalkanes into primary, secondary and tertiary

3 describe the following nucleophilic substitution reactions:
   (a) the reaction with NaOH(aq) and heat to produce an alcohol
   (b) the reaction with KCN in ethanol and heat to produce a nitrile
   (c) the reaction with NH_3 in ethanol heated under pressure to produce an amine
   (d) the reaction with aqueous silver nitrate in ethanol as a method of identifying the halogen present as exemplified by bromoethane

4 describe the elimination reaction with NaOH in ethanol and heat to produce an alkene as exemplified by bromoethane

5 describe the S_N1 and S_N2 mechanisms of nucleophilic substitution in halogenoalkanes including the inductive effects of alkyl groups

6 recall that primary halogenoalkanes tend to react via the S_N2 mechanism; tertiary halogenoalkanes via the S_N1 mechanism; and secondary halogenoalkanes by a mixture of the two, depending on structure

7 describe and explain the different reactivities of halogenoalkanes (with particular reference to the relative strengths of the C–X bonds as exemplified by the reactions of halogenoalkanes with aqueous silver nitrates)

16 Hydroxy compounds

16.1 Alcohols

Learning outcomes

Candidates should be able to:

1 recall the reactions (reagents and conditions) by which alcohols can be produced:
   (a) electrophilic addition of steam to an alkene, H_2O(g) and H_3PO_4 catalyst
   (b) reaction of alkenes with cold dilute acidified potassium manganate(VII) to form a diol
   (c) substitution of a halogenoalkane using NaOH(aq) and heat
   (d) reduction of an aldehyde or ketone using $NaBH_4$ or $LiAlH_4$
   (e) reduction of a carboxylic acid using $LiAlH_4$
   (f) hydrolysis of an ester using dilute acid or dilute alkali and heat

2 describe:
   (a) the reaction with oxygen (combustion)
   (b) substitution to form halogenoalkanes, e.g. by reaction with HX(g); or with KCl and concentrated H_2SO_4 or concentrated H_3PO_4; or with PCl_3 and heat; or with PCl_5; or with $SOCl_2$
   (c) the reaction with Na(s)
   (d) oxidation with acidified $K_2Cr_2O_7$ or acidified $KMnO_4$ to:
      (i) carbonyl compounds by distillation
      (ii) carboxylic acids by refluxing

      (primary alcohols give aldehydes which can be further oxidised to carboxylic acids, secondary alcohols give ketones, tertiary alcohols cannot be oxidised)
   (e) dehydration to an alkene, by using a heated catalyst, e.g. Al_2O_3 or a concentrated acid
   (f) formation of esters by reaction with carboxylic acids and concentrated H_2SO_4 as catalyst as exemplified by ethanol

3 (a) classify alcohols as primary, secondary and tertiary alcohols, to include examples with more than one alcohol group
   (b) state characteristic distinguishing reactions, e.g. mild oxidation with acidified $K_2Cr_2O_7$, colour change from orange to green

4 deduce the presence of a $CH_3CH(OH)$– group in an alcohol, $CH_3CH(OH)$–R, from its reaction with alkaline I_2(aq) to form a yellow precipitate of tri-iodomethane and an ion, RCO_2^-

5 explain the acidity of alcohols compared with water

17 Carbonyl compounds

17.1 Aldehydes and ketones

Learning outcomes

Candidates should be able to:

1 recall the reactions (reagents and conditions) by which aldehydes and ketones can be produced:
   (a) the oxidation of primary alcohols using acidified $K_2Cr_2O_7$ or acidified $KMnO_4$ and distillation to produce aldehydes
   (b) the oxidation of secondary alcohols using acidified $K_2Cr_2O_7$ or acidified $KMnO_4$ and distillation to produce ketones

2 describe:
   (a) the reduction of aldehydes and ketones using $NaBH_4$ or $LiAlH_4$ to produce alcohols
   (b) the reaction of aldehydes and ketones with HCN, KCN as catalyst, and heat to produce hydroxynitriles as exemplified by ethanal and propanone

3 describe the mechanism of the nucleophilic addition reactions of hydrogen cyanide with aldehydes and ketones in 17.1.2(b)

4 describe the use of 2,4-dinitrophenylhydrazine (2,4-DNPH reagent) to detect the presence of carbonyl compounds

5 deduce the nature (aldehyde or ketone) of an unknown carbonyl compound from the results of simple tests (Fehling's and Tollens' reagents; ease of oxidation)

6 deduce the presence of a CH_3CO- group in an aldehyde or ketone, $CH_3CO–R$, from its reaction with alkaline I_2(aq) to form a yellow precipitate of tri-iodomethane and an ion, RCO_2^-

18 Carboxylic acids and derivatives

18.1 Carboxylic acids

Learning outcomes

Candidates should be able to:

1 recall the reactions by which carboxylic acids can be produced:
   (a) oxidation of primary alcohols and aldehydes with acidified $K_2Cr_2O_7$ or acidified $KMnO_4$ and refluxing
   (b) hydrolysis of nitriles with dilute acid or dilute alkali followed by acidification
   (c) hydrolysis of esters with dilute acid or dilute alkali and heat followed by acidification

2 describe:
   (a) the redox reaction with reactive metals to produce a salt and H_2(g)
   (b) the neutralisation reaction with alkalis to produce a salt and H_2O(l)
   (c) the acid–base reaction with carbonates to produce a salt and H_2O(l) and CO_2(g)
   (d) esterification with alcohols with concentrated H_2SO_4 as catalyst
   (e) reduction by $LiAlH_4$ to form a primary alcohol

18.2 Esters

Learning outcomes

Candidates should be able to:

1 recall the reaction (reagents and conditions) by which esters can be produced:
   (a) the condensation reaction between an alcohol and a carboxylic acid with concentrated H_2SO_4 as catalyst
2 describe the hydrolysis of esters by dilute acid and by dilute alkali and heat

19 Nitrogen compounds

19.1 Primary amines

Learning outcomes

Candidates should be able to:

1 recall the reactions by which amines can be produced:
   (a) reaction of a halogenoalkane with NH_3 in ethanol heated under pressure

   Classification of amines will not be tested at AS Level.

19.2 Nitriles and hydroxynitriles

Learning outcomes

Candidates should be able to:

1 recall the reactions by which nitriles can be produced:
   (a) reaction of a halogenoalkane with KCN in ethanol and heat
2 recall the reactions by which hydroxynitriles can be produced:
   (a) the reaction of aldehydes and ketones with HCN, KCN as catalyst, and heat
3 describe the hydrolysis of nitriles with dilute acid or dilute alkali followed by acidification to produce a carboxylic acid

20 Polymerisation

20.1 Addition polymerisation

Learning outcomes

Candidates should be able to:

1 describe addition polymerisation as exemplified by poly(ethene) and poly(chloroethene), PVC
2 deduce the repeat unit of an addition polymer obtained from a given monomer
3 identify the monomer(s) present in a given section of an addition polymer molecule
4 recognise the difficulty of the disposal of poly(alkene)s, i.e. non-biodegradability and harmful combustion products

21 Organic synthesis

21.1 Organic synthesis

Learning outcomes

Candidates should be able to:

1 for an organic molecule containing several functional groups:
   (a) identify organic functional groups using the reactions in the syllabus
   (b) predict properties and reactions
2 devise multi-step synthetic routes for preparing organic molecules using the reactions in the syllabus
3 analyse a given synthetic route in terms of type of reaction and reagents used for each step of it, and possible by-products

Analysis

22 Analytical techniques

22.1 Infrared spectroscopy

Learning outcomes

Candidates should be able to:

1 analyse an infrared spectrum of a simple molecule to identify functional groups (see the Data section for the functional groups required)

22.2 Mass spectrometry

Learning outcomes

Candidates should be able to:

1 analyse mass spectra in terms of *m/e* values and isotopic abundances (knowledge of the working of the mass spectrometer is not required)
2 calculate the relative atomic mass of an element given the relative abundances of its isotopes, or its mass spectrum
3 deduce the molecular mass of an organic molecule from the molecular ion peak in a mass spectrum
4 suggest the identity of molecules formed by simple fragmentation in a given mass spectrum
5 deduce the number of carbon atoms, *n*, in a compound using the $[M + 1]^+$ peak and the formula
$$n = \frac{100 \times \text{abundance of } [M + 1]^+ \text{ ion}}{1.1 \times \text{abundance of } M^+ \text{ ion}}$$
6 deduce the presence of bromine and chlorine atoms in a compound using the $[M + 2]^+$ peak

A Level subject content
Physical chemistry

23 Chemical energetics

23.1 Lattice energy and Born-Haber cycles

Learning outcomes

Candidates should be able to:

1 define and use the terms:
   (a) enthalpy change of atomisation, ΔH_{at}
   (b) lattice energy, ΔH_{latt} (the change from gas phase ions to solid lattice)
2 (a) define and use the term first electron affinity, EA
   (b) explain the factors affecting the electron affinities of elements
   (c) describe and explain the trends in the electron affinities of the Group 16 and Group 17 elements
3 construct and use Born–Haber cycles for ionic solids
   (limited to +1 and +2 cations, –1 and –2 anions)
4 carry out calculations involving Born–Haber cycles
5 explain, in qualitative terms, the effect of ionic charge and of ionic radius on the numerical magnitude of a lattice energy

23.2 Enthalpies of solution and hydration

Learning outcomes

Candidates should be able to:

1 define and use the term enthalpy change with reference to hydration, ΔH_{hyd}, and solution, ΔH_{sol}
2 construct and use an energy cycle involving enthalpy change of solution, lattice energy and enthalpy change of hydration
3 carry out calculations involving the energy cycles in 23.2.2
4 explain, in qualitative terms, the effect of ionic charge and of ionic radius on the numerical magnitude of an enthalpy change of hydration

23.3 Entropy change, ΔS

Learning outcomes

Candidates should be able to:

1 define the term entropy, S, as the number of possible arrangements of the particles and their energy in a given system

2 predict and explain the sign of the entropy changes that occur:

(a) during a change in state, e.g. melting, boiling and dissolving (and their reverse)

(b) during a temperature change

(c) during a reaction in which there is a change in the number of gaseous molecules

3 calculate the entropy change for a reaction, ΔS, given the standard entropies, $S^{\ominus}$, of the reactants and products, $\Delta S^{\ominus} = \Sigma S^{\ominus}$ (products) – $\Sigma S^{\ominus}$ (reactants)

(use of $\Delta S^{\ominus} = \Delta S^{\ominus}_{surr} + \Delta S^{\ominus}_{sys}$ is not required)

23.4 Gibbs free energy change, ΔG

Learning outcomes

Candidates should be able to:

1 state and use the Gibbs equation $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$

2 perform calculations using the equation $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$

3 state whether a reaction or process will be feasible by using the sign of ΔG

4 predict the effect of temperature change on the feasibility of a reaction, given standard enthalpy and entropy changes

24 Electrochemistry

24.1 Electrolysis

Learning outcomes

Candidates should be able to:

1 predict the identities of substances liberated during electrolysis from the state of electrolyte (molten or aqueous), position in the redox series (electrode potential) and concentration

2 state and apply the relationship $F = Le$ between the Faraday constant, F, the Avogadro constant, L, and the charge on the electron, e

3 calculate:

(a) the quantity of charge passed during electrolysis, using $Q = It$

(b) the mass and/or volume of substance liberated during electrolysis

4 describe the determination of a value of the Avogadro constant by an electrolytic method

24.2 Standard electrode potentials $E^{\ominus}$, standard cell potentials $E^{\ominus}_{cell}$ and the Nernst equation

Learning outcomes

Candidates should be able to:

1 define the terms:
   (a) standard electrode (reduction) potential
   (b) standard cell potential
2 describe the standard hydrogen electrode
3 describe methods used to measure the standard electrode potentials of:
   (a) metals or non-metals in contact with their ions in aqueous solution
   (b) ions of the same element in different oxidation states
4 calculate a standard cell potential by combining two standard electrode potentials
5 use standard cell potentials to:
   (a) deduce the polarity of each electrode and hence explain/deduce the direction of electron flow in the external circuit of a simple cell
   (b) predict the feasibility of a reaction
6 deduce from $E^{\ominus}$ values the relative reactivity of elements, compounds and ions as oxidising agents or as reducing agents
7 construct redox equations using the relevant half-equations
8 predict qualitatively how the value of an electrode potential, E, varies with the concentrations of the aqueous ions
9 use the Nernst equation, e.g. $E = E^{\ominus} + (0.059/z) \log \frac{[\text{oxidised species}]}{[\text{reduced species}]}$,
   to predict quantitatively how the value of an electrode potential varies with the concentrations of the aqueous ions; examples include $Cu^{2+}(aq) + 2e^{-} \rightleftharpoons Cu(s)$, $Fe^{3+}(aq) + e^{-} \rightleftharpoons Fe^{2+}(aq)$
10 understand and use the equation $\Delta G^{\ominus} = -nE^{\ominus}_{cell}F$

25 Equilibria

25.1 Acids and bases

Learning outcomes

Candidates should be able to:

1 understand and use the terms conjugate acid and conjugate base

2 define conjugate acid–base pairs, identifying such pairs in reactions

3 define mathematically the terms pH, K_a, pK_a and K_w and use them in calculations (K_b and the equation $K_w = K_a \times K_b$ will not be tested)

4 calculate [H^+(aq)] and pH values for:
   (a) strong acids
   (b) strong alkalis
   (c) weak acids

5 (a) define a buffer solution
   (b) explain how a buffer solution can be made
   (c) explain how buffer solutions control pH; use chemical equations in these explanations
   (d) describe and explain the uses of buffer solutions, including the role of HCO_3^- in controlling pH in blood

6 calculate the pH of buffer solutions, given appropriate data

7 understand and use the term solubility product, K_{sp}

8 write an expression for K_{sp}

9 calculate K_{sp} from concentrations and vice versa

10 (a) understand and use the common ion effect to explain the different solubility of a compound in a solution containing a common ion
   (b) perform calculations using K_{sp} values and concentration of a common ion

25.2 Partition coefficients

Learning outcomes

Candidates should be able to:

1 state what is meant by the term partition coefficient, K_{pc}

2 calculate and use a partition coefficient for a system in which the solute is in the same physical state in the two solvents

3 understand the factors affecting the numerical value of a partition coefficient in terms of the polarities of the solute and the solvents used

26 Reaction kinetics

26.1 Simple rate equations, orders of reaction and rate constants

Learning outcomes

Candidates should be able to:

1 explain and use the terms rate equation, order of reaction, overall order of reaction, rate constant, half-life, rate-determining step and intermediate

2 (a) understand and use rate equations of the form rate = k $[A]^m[B]^n$ (for which m and n are 0, 1 or 2)
  (b) deduce the order of a reaction from concentration–time graphs or from experimental data relating to the initial rates method and half-life method
  (c) interpret experimental data in graphical form, including concentration–time and rate–concentration graphs
  (d) calculate an initial rate using concentration data
  (e) construct a rate equation

3 (a) show understanding that the half-life of a first-order reaction is independent of concentration
  (b) use the half-life of a first-order reaction in calculations

4 calculate the numerical value of a rate constant, for example by:
  (a) using the initial rates and the rate equation
  (b) using the half-life, $t_{½}$, and the equation $k = 0.693/t_{½}$

5 for a multi-step reaction:
  (a) suggest a reaction mechanism that is consistent with the rate equation and the equation for the overall reaction
  (b) predict the order that would result from a given reaction mechanism and rate-determining step
  (c) deduce a rate equation using a given reaction mechanism and rate-determining step for a given reaction
  (d) identify an intermediate or catalyst from a given reaction mechanism
  (e) identify the rate determining step from a rate equation and a given reaction mechanism

6 describe qualitatively the effect of temperature change on the rate constant and hence the rate of a reaction

26.2 Homogeneous and heterogeneous catalysts

Learning outcomes

Candidates should be able to:

1 explain that catalysts can be homogeneous or heterogeneous

2 describe the mode of action of a heterogeneous catalyst to include adsorption of reactants, bond weakening and desorption of products, for example:
  (a) iron in the Haber process
  (b) palladium, platinum and rhodium in the catalytic removal of oxides of nitrogen from the exhaust gases of car engines

3 describe the mode of action of a homogeneous catalyst by being used in one step and reformed in a later step, for example:
  (a) atmospheric oxides of nitrogen in the oxidation of atmospheric sulfur dioxide
  (b) Fe^{2+} or Fe^{3+} in the $I^-/S_2O_8^{2-}$ reaction

Inorganic chemistry

27 Group 2

27.1 Similarities and trends in the properties of the Group 2 metals, magnesium to barium, and their compounds

Learning outcomes

Candidates should be able to:

1 describe and explain qualitatively the trend in the thermal stability of the nitrates and carbonates including the effect of ionic radius on the polarisation of the large anion

2 describe and explain qualitatively the variation in solubility and of enthalpy change of solution, $\Delta H^{\ominus}_{sol}$, of the hydroxides and sulfates in terms of relative magnitudes of the enthalpy change of hydration and the lattice energy

28 Chemistry of transition elements

28.1 General physical and chemical properties of the first row of transition elements, titanium to copper

Learning outcomes

Candidates should be able to:

1 define a transition element as a d-block element which forms one or more stable ions with incomplete d orbitals

2 sketch the shape of a $3d_{xy}$ orbital and $3d_{z^2}$ orbital

3 understand that transition elements have the following properties:

(a) they have variable oxidation states

(b) they behave as catalysts

(c) they form complex ions

(d) they form coloured compounds

4 explain why transition elements have variable oxidation states in terms of the similarity in energy of the 3d and the 4s sub-shells

5 explain why transition elements behave as catalysts in terms of having more than one stable oxidation state, and vacant d orbitals that are energetically accessible and can form dative bonds with ligands

6 explain why transition elements form complex ions in terms of vacant d orbitals that are energetically accessible

28.2 General characteristic chemical properties of the first set of transition elements, titanium to copper

Learning outcomes

Candidates should be able to:

1 describe and explain the reactions of transition elements with ligands to form complexes, including the complexes of copper(II) and cobalt(II) ions with water and ammonia molecules and hydroxide and chloride ions

2 define the term ligand as a species that contains a lone pair of electrons that forms a dative covalent bond to a central metal atom/ion

3 understand and use the terms:

(a) monodentate ligand including as examples H_2O, NH_3, Cl^- and CN^-

(b) bidentate ligand including as examples 1,2-diaminoethane, *en*, $H_2NCH_2CH_2NH_2$ and the ethanedioate ion, $C_2O_4^{2-}$

(c) polydentate ligand including as an example $EDTA^{4-}$

4 define the term complex as a molecule or ion formed by a central metal atom/ion surrounded by one or more ligands

5 describe the geometry (shape and bond angles) of transition element complexes which are linear, square planar, tetrahedral or octahedral

6 (a) state what is meant by coordination number

(b) predict the formula and charge of a complex ion, given the metal ion, its charge or oxidation state, the ligand and its coordination number or geometry

7 explain qualitatively that ligand exchange can occur, including the complexes of copper(II) ions and cobalt(II) ions with water and ammonia molecules and hydroxide and chloride ions

8 predict, using $E^{\ominus}$ values, the feasibility of redox reactions involving transition elements and their ions

9 describe the reactions of, and perform calculations involving:

(a) $MnO_4^-/C_2O_4^{2-}$ in acid solution given suitable data

(b) MnO_4^-/Fe^{2+} in acid solution given suitable data

(c) Cu^{2+}/I^- given suitable data

10 perform calculations involving other redox systems given suitable data

28.3 Colour of complexes

Learning outcomes

Candidates should be able to:

1 define and use the terms degenerate and non-degenerate d orbitals

2 describe the splitting of degenerate d orbitals into two non-degenerate sets of d orbitals of higher energy, and use of ΔE in:

(a) octahedral complexes, two higher and three lower d orbitals

(b) tetrahedral complexes, three higher and two lower d orbitals

3 explain why transition elements form coloured compounds in terms of the frequency of light absorbed as an electron is promoted between two non-degenerate d orbitals

4 describe, in qualitative terms, the effects of different ligands on ΔE, frequency of light absorbed, and hence the complementary colour that is observed

5 use the complexes of copper(II) ions and cobalt(II) ions with water and ammonia molecules and hydroxide and chloride ions as examples of ligand exchange affecting the colour observed

28.4 Stereoisomerism in transition element complexes

Learning outcomes

Candidates should be able to:

1 describe the types of stereoisomerism shown by complexes, including those associated with bidentate ligands:
   (a) geometrical (cis/trans) isomerism, e.g. square planar such as $[Pt(NH_3)_2Cl_2]$ and octahedral such as $[Co(NH_3)_4(H_2O)_2]^{2+}$ and $[Ni(H_2NCH_2CH_2NH_2)_2(H_2O)_2]^{2+}$
   (b) optical isomerism, e.g. $[Ni(H_2NCH_2CH_2NH_2)_3]^{2+}$ and $[Ni(H_2NCH_2CH_2NH_2)_2(H_2O)_2]^{2+}$
2 deduce the overall polarity of complexes such as those described in 28.4.1(a) and 28.4.1(b)

28.5 Stability constants, K_{stab}

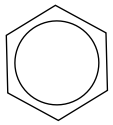
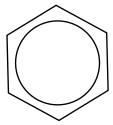
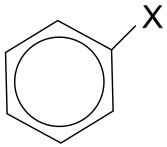
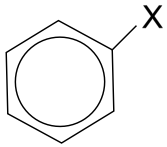
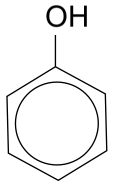
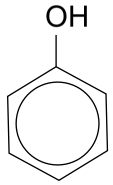
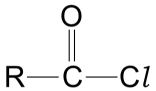
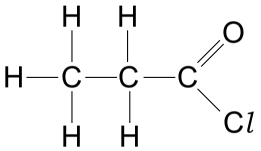
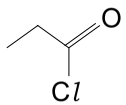
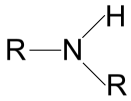
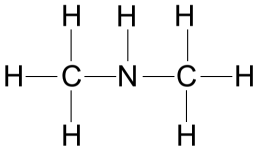
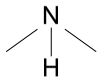
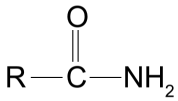
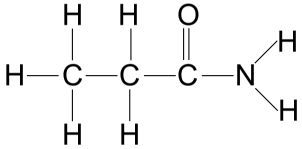
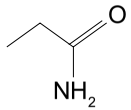
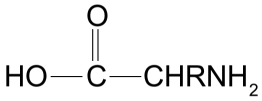
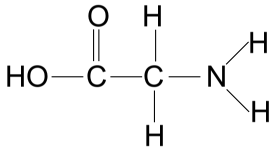
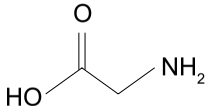
Learning outcomes

Candidates should be able to:

1 define the stability constant, K_{stab}, of a complex as the equilibrium constant for the formation of the complex ion in a solvent (from its constituent ions or molecules)
2 write an expression for a K_{stab} of a complex ($[H_2O]$ should not be included)
3 use K_{stab} expressions to perform calculations
4 describe and explain ligand exchanges in terms of K_{stab} values and understand that a large K_{stab} is due to the formation of a stable complex ion

Organic chemistry

29 An introduction to A Level organic chemistry

homologous series	name of functional group	structural formula of functional group	displayed formula	skeletal formula	name
arene	arene		*n/a		benzene
halogenoarene	halogen		*n/a		chlorobenzene (when X = C*l*)
phenol	phenol		*n/a		phenol
acyl chloride	acyl chloride				propanoyl chloride
amines (secondary and tertiary)	amine				(naming of secondary and tertiary amines is not required)
amide (primary, secondary and tertiary)	amide				propanamide
amino acid	amine and carboxyl				2-aminoethanoic acid

*Where a benzene ring is part of the molecule, a displayed formula would not be expected to be drawn.

29.1 Formulas, functional groups and the naming of organic compounds

Learning outcomes

Candidates should be able to:

1 understand that the compounds in the table on page 47 contain a functional group which dictates their physical and chemical properties

2 interpret and use the general, structural, displayed and skeletal formulas of the classes of compound stated in the table on page 47

3 understand and use systematic nomenclature of simple aliphatic organic molecules (including cyclic compounds containing a single ring of up to six carbon atoms) with functional groups detailed in the table on page 47, up to six carbon atoms (six plus six for esters and amides, straight chains only for esters and nitriles)

4 understand and use systematic nomenclature of simple aromatic molecules with one benzene ring and one or more simple substituents, for example 3-nitrobenzoic acid or 2,4,6-tribromophenol

29.2 Characteristic organic reactions

Learning outcomes

Candidates should be able to:

1 understand and use the following terminology associated with types of organic mechanisms:

(a) electrophilic substitution

(b) addition–elimination

29.3 Shapes of aromatic organic molecules; σ and π bonds

Learning outcomes

Candidates should be able to:

1 describe and explain the shape of benzene and other aromatic molecules, including sp^2 hybridisation, in terms of σ bonds and a delocalised π system

29.4 Isomerism: optical

Learning outcomes

Candidates should be able to:

1 understand that enantiomers have identical physical and chemical properties apart from their ability to rotate plane polarised light and their potential biological activity

2 understand and use the terms optically active and racemic mixture

3 describe the effect on plane polarised light of the two optical isomers of a single substance

4 explain the relevance of chirality to the synthetic preparation of drug molecules including:

(a) the potential different biological activity of the two enantiomers

(b) the need to separate a racemic mixture into two pure enantiomers

(c) the use of chiral catalysts to produce a single pure optical isomer

(Candidates should appreciate that compounds can contain more than one chiral centre, but knowledge of meso compounds and nomenclature such as diastereoisomers is **not** required.)

30 Hydrocarbons

30.1 Arenes

Learning outcomes

Candidates should be able to:

1 describe the chemistry of arenes as exemplified by the following reactions of benzene and methylbenzene:
   (a) substitution reactions with Cl_2 and with Br_2 in the presence of a catalyst, $AlCl_3$ or $AlBr_3$, to form halogenoarenes (aryl halides)
   (b) nitration with a mixture of concentrated HNO_3 and concentrated H_2SO_4 at a temperature between 25 °C and 60 °C
   (c) Friedel–Crafts alkylation by CH_3Cl and $AlCl_3$ and heat
   (d) Friedel–Crafts acylation by CH_3COCl and $AlCl_3$ and heat
   (e) complete oxidation of the side-chain using hot alkaline $KMnO_4$ and then dilute acid to give a benzoic acid
   (f) hydrogenation of the benzene ring using H_2 and Pt/Ni catalyst and heat to form a cyclohexane ring
2 describe the mechanism of electrophilic substitution in arenes:
   (a) as exemplified by the formation of nitrobenzene and bromobenzene
   (b) with regards to the effect of delocalisation (aromatic stabilisation) of electrons in arenes to explain the predomination of substitution over addition
3 predict whether halogenation will occur in the side-chain or in the aromatic ring in arenes depending on reaction conditions
4 describe that in the electrophilic substitution of arenes, different substituents direct to different ring positions (limited to the directing effects of $–NH_2$, –OH, –R, $–NO_2$, –COOH and –COR)

31 Halogen compounds

31.1 Halogen compounds

Learning outcomes

Candidates should be able to:

1 recall the reactions by which halogenoarenes can be produced: substitution of an arene with Cl_2 or Br_2 in the presence of a catalyst, $AlCl_3$ or $AlBr_3$ to form a halogenoarene, exemplified by benzene to form chlorobenzene and methylbenzene to form 2-chloromethylbenzene and 4-chloromethylbenzene
2 explain the difference in reactivity between a halogenoalkane and a halogenoarene as exemplified by chloroethane and chlorobenzene

32 Hydroxy compounds

32.1 Alcohols

Learning outcomes

Candidates should be able to:

1 describe the reaction with acyl chlorides to form esters using ethyl ethanoate

32.2 Phenol

Learning outcomes

Candidates should be able to:

1 recall the reactions (reagents and conditions) by which phenol can be produced:
   (a) reaction of phenylamine with HNO_2 or $NaNO_2$ and dilute acid below 10 °C to produce the diazonium salt; further warming of the diazonium salt with H_2O to give phenol
2 recall the chemistry of phenol, as exemplified by the following reactions:
   (a) with bases, for example NaOH(aq) to produce sodium phenoxide
   (b) with Na(s) to produce sodium phenoxide and H_2(g)
   (c) in NaOH(aq) with diazonium salts, to give azo compounds
   (d) nitration of the aromatic ring with dilute HNO_3(aq) at room temperature to give a mixture of 2-nitrophenol and 4-nitrophenol
   (e) bromination of the aromatic ring with Br_2(aq) to form 2,4,6-tribromophenol
3 explain the acidity of phenol
4 describe and explain the relative acidities of water, phenol and ethanol
5 explain why the reagents and conditions for the nitration and bromination of phenol are different from those for benzene
6 recall that the hydroxyl group of a phenol directs to the 2-, 4- and 6-positions
7 apply knowledge of the reactions of phenol to those of other phenolic compounds, e.g. naphthol

33 Carboxylic acids and derivatives

33.1 Carboxylic acids

Learning outcomes

Candidates should be able to:

1 recall the reaction by which benzoic acid can be produced:
   (a) reaction of an alkylbenzene with hot alkaline $KMnO_4$ and then dilute acid, exemplified by methylbenzene
2 describe the reaction of carboxylic acids with PCl_3 and heat, PCl_5 or $SOCl_2$ to form acyl chlorides
3 recognise that some carboxylic acids can be further oxidised:
   (a) the oxidation of methanoic acid, HCOOH, with Fehling's reagent or Tollens' reagent or acidified $KMnO_4$ or acidified $K_2Cr_2O_7$ to carbon dioxide and water
   (b) the oxidation of ethanedioic acid, HOOCCOOH, with warm acidified $KMnO_4$ to carbon dioxide
4 describe and explain the relative acidities of carboxylic acids, phenols and alcohols
5 describe and explain the relative acidities of chlorine-substituted carboxylic acids

33.2 Esters

Learning outcomes

Candidates should be able to:

1 recall the reaction by which esters can be produced:
   (a) reaction of alcohols with acyl chlorides using the formation of ethyl ethanoate and phenyl benzoate as examples

33.3 Acyl chlorides

Learning outcomes

Candidates should be able to:

1 recall the reactions (reagents and conditions) by which acyl chlorides can be produced:
   (a) reaction of carboxylic acids with PCl_3 and heat, PCl_5 or $SOCl_2$
2 describe the following reactions of acyl chlorides:
   (a) hydrolysis on addition of water at room temperature to give the carboxylic acid and HCl
   (b) reaction with an alcohol at room temperature to produce an ester and HCl
   (c) reaction with phenol at room temperature to produce an ester and HCl
   (d) reaction with ammonia at room temperature to produce an amide and HCl
   (e) reaction with a primary or secondary amine at room temperature to produce an amide and HCl
3 describe the addition–elimination mechanism of acyl chlorides in reactions in 33.3.2(a)–(e)
4 explain the relative ease of hydrolysis of acyl chlorides, alkyl chlorides and halogenoarenes (aryl chlorides)

34 Nitrogen compounds

34.1 Primary and secondary amines

Learning outcomes

Candidates should be able to:

1 recall the reactions (reagents and conditions) by which primary and secondary amines are produced:
   (a) reaction of halogenoalkanes with NH_3 in ethanol heated under pressure
   (b) reaction of halogenoalkanes with primary amines in ethanol, heated in a sealed tube/under pressure
   (c) the reduction of amides with $LiAlH_4$
   (d) the reduction of nitriles with $LiAlH_4$ or H_2/Ni
2 describe the condensation reaction of ammonia or an amine with an acyl chloride at room temperature to give an amide
3 describe and explain the basicity of aqueous solutions of amines

34.2 Phenylamine and azo compounds

Learning outcomes

Candidates should be able to:

1 describe the preparation of phenylamine via the nitration of benzene to form nitrobenzene followed by reduction with hot Sn/concentrated HC*l* followed by NaOH(aq)

2 describe:
   (a) the reaction of phenylamine with Br_2(aq) at room temperature
   (b) the reaction of phenylamine with HNO_2 or $NaNO_2$ and dilute acid below 10 °C to produce the diazonium salt; further warming of the diazonium salt with H_2O to give phenol

3 describe and explain the relative basicities of aqueous ammonia, ethylamine and phenylamine

4 recall the following about azo compounds:
   (a) describe the coupling of benzenediazonium chloride with phenol in NaOH(aq) to form an azo compound
   (b) identify the azo group
   (c) state that azo compounds are often used as dyes
   (d) that other azo dyes can be formed via a similar route

34.3 Amides

Learning outcomes

Candidates should be able to:

1 recall the reactions (reagents and conditions) by which amides are produced:
   (a) the reaction between ammonia and an acyl chloride at room temperature
   (b) the reaction between a primary amine and an acyl chloride at room temperature

2 describe the reactions of amides:
   (a) hydrolysis with aqueous alkali or aqueous acid
   (b) the reduction of the CO group in amides with LiA*l*H_4 to form an amine

3 state and explain why amides are much weaker bases than amines

34.4 Amino acids

Learning outcomes

Candidates should be able to:

1 describe the acid/base properties of amino acids and the formation of zwitterions, to include the isoelectric point

2 describe the formation of amide (peptide) bonds between amino acids to give di- and tripeptides

3 interpret and predict the results of electrophoresis on mixtures of amino acids and dipeptides at varying pHs (the assembling of the apparatus will not be tested)

35 Polymerisation

35.1 Condensation polymerisation

Learning outcomes

Candidates should be able to:

1 describe the formation of polyesters:
   (a) the reaction between a diol and a dicarboxylic acid or dioyl chloride
   (b) the reaction of a hydroxycarboxylic acid
2 describe the formation of polyamides:
   (a) the reaction between a diamine and a dicarboxylic acid or dioyl chloride
   (b) the reaction of an aminocarboxylic acid
   (c) the reaction between amino acids
3 deduce the repeat unit of a condensation polymer obtained from a given monomer or pair of monomers
4 identify the monomer(s) present in a given section of a condensation polymer molecule

35.2 Predicting the type of polymerisation

Learning outcomes

Candidates should be able to:

1 predict the type of polymerisation reaction for a given monomer or pair of monomers
2 deduce the type of polymerisation reaction which produces a given section of a polymer molecule

35.3 Degradable polymers

Learning outcomes

Candidates should be able to:

1 recognise that poly(alkenes) are chemically inert and can therefore be difficult to biodegrade
2 recognise that some polymers can be degraded by the action of light
3 recognise that polyesters and polyamides are biodegradable by acidic and alkaline hydrolysis

36 Organic synthesis

36.1 Organic synthesis

Learning outcomes

Candidates should be able to:

1 for an organic molecule containing several functional groups:
   (a) identify organic functional groups using the reactions in the syllabus
   (b) predict properties and reactions
2 devise multi-step synthetic routes for preparing organic molecules using the reactions in the syllabus
3 analyse a given synthetic route in terms of type of reaction and reagents used for each step of it, and possible by-products

Analysis

37 Analytical techniques

37.1 Thin-layer chromatography

Learning outcomes

Candidates should be able to:

1 describe and understand the terms
   (a) stationary phase, for example aluminium oxide (on a solid support)
   (b) mobile phase; a polar or non-polar solvent
   (c) R_f value
   (d) solvent front and baseline
2 interpret R_f values
3 explain the differences in R_f values in terms of interaction with the stationary phase and of relative solubility in the mobile phase

37.2 Gas/liquid chromatography

Learning outcomes

Candidates should be able to:

1 describe and understand the terms
   (a) stationary phase; a high boiling point non-polar liquid (on a solid support)
   (b) mobile phase; an unreactive gas
   (c) retention time
2 interpret gas/liquid chromatograms in terms of the percentage composition of a mixture
3 explain retention times in terms of interaction with the stationary phase

37.3 Carbon-13 NMR spectroscopy

Learning outcomes

Candidates should be able to:

1 analyse and interpret a carbon-13 NMR spectrum of a simple molecule to deduce:
   (a) the different environments of the carbon atoms present
   (b) the possible structures for the molecule
2 predict or explain the number of peaks in a carbon-13 NMR spectrum for a given molecule

37.4 Proton (^{1}H) NMR spectroscopy

Learning outcomes

Candidates should be able to:

1 analyse and interpret a proton (^{1}H) NMR spectrum of a simple molecule to deduce:
   (a) the different environments of proton present using chemical shift values
   (b) the relative numbers of each type of proton present from relative peak areas
   (c) the number of equivalent protons on the carbon atom adjacent to the one to which the given proton is attached from the splitting pattern, using the $n + 1$ rule (limited to singlet, doublet, triplet, quartet and multiplet)
   (d) the possible structures for the molecule
2 predict the chemical shifts and splitting patterns of the protons in a given molecule
3 describe the use of tetramethylsilane, TMS, as the standard for chemical shift measurements
4 state the need for deuterated solvents, e.g. $CDCl_3$, when obtaining a proton NMR spectrum
5 describe the identification of O–H and N–H protons by proton exchange using D_2O

4 Details of the assessment

Paper 1 Multiple Choice

Written paper, 1 hour 15 minutes, 40 marks

Forty multiple-choice questions of the four-choice type testing assessment objectives AO1 and AO2.

Questions are based on the AS Level syllabus content.

Paper 2 AS Level Structured Questions

Written paper, 1 hour 15 minutes, 60 marks

Structured questions testing assessment objectives AO1 and AO2.

Questions are based on the AS Level syllabus content.

Paper 3 Advanced Practical Skills

Practical test, 2 hours, 40 marks

This paper tests assessment objective AO3 in a practical context.

Questions are based on the experimental skills in the Practical assessment section of the syllabus for Paper 3.

Paper 4 A Level Structured Questions

Written paper, 2 hours, 100 marks

Structured questions testing assessment objectives AO1 and AO2.

Questions are based on the A Level syllabus content; knowledge of material from the AS Level syllabus content will be required.

Paper 5 Planning, Analysis and Evaluation

Written paper, 1 hour 15 minutes, 30 marks

Structured questions testing assessment objective AO3.

Questions are based on the experimental skills of planning, analysis and evaluation in the Practical assessment section of the syllabus for Paper 5. The context of the questions may be outside the syllabus content.

Command words

Command words and their meanings help candidates know what is expected from them in the exam. The table below includes command words used in the assessment for this syllabus. The use of the command word will relate to the subject context.

Command word	What it means
Analyse	examine in detail to show meaning, identify elements and the relationship between them
Calculate	work out from given facts, figures or information
Compare	identify/comment on similarities and/or differences
Consider	review and respond to given information
Contrast	identify/comment on differences
Deduce	conclude from available information
Define	give precise meaning
Demonstrate	show how or give an example
Describe	state the points of a topic / give characteristics and main features
Determine	establish an answer using the information available
Discuss	write about issue(s) or topic(s) in depth in a structured way
Evaluate	judge or calculate the quality, importance, amount, or value of something
Examine	investigate closely, in detail
Explain	set out purposes or reasons / make the relationships between things evident / provide why and/or how and support with relevant evidence
Give	produce an answer from a given source or recall/memory
Identify	name/select/recognise
Justify	support a case with evidence/argument
Predict	suggest what may happen based on available information
Show (that)	provide structured evidence that leads to a given result
Sketch	make a simple drawing showing the key features
State	express in clear terms
Suggest	apply knowledge and understanding to situations where there are a range of valid responses in order to make proposals / put forward considerations

5 Practical assessment

Introduction

Teachers should ensure that learners practise experimental skills throughout their course of study. As a guide, learners should spend at least 20 per cent of their time doing practical work individually or in small groups. This 20 per cent does not include the time spent observing demonstrations of experiments.

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

- provide learning opportunities so they develop the skills they need to carry out experimental and investigative work
- reinforce their learning of the theoretical subject content of the syllabus
- instil an understanding of the relationship between experimentation and theory in scientific method
- be enjoyable, contributing to the motivation of learners.

Candidates' experimental skills will be assessed in Paper 3 and Paper 5. In each of these papers, the questions may be based on chemistry not included in the syllabus content, but candidates will be assessed on their practical skills gained during the course rather than their knowledge of theory. Where appropriate, candidates will be given any additional information that they need.

Paper 3 Advanced Practical Skills

Paper 3 is a timetabled, laboratory-based practical paper focusing on the experimental skills of:

- manipulation, measurement and observation
- presentation of data and observations
- analysis, conclusions and evaluation.

Centres should refer to the document 'How to manage your science practical exams' for advice on making entries and organisation of candidates for practical exams.

Paper 3 consists of two or three questions, totalling 40 marks.

One question is an observational problem in which the candidate is asked to investigate an unknown substance or substances in specified experiments. The substances may be elements, compounds or mixtures. Candidates are expected to record their observations, analyse their results and draw appropriate conclusions. For this question, Qualitative analysis notes are provided as part of the exam paper. These are reproduced on pages 69 and 70.

The other question or questions are quantitative, involving either a titration or measurement of a quantity, e.g. time, temperature, mass or gas volume. Candidates will be expected to draw suitable tables or graphs. They will analyse the data, perform calculations and draw appropriate conclusions from them.

One or more of the questions may require candidates to comment on the accuracy of the procedure or identify sources of error and make suggestions for change.

The apparatus requirements for Paper 3 will vary from paper to paper. A complete list of apparatus and materials required will be issued to the centre in the Confidential Instructions. The Confidential Instructions should be followed very carefully. If there is any doubt about how the practical exam should be set up or if a particular chemical cannot be obtained or is not permitted for use in schools, it is vital that centres contact Cambridge International as soon as possible. A list of laboratory equipment and chemicals expected to be available is provided on pages 65–68.

Mark allocations for Paper 3

Marks will be allocated for Paper 3 according to the table below. The expectations for each skill are listed in the sections that follow.

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

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

Expectations for each skill (Paper 3)

Manipulation, measurement and observation

Successful collection of data and observations

Candidates should be able to:

- set up apparatus
- follow instructions given in the form of written instructions or diagrams
- use apparatus to collect an appropriate quantity of data
- make observations, including subtle differences in colour, solubility or quantity of materials
- make measurements using pipettes, burettes, measuring cylinders, thermometers and other common laboratory apparatus; candidates should record burette readings to the nearest 0.05 cm^3 and, when using a thermometer calibrated at 1 °C intervals, temperature readings should be recorded to the nearest 0.5 °C.

Some candidates may be unable to set up their apparatus without help and may ask for assistance from the Supervisor. Supervisors will be given clear instructions on what assistance may be given to candidates, but this assistance should never go beyond the minimum necessary to enable candidates to take some readings: under no circumstances should help be given with the presentation of data, analysis or evaluation sections. All assistance must be reported to the Examiners by recording details of the help given on the Supervisor's report, and candidates who require assistance may not be awarded full credit for the successful collection of data.

Quality of measurements or observations

Candidates should be able to:

- make accurate and consistent measurements and observations, including achieving concordant titres (two titres within 0.10 cm^3 of each other) and precise colour descriptions.

Marks will be awarded for consistency and accuracy of readings. For example, candidates' data or observations may be compared with those supplied by the Supervisor or known to the Examiners or the award of the mark may be based on the scatter of points on a graph. Candidates are expected to work to the precision of the apparatus and materials provided.

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
- identify where repeated readings or observations are appropriate
- replicate readings or observations as necessary, including where an anomaly is suspected
- identify where confirmatory tests are appropriate and the nature of such tests
- select reagents to distinguish between given ions.

Presentation of data and observations

Recording data and observations

Candidates should be able to:

- present numerical data, values or observations in a single table of results with headings and units that conform to accepted scientific conventions, i.e. volume / cm^3, volume (cm^3) or volume in cm^3
- record raw readings of a quantity to the same degree of precision, e.g. if one measurement of mass in a collection of raw data is given as 0.06 g, then all the masses in that collection should be given to the nearest 0.01 g. The degree of precision recorded should be compatible with the measuring instrument used, e.g. a measuring cylinder calibrated at 1.0 cm^3 should be read to the nearest 0.5 cm^3
- record observations to the same level of detail, e.g. observations of qualitative variables such as colour should be recorded in simple language such as 'blue' or 'yellow'. Where fine discrimination is required, terms such as 'pale' or 'dark' should be used, and comparisons made such as 'darker brown than at three minutes' or 'paler green than with 0.2 $mol\,dm^{-3}$'.

For recording of data, appropriate symbols may be used provided that their meaning is clear and unambiguous in the given context (e.g. time, t or t /s but temperature, T or T / °C). Conventional symbols or abbreviations, such as ΔH for enthalpy change or ppt. for precipitate, may be used without explanation.

Display of calculation and reasoning

Candidates should be able to:

- show working in calculations and key steps in reasoning: where calculations are carried out, all the stages in the calculation should be recorded, so that credit can be given for correctly displayed working
- use the correct number of significant figures for calculated quantities (this should be the same as or one more than the smallest number of significant figures in the provided or experimentally determined data). For example, if titre volume is measured to four significant figures, e.g. 23.45 cm^3, then the calculated molar concentrations from this should be given to four significant figures, e.g. 1.305 mol dm^{-3} or 0.9876 mol dm^{-3}. However, if the concentration of one of the reactants is given to three significant figures, then the calculated concentration could be given to three or four significant figures. For example, if the concentration of alkali in an acid–base titration is given as 0.100 mol dm^{-3}, then the concentration of the acid may be shown as 0.1305 mol dm^{-3} or 0.131 mol dm^{-3}.

Data layout

Candidates should be able to:

- present data in a single table of results
- draw an appropriate table in advance of taking readings or making observations, so that they do not have to copy their results
- record all data in the table
- use the appropriate presentation method to produce a clear presentation of the data, e.g. graph lines and graph points should be drawn using a sharp pencil
- plot appropriate variables on appropriate, clearly labelled *x*- and *y*-axes (the same convention for axis labels should be used as for table headings)
- choose scales for graph axes that allow the graph to be read easily, such as 1, 2 or 5 units to a 20 mm square; the data points should occupy at least half of the graph grid in both *x*- and *y*-directions
- plot all points using a cross × or circled dot ⊙ to an appropriate accuracy
- draw straight lines or smooth curves of best fit to show the trend of a graph; a line of best fit should show an even distribution of points on either side of the line along its entire length, anomalous points should be identified.

Analysis, conclusions and evaluation

Interpretation of data or observations

Candidates should be able to:

- describe the patterns and trends shown by data in tables and graphs
- describe and summarise the key points of a set of observations
- calculate quantities from data, or calculate the mean from repeated values, or make other appropriate calculations
- find an unknown value by using coordinates, a point of intersection or intercepts on a graph
- determine the gradient of a straight-line graph, using two points that are more than half of the length of the axes apart
- extrapolate the line of a graph.

Calculations may involve mean, percentage, percentage gain or loss, rate of reaction, concentration, molar mass and volume of gases or other appropriate calculations.

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 support a given hypothesis, and making further predictions
- draw conclusions from interpretations of observations, data and calculated values
- make scientific explanations of data, observations and conclusions that they have described.

Candidates may be required to prove or disprove given hypotheses, using deductions from the data, observations or calculated values. Simple scientific explanations form a part of such conclusions and therefore candidates will be expected to refer to knowledge and understanding gained in the theory part of the course in order to provide explanations of their practical conclusions.

Identifying sources of error and suggesting improvements

Candidates should be able to:

- evaluate the effectiveness of control variables
- comment on errors intrinsic in measuring devices, e.g. a thermometer consistently reading 1 °C above actual temperature, or in experiments where limitations of the method introduce errors, e.g. heat loss when trying to assess enthalpy change
- show an understanding of the distinction between systematic errors, e.g. zero error in a balance hence the reason for using the same balance for all weighings within an experiment, and random errors, e.g. change in room temperature when investigating the effect of changing concentration on the rate of a reaction. (A statement of 'human errors' is not acceptable; though there are occasionally errors arising in the observer's ability to observe, e.g. in the disappearing cross experiment, which would be a random error.)
- identify the most significant sources of error in an experiment
- state the uncertainty in a quantitative measurement and express such uncertainty in a measurement as an actual or percentage error. For the purpose of this syllabus, the maximum uncertainty in a quantitative measurement is half the difference between the closest calibrations, e.g. for a thermometer calibrated at 1 °C the maximum uncertainty is ± 0.5 °C, therefore the maximum percentage error in a temperature change of 14.0 °C = ((2 × 0.5)/14.0) × 100 = 7.14%
- suggest realistic modifications to an experimental arrangement that will improve the accuracy of the experiment or the observations that can be made
- suggest ways in which to extend the investigation to answer a new question.

Practical procedures

Quantitative analysis

Candidates should have experience of carrying out the following types of quantitative analysis experiments.

Titration experiments

Candidates are expected to understand how to correctly set up a burette in order to carry out titrations.

Candidates are expected to carry out a rough titration first.

Candidates are expected to carry out titrations until concordant results are obtained.

A knowledge of the following titrations will be expected:

- acid–alkali titration (this could be weak or strong acid and weak or strong alkali) and the use of indicators listed on page 67
- potassium manganate(VII) titration with hydrogen peroxide, iron(II) ions or ethanedioic acid or its salts
- sodium thiosulfate and iodine titrations.

This list is not exhaustive, and simple titrations involving other reagents may also be set and additional information provided where necessary.

Rates experiments

Candidates are expected to be able to follow instructions to mix reagents and record the time for an observation to occur; an example of such an experiment is the time taken on mixing solutions of sodium thiosulfate and an acid for the print on a piece of paper to be obscured by the precipitate produced.

Gravimetric experiments

Candidates are expected to be able to heat a solid in a crucible on a pipe-clay triangle and record any mass change; an example of such an experiment is the determination of the water of hydration of a hydrated salt by evaporation of the water and calculation of the change in mass.

Thermometric experiments

Candidates are expected to be able to accurately use and take readings from thermometers; an example of such an experiment is the determination of the enthalpy change of reaction by recording of temperature changes and subsequent calculation of enthalpy changes and use of Hess's law.

Gas volume experiments

Candidates are expected to be able to set up apparatus for a gas collection over water method; an example of such an experiment is the determination of the composition of a solid from the volume of carbon dioxide produced on reaction of a carbonate with an acid.

Qualitative analysis

Candidates should understand the appropriate methods to be used when carrying out qualitative analysis tests:

- to treat all unknown materials with caution
- to use an appropriate quantity of the material under test
- to add only the specified amount
- to work safely, e.g. to use a test-tube holder when heating a solid in a hard-glass test-tube
- to record all observations, even when this is 'no change' or 'remains a colourless solution'
- to use excess alkali where a precipitate is produced on addition of NaOH(aq) or NH_3(aq) to determine its solubility
- to identify a gas whose formation is shown by effervescence.

Candidates should be familiar with carrying out qualitative analysis reactions for all elements, compounds and ions listed in the Qualitative analysis notes, and with using these notes to make conclusions about the unknown substance being tested. However, the substances to be investigated may contain ions not included in these notes. In such cases, candidates will not be expected to identify the ions but only to record observations and draw conclusions of a general nature where possible.

Candidates may also be required to carry out the following organic analysis tests and/or interpret the positive test result to identify the functional group present:

- the production of an orange/red precipitate with Fehling's reagent to indicate the presence of the aldehyde functional group
- the production of a silver mirror/black precipitate with Tollens' reagent to indicate the presence of the aldehyde functional group
- the production of a yellow precipitate with alkaline aqueous iodine to indicate the presence of the CH_3CO or $CH_3CH(OH)$ group
- the change in colour of acidified potassium manganate(VII) from purple to colourless to indicate the presence of a compound that can be oxidised.

Administration of Paper 3

Detailed regulations on the administration of Cambridge International practical examinations are contained in the *Cambridge Handbook*.

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. Centres should contact Cambridge International if they have not received the Confidential Instructions.

It is the responsibility of centres to provide the apparatus and chemicals required for practical examinations. Cambridge International is not able to supply apparatus or chemicals directly, nor provide advice on local suppliers.

Apparatus and materials

This section gives guidance to schools concerning the apparatus and materials that are expected to be available within the centre for use during practical exams. The lists are not intended to be exhaustive. Unless otherwise stated, for apparatus the number given is 'per candidate'. Centres should keep these apparatus and materials in stock and candidates should be accustomed to using them.

Apparatus

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.

1 × 10 cm^3 pipette (ISO648 or grade B)
1 × 25 cm^3 pipette (ISO648 or grade B)
1 × pipette filler
2 × 50 cm^3 burette (ISO385 or grade B)
2 × 150 cm^3 or 250 cm^3 conical flask
1 × 25 cm^3 measuring cylinder (ISO6706 or ISO4788 or grade B)
1 × 50 cm^3 measuring cylinder (ISO6706 or ISO4788 or grade B)
1 × 250 cm^3 plastic or glass measuring cylinder
2 × burette stand and clamp
1 × 250 cm^3 one-mark graduated volumetric flask (ISO1042 or grade B)
2 × 100 cm^3 beaker, squat form with lip
2 × 250 cm^3 beaker, squat form with lip
1 × funnel (for filling burette)
1 × white tile
1 × stand and clamp
1 × tub suitable for acting as a trough (minimum capacity 1 dm^3)
1 × side-arm conical flask with bung connected to approximately 50 cm of plastic/rubber delivery tube OR additional 150 cm^3 or 250 cm^3 conical flask with one-hole bung connected to approximately 50 cm of plastic/rubber delivery tube
1 × thermometer (–10 °C to +110 °C at 1 °C)
2 × plastic or cardboard cup, capacity approximately 150 cm^3
1 × glass rod
1 × stop-clock to measure to an accuracy of 1 second
2 × teat/dropping pipette
1 × spatula
2 × crucible with lid (approximate capacity 15 cm^3)
1 × crucible tongs
1 × pipe-clay triangle
1 × tripod
1 × gauze
1 × Bunsen burner (propane or butane burners are suitable, spirit burners are not recommended)
1 × heat-proof mat
1 × test-tube holder
2 × boiling tube, approximately 150 mm × 25 mm
2 × hard-glass test-tube
8 × test-tube, approximately 125 mm × 16 mm
1 × test-tube rack
1 x funnel (for filtering)
filter paper
balance, single-pan, direct reading, minimum accuracy 0.01 g (1 per 8–12 candidates) weighing up to 200 g
1 × wash bottle with distilled water
1 × pen for labelling glassware
red and blue litmus papers
aluminium foil
wooden splints

Materials

The following table gives guidance for technicians for the preparation of solutions commonly used in practical papers. Candidates are not expected to be familiar with these preparations.

Centres are recommended to maintain stocks of all the materials detailed in this section as they are regularly used in the practical exams.

Hazard codes will be used where relevant and in accordance with information provided by CLEAPSS.[1]

C corrosive
HH health hazard
F flammable
N hazardous to the aquatic environment
MH moderate hazard
T toxic
O oxidising

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.

Label	Identity	Instructions
dilute hydrochloric acid	2.0 mol dm^{-3} HCl	Dilute 170 cm^3 of concentrated (35–37%; approximately 11 mol dm^{-3}) hydrochloric acid **[C][MH]** to 1 dm^3.
dilute nitric acid [C]	2.0 mol dm^{-3} HNO_3	Dilute 128 cm^3 of concentrated (70%) nitric acid **[C][O]** to 1 dm^3.
dilute sulfuric acid [MH]	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*.
aqueous ammonia [C][MH][N]	2.0 mol dm^{-3} NH_3	Dilute 112 cm^3 of concentrated (35%) ammonia **[C][MH][N]** to 1 dm^3.
aqueous sodium hydroxide [C]	1.0 mol dm^{-3} NaOH	Dissolve 40.0 g of NaOH **[C]** in each dm^3 of solution. ***Care***: *the process of solution is exothermic and any concentrated solution is very corrosive.*
barium chloride or barium nitrate	0.1 mol dm^{-3} $BaCl_2$ or 0.1 mol dm^{-3} $Ba(NO_3)_2$	Dissolve 24.4 g of $BaCl_2 \bullet 2H_2O$ **[T]** in each dm^3 of solution or dissolve 26.1 g of $Ba(NO_3)_2$ **[HH][O]** in each dm^3 of solution.
silver nitrate [N]	0.05 mol dm^{-3} $AgNO_3$	Dissolve 8.5 g of $AgNO_3$ **[C][O][N]** in each dm^3 of solution.
limewater [MH]	saturated aqueous $Ca(OH)_2$	Prepare fresh limewater by leaving distilled water to stand over solid calcium hydroxide **[C][MH]** for several days, shaking occasionally. Decant or filter the solution.

1 An advisory service providing support in practical science and technology for schools and colleges (**www.cleapss.org.uk**)

Label	Identity	Instructions
acidified aqueous potassium manganate(VII) [MH]	0.01 mol dm^{-3} $KMnO_4$ in 0.5 mol dm^{-3} H_2SO_4	Mix equal volumes of 0.02 mol dm^{-3} $KMnO_4$ and 1.0 mol dm^{-3} H_2SO_4 **[MH]**.
starch solution	freshly prepared aqueous starch solution (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 [F][HH][MH]	methyl orange indicator (pH range 2.9 to 4.6)	Use commercially produced solution or dissolve 0.4 g of solid indicator **[T]** in 200 cm^3 of ethanol (IMS) **[F][HH][MH]** and make up to 1 dm^3 with distilled water.
bromophenol blue indicator [F][HH][MH]	bromophenol blue indicator (pH range 3.0 to 4.5)	Dissolve 0.4 g of the solid indicator in 200 cm^3 of ethanol (IMS) **[F][HH][MH]** and make up to 1 dm^3 with distilled water.
thymol blue indicator [F][HH][MH]	thymol blue indicator (pH range 8.0 to 9.6)	Dissolve 0.4 g of the solid indicator in 200 cm^3 of ethanol (IMS) **[F][HH][MH]** and make up to 1 dm^3 with distilled water.
thymolphthalein indicator [F][HH][MH]	thymolphthalein indicator (pH range 9.3 to 10.5)	Dissolve 2.0 g of the solid indicator in 1 dm^3 of ethanol (IMS) **[F][HH][MH]**.

In addition to the materials in the table above, the following materials are recommended to be used in the centre as part of the practical course:

- hydrogen peroxide
- aqueous iodine (approximately 0.01 mol dm^{-3} in 0.2 mol dm^{-3} potassium iodide)
- iron(II) sulfate or ammonium iron(II) sulfate
- sodium nitrite
- copper(II) sulfate
- iron, magnesium and zinc metals
- potassium iodide
- potassium peroxydisulfate
- sodium thiosulfate
- solid hydrated barium chloride and magnesium sulfate
- sodium carbonate or sodium hydrogencarbonate
- magnesium ribbon
- pH indicator papers
- universal indicator (paper or solution)
- the carbonates (where they exist), sulfates, nitrates and chlorides of the cations listed in the Qualitative analysis notes on page 69

- the sodium and/or potassium salts of the anions listed in the Qualitative analysis notes on page 69
- weak acids, e.g. methanoic acid, ethanoic acid, propanoic acid
- alcohols (primary, secondary, tertiary), e.g. ethanol, propan-1-ol, propan-2-ol, butan-1-ol, butan-2-ol, methylpropan-1-ol
- aldehydes and ketones, e.g. propanal, propanone (**Note:** Tests for aldehydes may be performed by substituting glucose for the aldehyde)
- carboxylic acids and esters, e.g. methanoic acid, ethanoic acid, propanoic acid, ethyl ethanoate
- ethanedioic acid or its soluble salts
- halogenoalkanes, e.g. 1-chlorobutane, 1-bromobutane, 1-iodobutane.

These materials should be kept in stock as they may be required for the practical examination. Practical examinations may also require materials that are not listed.

Safety in the laboratory

Responsibility for safety matters rests with centres.

Supervisors must follow national and local regulations relating to safety and first aid.

Hazard data sheets relating to substances should be available from your chemical supplier.

Qualitative analysis notes

1 Reactions of 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 warming	–
barium, Ba^{2+}(aq)	faint white ppt. is observed unless [Ba^{2+}(aq)] is very low	no ppt.
calcium, Ca^{2+}(aq)	white ppt. unless [Ca^{2+}(aq)] is very low	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	pale blue ppt. soluble in excess giving dark blue solution
iron(II), Fe^{2+}(aq)	green ppt. turning brown on contact with air insoluble in excess	green ppt. turning brown on contact with air insoluble in excess
iron(III), Fe^{3+}(aq)	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
magnesium, Mg^{2+}(aq)	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), Mn^{2+}(aq)	off-white ppt. rapidly turning brown on contact with air insoluble in excess	off-white ppt. rapidly turning brown on contact with air insoluble in excess
zinc, Zn^{2+}(aq)	white ppt. soluble in excess	white ppt. soluble in excess

2 Reactions of anions

anion	reaction
carbonate, CO_3^{2-}	CO_2 liberated by dilute acids
chloride, Cl^-(aq)	gives white ppt. with Ag^+(aq) (soluble in NH_3(aq))
bromide, Br^-(aq)	gives cream / off-white ppt. with Ag^+(aq) (partially soluble in NH_3(aq))
iodide, I^-(aq)	gives pale yellow ppt. with Ag^+(aq) (insoluble in NH_3(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; decolourises acidified aqueous $KMnO_4$
sulfate, SO_4^{2-}(aq)	gives white ppt. with Ba^{2+}(aq) (insoluble in excess dilute strong acids); gives white ppt. with high [Ca^{2+}(aq)]
sulfite, SO_3^{2-}(aq)	gives white ppt. with Ba^{2+}(aq) (soluble in excess dilute strong acids); decolourises acidified aqueous $KMnO_4$
thiosulfate, $S_2O_3^{2-}$(aq)	gives off-white / pale yellow ppt. slowly with H^+

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
hydrogen, H_2	'pops' with a lighted splint
oxygen, O_2	relights a glowing splint

4 Tests for elements

element	test and test result
iodine, I_2	gives blue-black colour on addition of starch solution

Paper 5 Planning, Analysis and Evaluation

Paper 5 is a timetabled, written paper focusing on the higher-order experimental skills of:

- planning
- analysis
- drawing conclusions
- evaluation.

This exam will not require laboratory facilities.

It should be emphasised that candidates cannot be adequately prepared for this exam without extensive laboratory work of A Level standard during their course of study. This requires many hours of laboratory-based work with careful supervision from teachers to ensure that experiments are planned and carried out safely.

Paper 5 consists of two or more questions totalling 30 marks.

Candidates may be required to design an experimental investigation of a given problem. Such questions may not be highly structured: candidates may 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 may be questions in which candidates are given experimental data and are required to analyse, evaluate and draw conclusions from this.

Some questions may be set in areas of chemistry that are difficult to investigate experimentally in school laboratories, possibly for reasons of cost or safety. No question will require knowledge of theory or equipment that is beyond that expected of A Level practical work in the syllabus. Information that candidates are not expected to know will be provided in the examination paper.

Mark allocations for Paper 5

Marks will be allocated for Paper 5 according to the table below. The expectations for each skill are listed in the sections that follow.

Skill	Breakdown of skills	Minimum mark allocation*
Planning	Defining the problem	12 marks
	Method	
Analysis, conclusion and evaluation	Dealing with data	12 marks
	Conclusion	
	Evaluation	

* The remaining 6 marks will be allocated across the skills in this grid and their allocation may vary from paper to paper.

Expectations for each skill (Paper 5)

Candidates will be provided with information about the aims of an experiment, and some background information relating to it.

Planning

Defining the problem

Candidates should be able to:

- identify a safe and efficient procedure that when followed would lead to a reliable result
- identify the steps necessary to carry out the procedure
- identify apparatus that is suitable for carrying out each step of the procedure
- show an understanding of the risks of a proposed experiment
- identify the independent variable in an experiment
- identify the dependent variable in an experiment
- express the aim of an experiment in terms of a prediction, and express this in words or in the form of a predicted graph
- identify any variables that are to be controlled
- show an understanding of how and why the procedure suggested will be effective.

Method

Candidates should be able to:

- describe the method to be used when carrying out the experiment to its full conclusion, 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 prediction
- describe the arrangement of apparatus, by use of words or labelled diagrams, and the steps in the procedure to be followed in order to collect all relevant data
- suggest the use of appropriate measuring instruments so that the data are recorded to a suitable precision
- suggest appropriate volumes and concentrations of reagents
- describe precautions that should be taken to keep risks to a minimum; these include use of a fume hood for hazardous gases, use of a face mask for hazardous particles, avoidance of naked flames for flammable materials and wearing chemically resistant gloves for handling irritant materials
- describe how to vary the independent variable and how the dependent variable is to be measured, and describe how each of the other key variables might be controlled
- explain how any control experiments might be used to verify that it is the independent variable that is affecting the dependent variable and not some other factor
- describe the outcome of steps in the procedure where these are relevant to the overall experiment
- draw up appropriately headed tables for data to be recorded and describe how the data might be used in order to reach a conclusion
- describe standard laboratory practice when carrying out quantitative determinations, e.g. making up of standard solutions, weighing by difference, concordancy of titrations, heating to constant mass, taking more readings about the inflexion point of a plot of data values.

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, including calculation of mean, percentage and percentage gain or loss
- use tables and graphs to draw attention to the key points in quantitative data, including the variability of data
- analyse data to draw appropriate conclusions
- plot an appropriate graph from provided or calculated data fulfilling the criteria for plotting detailed in the Paper 3 section on page 61
- plot a graph of y against x and use the graph to find the values of m and c in an equation of the form $y = mx + c$
- suggest appropriate axes from a range of data values
- calculate the percentage error of a measurement
- calculate quantities from raw data
- use the correct number of significant figures for these calculated quantities.

Conclusion

Candidates should be able to:

- draw a conclusion from an investigation, providing a detailed description of the key features of the data and analyses, and considering whether experimental data support the conclusion reached
- make detailed scientific explanations of the data, analyses and conclusion described
- make further predictions and suggest improvements
- conclude whether errors in experimentally obtained data could be accounted for by a measurement error or by other factors.

Evaluation

Candidates should be able to:

- identify anomalous values in provided data, suggest possible explanations for anomalous readings and suggest appropriate means of dealing with such anomalies
- identify the extent to which provided readings have been adequately replicated and the benefit of this
- describe the adequacy of the range of data provided
- use provided information to assess the extent to which selected variables have been effectively controlled
- identify and explain the weaknesses of the experimental procedure used
- suggest and explain the effect that a change in the concentrations of reagents or the conditions used for the experiment might have on the results obtained
- suggest the consequences that the incorrect use of apparatus might have on the results obtained
- explain that data that obey a line of best fit are reliable because there are no anomalous points
- comment on the validity of data with regards to their suitability to prove or disprove a prediction

- identify instances where additional readings being taken during the experiment would be advantageous in order to give a more comprehensive range of values
- draw together all available information to make judgements about the reliability of the investigation and the trustworthiness of its outcomes
- comment on the quality of data and state whether or not the data support a prediction
- use evaluations and provided information to make informed judgements on the confidence with which conclusions may be drawn.

6 Additional information

Mathematical requirements

We expect candidates to be able to use the following mathematical skills and knowledge in the assessment. Teaching the mathematical requirements should be embedded into the AS & A Level Chemistry course.

At AS Level and A Level:

Candidates should be able to:

- perform calculations involving addition, subtraction, multiplication and division of quantities
- understand the term integer
- make approximate evaluations of numerical expressions
- correctly round numbers
- provide answers to an appropriate number of significant figures; this is the same as or one more than the minimum number of significant figures in the values used for the calculation
- calculate a percentage
- express fractions as percentages, and vice versa
- calculate an arithmetic mean
- carry out the following unit conversions (and their reverse)
  - cm^3 to dm^3 to m^3
  - Pa to kPa
  - seconds to minutes
  - mg to g to kg to tonne
  - degrees Celsius to Kelvin
  - J to kJ
- convert numbers in decimal notation to standard form notation (scientific notation) and vice versa
- use tables or calculators to evaluate logarithms (for pH calculations), squares, square roots, cubes, cube roots and reciprocals
- change the subject of a formula (most such equations involve only the simpler operations but may include positive and negative indices and square roots)
- substitute physical quantities into a formula 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
- solve simple algebraic equations (not including quadratic equations)
- understand and use the symbols/notations $<$, $>$, $\approx$, $/$, Δ
- test tabulated pairs of values for direct proportionality by a graphical method or by constancy of ratio
- select appropriate variables and scales for plotting a graph, especially to obtain a linear graph of the form $y = mx + c$
- determine and interpret the gradient (slope) and intercept of a linear graph
- choose by inspection a straight line or curve that will serve as the line of best fit for a set of data presented graphically
- use plotted points that are × or ⊙

- understand:
  - the gradient of a tangent to a curve as a measure of rate of change
  - the area below a curve where the area has physical significance, e.g. Boltzmann distribution curves
- estimate orders of magnitude
- set up simple algebraic equations as mathematical models, e.g. construct a rate equation, and identify limitations of such models
- use the terms log *x* (to mean log to base 10 of *x*) and ln *x* (to mean log to base e of *x*)
- perform calculations using the following:
  density = mass ÷ volume
  concentration = amount ÷ volume
  number of moles = mass ÷ molar mass.

Calculators

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

+, –, ×, ÷, $\sqrt{x}$, x^2, xy, log x, ln x, x^3, $\sqrt[3]{x}$

Summary of key quantities, symbols 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	Usual 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		
Avogadro constant	L	mol^{-1}
electric potential difference	V	V
charge	Q	C
Faraday constant	F	$C\,mol^{-1}$
half-life	$T_{\frac{1}{2}}$, $t_{\frac{1}{2}}$	s
ionic product of water	K_w	$mol^2\,dm^{-6}$
molar gas constant	R	$J\,K^{-1}\,mol^{-1}$
relative atomic (isotopic) mass	A_r	–
relative molecular mass	M_r	–
(standard) electrode (reduction) potential	$(E^{\ominus})\ E$	V
standard enthalpy change of reaction	$\Delta H^{\ominus}$	$J\,mol^{-1}$, $kJ\,mol^{-1}$
temperature	t	°C
volume	V, v	m^3, dm^3, cm^3

Expected conventions for representing organic structures

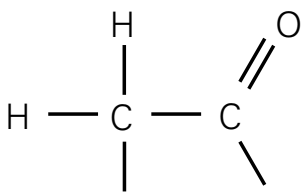
This section gives details of the terminology used when referring to organic structures, reactions and mechanisms.

Structural formulas

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 $CH_3CHCHCH_3$ for but-2-ene, not C_4H_8.

Displayed formulas

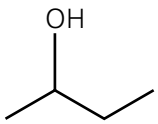
A displayed formula should show both the relative placing of atoms and the number of bonds between them, for example ethanoic acid.

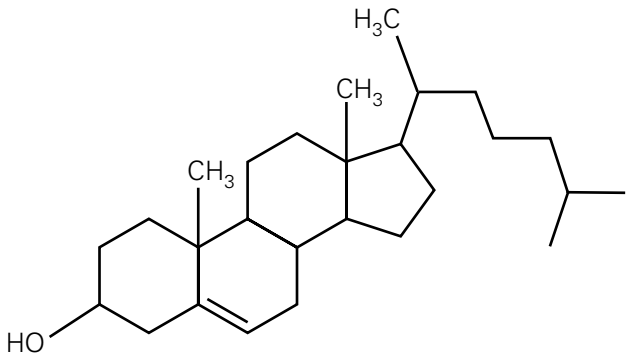


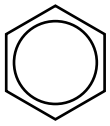
Skeletal formulas

A skeletal formula is a simplified representation of an organic structure. It is derived from the displayed 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.

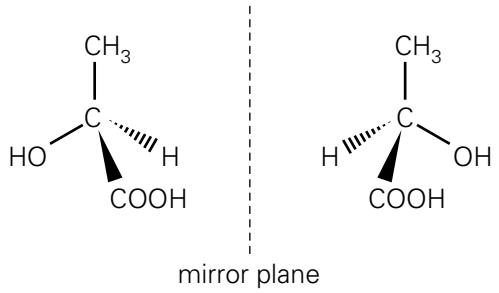




The  convention for representing the aromatic ring is preferred.

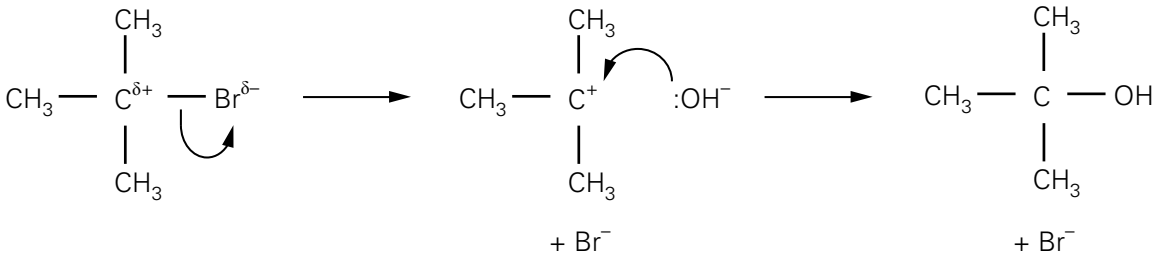
Optical isomers

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



Organic reaction mechanisms

When drawing an organic reaction mechanism, candidates should use charges, dipoles, lone pairs of electrons and curly arrows to indicate the mechanism involved. An example is shown.



Data section

Contents: Tables of chemical data

1 Important values, constants and standards
2 Ionisation energies (1st, 2nd, 3rd and 4th) of selected elements in $kJ\,mol^{-1}$
3 Bond energies
4 Standard electrode (reduction) potentials, $E^{\ominus}$, at 298 K (25 °C)
5 Pauling electronegativity values
6 Typical proton (^{1}H) NMR chemical shift values (δ) relative to TMS = 0
7 Typical carbon–13 (^{13}C) NMR chemical shift values (δ) relative to TMS = 0
8 Characteristic infrared absorption frequencies for some selected bonds
9 The Periodic Table of Elements

1 Important values, constants and standards

molar gas constant	$R = 8.31\ J\,K^{-1}\,mol^{-1}$
Faraday constant	$F = 9.65 \times 10^{4}\ C\,mol^{-1}$
Avogadro constant	$L = 6.022 \times 10^{23}\ mol^{-1}$
electronic charge	$e = -1.60 \times 10^{-19}\ C$
molar volume of gas	$V_m = 22.4\ dm^3\,mol^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0\ dm^3\,mol^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14}\ mol^2\,dm^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18\ kJ\,kg^{-1}\,K^{-1}$ ($4.18\ J\,g^{-1}\,K^{-1}$)

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

	proton number	1st	2nd	3rd	4th
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

	proton number	1st	2nd	3rd	4th
Ni	28	736	1750	3390	5400
Cu	29	745	1960	3350	5690
Zn	30	908	1730	3828	5980
Ga	31	577	1980	2960	6190
Br	35	1140	2080	3460	4850
Rb	37	403	2632	3900	5080
Sr	38	548	1060	4120	5440
Ag	47	731	2074	3361	5000
I	53	1010	1840	3000	4030
Cs	55	376	2420	3300	4400
Ba	56	502	966	3390	4700

3 Bond energies

3(a) Bond energies in diatomic molecules (these are exact values)

Homonuclear

bond	energy / kJ mol^{-1}
H–H	436
N≡N	944
O=O	496
P≡P	485
S=S	425
F–F	158
Cl–Cl	242
Br–Br	193
I–I	151

Heteronuclear

bond	energy / kJ mol^{-1}
H–F	562
H–Cl	431
H–Br	366
H–I	299
C≡O	1077

3(b) Bond energies in polyatomic molecules (these are average values)

Homonuclear

bond	energy / kJ mol^{-1}
C–C	350
C=C	610
C≡C	840
C⋯C (benzene)	520
N–N	160
N=N	410
O–O	150
Si–Si	225
P–P	200
S–S	265

Heteronuclear

bond	energy / kJ mol^{-1}
C–H	410
C–*Cl*	340
C–Br	280
C–I	240
C–N	305
C=N	610
C≡N	890
C–O	360
C=O	740
C=O in CO_2	805
N–H	390
N–*Cl*	310
O–H	460
Si–*Cl*	360
Si–H	320
Si–O (in SiO_2(s))	460
Si=O (in SiO_2(g))	640
P–H	320
P–*Cl*	330
P–O	340
P=O	540
S–H	340
S–*Cl*	250
S–O	360
S=O	500

4 Standard electrode (reduction) potentials, $E^{\ominus}$, at 298 K (25 °C)

$E^{\ominus}$ in alphabetical order

electrode reaction			$E^{\ominus}$ / V
$Ag^+ + e^-$	⇌	Ag	+0.80
$Al^{3+} + 3e^-$	⇌	Al	–1.66
$Ba^{2+} + 2e^-$	⇌	Ba	–2.90
$Br_2 + 2e^-$	⇌	$2Br^-$	+1.07
$Ca^{2+} + 2e^-$	⇌	Ca	–2.87
$Cl_2 + 2e^-$	⇌	$2Cl^-$	+1.36
$2HOCl + 2H^+ + 2e^-$	⇌	$Cl_2 + 2H_2O$	+1.64
$ClO^- + H_2O + 2e^-$	⇌	$Cl^- + 2OH^-$	+0.89
$Co^{2+} + 2e^-$	⇌	Co	–0.28
$Co^{3+} + e^-$	⇌	Co^{2+}	+1.82
$[Co(NH_3)_6]^{2+} + 2e^-$	⇌	$Co + 6NH_3$	–0.43
$Cr^{2+} + 2e^-$	⇌	Cr	–0.91
$Cr^{3+} + 3e^-$	⇌	Cr	–0.74
$Cr^{3+} + e^-$	⇌	Cr^{2+}	–0.41
$Cr_2O_7^{2-} + 14H^+ + 6e^-$	⇌	$2Cr^{3+} + 7H_2O$	+1.33
$Cu^+ + e^-$	⇌	Cu	+0.52
$Cu^{2+} + 2e^-$	⇌	Cu	+0.34
$Cu^{2+} + e^-$	⇌	Cu^+	+0.15
$[Cu(NH_3)_4]^{2+} + 2e^-$	⇌	$Cu + 4NH_3$	–0.05
$F_2 + 2e^-$	⇌	$2F^-$	+2.87
$Fe^{2+} + 2e^-$	⇌	Fe	–0.44
$Fe^{3+} + 3e^-$	⇌	Fe	–0.04
$Fe^{3+} + e^-$	⇌	Fe^{2+}	+0.77
$[Fe(CN)_6]^{3-} + e^-$	⇌	$[Fe(CN)_6]^{4-}$	+0.36
$Fe(OH)_3 + e^-$	⇌	$Fe(OH)_2 + OH^-$	–0.56
$2H^+ + 2e^-$	⇌	H_2	0.00

electrode reaction			$E^{\ominus}$ / V
$2H_2O + 2e^-$	⇌	$H_2 + 2OH^-$	–0.83
$I_2 + 2e^-$	⇌	$2I^-$	+0.54
$K^+ + e^-$	⇌	K	–2.92
$Li^+ + e^-$	⇌	Li	–3.04
$Mg^{2+} + 2e^-$	⇌	Mg	–2.38
$Mn^{2+} + 2e^-$	⇌	Mn	–1.18
$Mn^{3+} + e^-$	⇌	Mn^{2+}	+1.49
$MnO_2 + 4H^+ + 2e^-$	⇌	$Mn^{2+} + 2H_2O$	+1.23
$MnO_4^- + e^-$	⇌	MnO_4^{2-}	+0.56
$MnO_4^- + 4H^+ + 3e^-$	⇌	$MnO_2 + 2H_2O$	+1.67
$MnO_4^- + 8H^+ + 5e^-$	⇌	$Mn^{2+} + 4H_2O$	+1.52
$NO_3^- + 2H^+ + e^-$	⇌	$NO_2 + H_2O$	+0.81
$NO_3^- + 3H^+ + 2e^-$	⇌	$HNO_2 + H_2O$	+0.94
$NO_3^- + 10H^+ + 8e^-$	⇌	$NH_4^+ + 3H_2O$	+0.87
$Na^+ + e^-$	⇌	Na	–2.71
$Ni^{2+} + 2e^-$	⇌	Ni	–0.25
$[Ni(NH_3)_6]^{2+} + 2e^-$	⇌	$Ni + 6NH_3$	–0.51
$H_2O_2 + 2H^+ + 2e^-$	⇌	$2H_2O$	+1.77
$HO_2^- + H_2O + 2e^-$	⇌	$3OH^-$	+0.88
$O_2 + 4H^+ + 4e^-$	⇌	$2H_2O$	+1.23
$O_2 + 2H_2O + 4e^-$	⇌	$4OH^-$	+0.40
$O_2 + 2H^+ + 2e^-$	⇌	H_2O_2	+0.68
$O_2 + H_2O + 2e^-$	⇌	$HO_2^- + OH^-$	–0.08
$Pb^{2+} + 2e^-$	⇌	Pb	–0.13
$Pb^{4+} + 2e^-$	⇌	Pb^{2+}	+1.69
$PbO_2 + 4H^+ + 2e^-$	⇌	$Pb^{2+} + 2H_2O$	+1.47
$SO_4^{2-} + 4H^+ + 2e^-$	⇌	$SO_2 + 2H_2O$	+0.17
$S_2O_8^{2-} + 2e^-$	⇌	$2SO_4^{2-}$	+2.01

electrode reaction			$E^{\ominus}$ / V
$S_4O_6^{2-} + 2e^-$	⇌	$2S_2O_3^{2-}$	+0.09
$Sn^{2+} + 2e^-$	⇌	Sn	–0.14
$Sn^{4+} + 2e^-$	⇌	Sn^{2+}	+0.15
$V^{2+} + 2e^-$	⇌	V	–1.20
$V^{3+} + e^-$	⇌	V^{2+}	–0.26
$VO^{2+} + 2H^+ + e^-$	⇌	$V^{3+} + H_2O$	+0.34
$VO_2^+ + 2H^+ + e^-$	⇌	$VO^{2+} + H_2O$	+1.00
$VO_3^- + 4H^+ + e^-$	⇌	$VO^{2+} + 2H_2O$	+1.00
$Zn^{2+} + 2e^-$	⇌	Zn	–0.76

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

5 Pauling electronegativity values

H 2.1																
Li 1.0	Be 1.6											B 2.0	C 2.5	N 3.0	O 3.5	F 4.0
Na 0.9	Mg 1.3											Al 1.5	Si 1.9	P 2.2	S 2.6	Cl 3.0
K 0.8	Ca 1.0	Sc 1.4	Ti 1.5	V 1.6	Cr 1.7	Mn 1.5	Fe 1.8	Co 1.9	Ni 1.9	Cu 1.9	Zn 1.6	Ga 1.8	Ge 2.0	As 2.2	Se 2.6	Br 2.6

6 Typical proton (^{1}H) NMR chemical shift values (δ) relative to TMS = 0

environment of proton	example	chemical shift range δ/ppm
alkane	–C**H**$_3$, –C**H**$_2$–, >C**H**–	0.9–1.7
alkyl next to C=O	C**H**$_3$–C=O, –C**H**$_2$–C=O, >C**H**–C=O	2.2–3.0
alkyl next to aromatic ring	C**H**$_3$–Ar, –C**H**$_2$–Ar, >C**H**–Ar	2.3–3.0
alkyl next to electronegative atom	C**H**$_3$–O, –C**H**$_2$–O, –C**H**$_2$–C*l*	3.2–4.0
attached to alkene	=C**H**R	4.5–6.0
attached to aromatic ring	**H**–Ar	6.0–9.0
aldehyde	**H**COR	9.3–10.5
alcohol	RO**H**	0.5–6.0
phenol	Ar–O**H**	4.5–7.0
carboxylic acid	RCOO**H**	9.0–13.0
alkyl amine	R–N**H**–	1.0–5.0
aryl amine	Ar–N**H**$_2$	3.0–6.0
amide	RCON**H**R	5.0–12.0

Note: δ values for O–H and N–H protons can vary depending on solvent and concentration. Ar is used to represent an aromatic ring.

7 Typical carbon-13 (^{13}C) NMR chemical shift values (δ) relative to TMS = 0

hybridisation of the carbon atom	environment of carbon atom	example	chemical shift range δ / ppm
sp^3	alkyl	**C**H_3–, **C**H_2–, –**C**H<, >**C**<	0–50
sp^3	next to alkene/arene	–**C**–C=C, –**C**–Ar	25–50
sp^3	next to carbonyl/carboxyl	**C**–COR, **C**–O_2R	30–65
sp^3	next to halogen	**C**–X	30–60
sp^3	next to oxygen	**C**–O	50–70
sp^2	alkene or arene	>**C**=**C**<,	110–160
sp^2	carboxyl	R–**C**OOH, R–**C**OOR	160–185
sp^2	carbonyl	R–**C**HO, R–**C**O–R	190–220
sp	nitrile	R–**C**≡N	100–125

8 Characteristic infrared absorption frequencies for some selected bonds

bond	functional groups containing the bond	characteristic infrared absorption range (in wavenumbers) / cm^{-1}
C–O	hydroxy, ester	1040–1300
C=C	aromatic compound, alkene	1500–1680
C=O	amide carbonyl, carboxyl ester	1640–1690 1670–1740 1710–1750
C≡N	nitrile	2200–2250
C–H	alkane	2850–2950
N–H	amine, amide	3300–3500
O–H	carboxyl hydroxy	2500–3000 3200–3600

9 The Periodic Table of Elements

The Periodic Table of Elements

Key

atomic number
atomic symbol
name
relative atomic mass

Group 1	Group 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
							1 **H** hydrogen 1.0										2 **He** helium 4.0
3 **Li** lithium 6.9	4 **Be** beryllium 9.0											5 **B** boron 10.8	6 **C** carbon 12.0	7 **N** nitrogen 14.0	8 **O** oxygen 16.0	9 **F** fluorine 19.0	10 **Ne** neon 20.2
11 **Na** sodium 23.0	12 **Mg** magnesium 24.3											13 **Al** aluminium 27.0	14 **Si** silicon 28.1	15 **P** phosphorus 31.0	16 **S** sulfur 32.1	17 **Cl** chlorine 35.5	18 **Ar** argon 39.9
19 **K** potassium 39.1	20 **Ca** calcium 40.1	21 **Sc** scandium 45.0	22 **Ti** titanium 47.9	23 **V** vanadium 50.9	24 **Cr** chromium 52.0	25 **Mn** manganese 54.9	26 **Fe** iron 55.8	27 **Co** cobalt 58.9	28 **Ni** nickel 58.7	29 **Cu** copper 63.5	30 **Zn** zinc 65.4	31 **Ga** gallium 69.7	32 **Ge** germanium 72.6	33 **As** arsenic 74.9	34 **Se** selenium 79.0	35 **Br** bromine 79.9	36 **Kr** krypton 83.8
37 **Rb** rubidium 85.5	38 **Sr** strontium 87.6	39 **Y** yttrium 88.9	40 **Zr** zirconium 91.2	41 **Nb** niobium 92.9	42 **Mo** molybdenum 95.9	43 **Tc** technetium –	44 **Ru** ruthenium 101.1	45 **Rh** rhodium 102.9	46 **Pd** palladium 106.4	47 **Ag** silver 107.9	48 **Cd** cadmium 112.4	49 **In** indium 114.8	50 **Sn** tin 118.7	51 **Sb** antimony 121.8	52 **Te** tellurium 127.6	53 **I** iodine 126.9	54 **Xe** xenon 131.3
55 **Cs** caesium 132.9	56 **Ba** barium 137.3	57–71 lanthanoids	72 **Hf** hafnium 178.5	73 **Ta** tantalum 180.9	74 **W** tungsten 183.8	75 **Re** rhenium 186.2	76 **Os** osmium 190.2	77 **Ir** iridium 192.2	78 **Pt** platinum 195.1	79 **Au** gold 197.0	80 **Hg** mercury 200.6	81 **Tl** thallium 204.4	82 **Pb** lead 207.2	83 **Bi** bismuth 209.0	84 **Po** polonium –	85 **At** astatine –	86 **Rn** radon –
87 **Fr** francium –	88 **Ra** radium –	89–103 actinoids	104 **Rf** rutherfordium –	105 **Db** dubnium –	106 **Sg** seaborgium –	107 **Bh** bohrium –	108 **Hs** hassium –	109 **Mt** meitnerium –	110 **Ds** darmstadtium –	111 **Rg** roentgenium –	112 **Cn** copernicium –	113 **Nh** nihonium –	114 **Fl** flerovium –	115 **Mc** moscovium –	116 **Lv** livermorium –	117 **Ts** tennessine –	118 **Og** oganesson –

lanthanoids	57 **La** lanthanum 138.9	58 **Ce** cerium 140.1	59 **Pr** praseodymium 140.9	60 **Nd** neodymium 144.4	61 **Pm** promethium –	62 **Sm** samarium 150.4	63 **Eu** europium 152.0	64 **Gd** gadolinium 157.3	65 **Tb** terbium 158.9	66 **Dy** dysprosium 162.5	67 **Ho** holmium 164.9	68 **Er** erbium 167.3	69 **Tm** thulium 168.9	70 **Yb** ytterbium 173.1	71 **Lu** lutetium 175.0
actinoids	89 **Ac** actinium –	90 **Th** thorium 232.0	91 **Pa** protactinium 231.0	92 **U** uranium 238.0	93 **Np** neptunium –	94 **Pu** plutonium –	95 **Am** americium –	96 **Cm** curium –	97 **Bk** berkelium –	98 **Cf** californium –	99 **Es** einsteinium –	100 **Fm** fermium –	101 **Md** mendelevium –	102 **No** nobelium –	103 **Lr** lawrencium –

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7 What else you need to know

This section is an overview of other information you need to know about this syllabus. It will help to share the administrative information with your exams officer so they know when you will need their support. Find more information about our administrative processes at **www.cambridgeinternational.org/eoguide**

Before you start

Previous study

We recommend that learners starting this course should have completed a course in Chemistry or Co-ordinated Science equivalent to Cambridge IGCSE™ or Cambridge O Level.

Guided learning hours

We design Cambridge International AS & A Level syllabuses to require about 180 guided learning hours for each Cambridge International AS Level and about 360 guided learning hours for a Cambridge International A Level. The number of hours a learner needs to achieve the qualification may vary according to each school and the learners' previous experience of the subject.

Availability and timetables

All Cambridge schools are allocated to an administrative zone. Each zone has a specific timetable.

You can view the timetable for your administrative zone at **www.cambridgeinternational.org/timetables**

You can enter candidates in the June and November exam series. If your school is in India, you can also enter your candidates in the March exam series.

Check you are using the syllabus for the year the candidate is taking the exam.

Private candidates can enter for this syllabus. 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. For more information, please refer to the *Cambridge Guide to Making Entries*.

Combining with other syllabuses

Candidates can take this syllabus alongside other Cambridge International syllabuses in a single exam series. The only exceptions are:

- syllabuses with the same title at the same level.

Group awards: Cambridge AICE

Cambridge AICE (Advanced International Certificate of Education) is a group award for Cambridge International AS & A Level. It allows schools to offer a broad and balanced curriculum by recognising the achievements of learners who pass exams in a range of different subjects.

Learn more about Cambridge AICE at **www.cambridgeinternational.org/aice**

Making entries

Exams officers are responsible for submitting entries to Cambridge International. We encourage them to work closely with you to make sure they enter the right number of candidates for the right combination of syllabus components. Entry option codes and instructions for submitting entries are in the *Cambridge Guide to Making Entries*. Your exams officer has a copy of this guide.

Exam administration

To keep our exams secure, we produce question papers for different areas of the world, known as administrative zones. We allocate all Cambridge schools to one administrative zone determined by their location. Each zone has a specific timetable. Some of our syllabuses offer candidates different assessment options. An entry option code is used to identify the components the candidate will take relevant to the administrative zone and the available assessment options.

Support for exams officers

We know how important exams officers are to the successful running of exams. We provide them with the support they need to make your entries on time. Your exams officer will find this support, and guidance for all other phases of the Cambridge Exams Cycle, at **www.cambridgeinternational.org/eoguide**

Retakes and carrying forward marks

Candidates can retake Cambridge International AS Level and Cambridge International A Level as many times as they want to. Information on retake entries is at **www.cambridgeinternational.org/retakes**

Candidates can carry forward the result of their Cambridge International AS Level assessment from one series to complete the Cambridge International A Level in a following series, subject to the rules and time limits described in the *Cambridge Handbook*.

Language

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

Accessibility and equality

Syllabus and assessment design

Cambridge International works to avoid direct or indirect discrimination. We develop and design syllabuses and assessment materials to maximise inclusivity for candidates of all national, cultural or social backgrounds and candidates with protected characteristics; these protected characteristics include special educational needs and disability, religion and belief, and characteristics related to gender and identity. In addition, the language and layout used are designed to make our materials as accessible as possible. This gives all candidates the fairest possible opportunity to demonstrate their knowledge, skills and understanding and helps to minimise the requirement to make reasonable adjustments during the assessment process.

Access arrangements

Access arrangements (including modified papers) are the principal way in which Cambridge International complies with our duty, as guided by the UK Equality Act (2010), to make 'reasonable adjustments' for candidates with special educational needs (SEN), disability, illness or injury. Where a candidate would otherwise be at a substantial disadvantage in comparison to a candidate with no SEN, disability, illness or injury, we may be able to agree pre-examination access arrangements. These arrangements help a candidate by minimising accessibility barriers and maximising their opportunity to demonstrate their knowledge, skills and understanding in an assessment.

Important:

- Requested access arrangements should be based on evidence of the candidate's barrier to assessment and should also reflect their normal way of working at school; this is in line with the *Cambridge Handbook* **www.cambridgeinternational.org/eoguide**
- For Cambridge International to approve an access arrangement, we will need to agree that it constitutes a reasonable adjustment, involves reasonable cost and timeframe and does not affect the security and integrity of the assessment.
- Availability of access arrangements should be checked by centres at the start of the course. Details of our standard access arrangements and modified question papers are available in the *Cambridge Handbook* **www.cambridgeinternational.org/eoguide**
- Please contact us at the start of the course to find out if we are able to approve an arrangement that is not included in the list of standard access arrangements.
- Candidates who cannot access parts of the assessment may be able to receive an award based on the parts they have completed.

After the exam

Grading and reporting

Grades A*, A, B, C, D or E indicate the standard a candidate achieved at Cambridge International A Level. A* is the highest and E is the lowest grade.

Grades a, b, c, d or e indicate the standard a candidate achieved at Cambridge International AS Level. 'a' is the highest and 'e' is the lowest grade.

'Ungraded' means that the candidate's performance did not meet the standard required for the lowest grade (E or e). 'Ungraded' is reported on the statement of results but not on the certificate. In specific circumstances your candidates may see one of the following letters on their statement of results:

- Q (PENDING)
- X (NO RESULT).

These letters do not appear 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 the AS Level components was sufficient to merit the award of a Cambridge International AS Level grade.

On the statement of results and certificates, Cambridge International AS & A Levels are shown as General Certificates of Education, GCE Advanced Subsidiary Level (GCE AS Level) and GCE Advanced Level (GCE A Level).

School feedback: 'Cambridge International A Levels are the 'gold standard' qualification. They are based on rigorous, academic syllabuses that are accessible to students from a wide range of abilities yet have the capacity to stretch our most able.'

Feedback from: Director of Studies, Auckland Grammar School, New Zealand

How students, teachers and higher education can use the grades

Cambridge International A Level

Assessment at Cambridge International A Level has two purposes:

1 to measure learning and achievement

The assessment confirms achievement and performance in relation to the knowledge, understanding and skills specified in the syllabus, to the levels described in the grade descriptions.

2 to show likely future success

The outcomes help predict which students are well prepared for a particular course or career and/or which students are more likely to be successful.

The outcomes help students choose the most suitable course or career.

Cambridge International AS Level

Assessment at Cambridge International AS Level has two purposes:

1 to measure learning and achievement

The assessment confirms achievement and performance in relation to the knowledge, understanding and skills specified in the syllabus.

2 to show likely future success

The outcomes help predict which students are well prepared for a particular course or career and/or which students are more likely to be successful.

The outcomes help students choose the most suitable course or career.

The outcomes help decide whether students part way through a Cambridge International A Level course are making enough progress to continue.

The outcomes guide teaching and learning in the next stages of the Cambridge International A Level course.

Grade descriptions

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

Grade descriptions for Cambridge International A Level Chemistry will be published after the first assessment of the A Level in 2022.

Changes to this syllabus for 2025, 2026 and 2027

The syllabus has been updated. This is version 2, published October 2026.

You must read the whole syllabus before planning your teaching programme. We review our syllabuses regularly to make sure they continue to meet the needs of our schools. In updating this syllabus, we have made it easier for teachers and students to understand, keeping the familiar features that teachers and schools value.

Changes to version 2 of the syllabus, published October 2026.

Other changes	• A weblink on page 92 has been updated.

Changes to version 1 of the syllabus, published September 2022.

Changes to syllabus content	• Update to reagents in 15.1(c) and 16.2(b).

Any textbooks endorsed to support the syllabus for examination from 2022 are still suitable for use with this syllabus.

School feedback: ‘While studying Cambridge IGCSE and Cambridge International A Levels, students broaden their horizons through a global perspective and develop a lasting passion for learning.’

Feedback from: Zhai Xiaoning, Deputy Principal, The High School Affiliated to Renmin University of China

We are committed to making our documents accessible in accordance with the WCAG 2.1 Standard. We are always looking to improve the accessibility of our documents. If you find any problems or you think we are not meeting accessibility requirements, contact us at **info@cambridgeinternational.org** with the subject heading: Digital accessibility. If you need this document in a different format, contact us and supply your name, email address and requirements and we will respond within 15 working days.

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