CAMBRIDGE
International Examinations

Cambridge
International
AS & A Level

SYLLABUS

Cambridge International AS & A Level
Chemistry

9701

For examination in June and November 2019, 2020 and 2021.
Also available for examination in March 2019, 2020 and 2021 for India only.

Cambridge Advanced

Version 1

Changes to the syllabus for 2019, 2020 and 2021

The latest syllabus is version 1, published September 2016

There are no significant changes which affect teaching.

Any textbooks endorsed to support the syllabus for examination from 2016 are still suitable for use with this syllabus.

| Significant changes to the syllabus are indicated by black vertical lines either side of the text. |

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

Contents

Welcome

Cambridge International AS & A Level Chemistry encourages learners to explore their subject in depth. The syllabus has been designed, in consultation with teachers and universities, to help learners develop not only subject knowledge, but also a strong understanding of some of the key concepts that are critical to mastering the subject.

All our syllabuses are reviewed and updated regularly so that they reflect the latest thinking of international experts and practitioners, and take account of the different national contexts in which they are taught. Consultation is an important part of the way we develop our syllabuses.

Consulting teachers

Teachers at Cambridge schools worldwide help us to shape our Cambridge International AS & A Level syllabuses. The feedback contributes to the development of syllabus content, assessments and support materials. Consulting teachers ensures that our materials are designed carefully around their needs and the needs of their learners.

Consulting universities

Like teachers, universities help to shape our Cambridge International AS & A Level syllabuses. We consult with leading higher education institutions to make sure the syllabuses encourage learners to get a firm grasp of the subject's key concepts and develop the skills necessary for success at university.

Key concepts

Key concepts are essential ideas, theories, principles or mental tools that help learners to develop a deep understanding of their subject and make links between the different topics. The key concepts that this syllabus is designed to develop are detailed on page 5.

Teacher support

Our comprehensive teacher support will help you deliver the syllabus confidently and effectively. The support includes resources for teaching and learning as well as exam preparation. The teaching support package helps teachers integrate the key concepts into their teaching, showing how they fit into the overall syllabus and suggesting ways to teach them with each topic. Learn more on page 7.

> “Cambridge International AS and 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.”
>
> Christoph Guttentag, Dean of Undergraduate Admissions, Duke University, USA

Why choose Cambridge International Examinations?

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

Our international qualifications are recognised by the world's best universities and employers, giving students a wide range of options in their education and career. As a not-for-profit organisation, we devote our resources to delivering high-quality educational programmes that can unlock learners' potential.

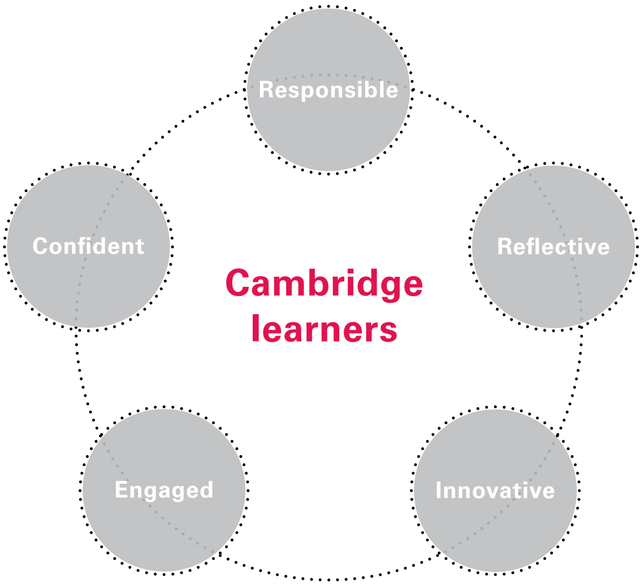
Our programmes and qualifications set the global standard for international education. They are created by subject experts, rooted in academic rigour and reflect the latest educational research. They provide a strong platform for learners to progress from one stage to the next, and are well supported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

Every year, nearly a million Cambridge learners from 10 000 schools in 160 countries prepare for their future with an international education from Cambridge.

Cambridge learners

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



Learn more about the Cambridge learner attributes in Chapter 2 of our *Implementing the curriculum with Cambridge* guide at **www.cie.org.uk/curriculumguide**

Why Cambridge International AS & A Levels?

Cambridge International AS & A Levels are international in outlook, but retain a local relevance. The syllabuses provide opportunities for contextualised learning and the content has been created to suit a wide variety of schools, avoid cultural bias and develop essential lifelong skills, including creative thinking and problem-solving.

Our aim is to balance knowledge, understanding and skills in our qualifications to enable students to become effective learners and to provide a solid foundation for their continuing educational journey. Cambridge International AS & A Levels give learners building blocks for an individualised curriculum that develops their knowledge, understanding and skills.

Cambridge International AS & A Level curricula are flexible. It is possible to offer almost any combination from a wide range of subjects. Cambridge International A Level is typically a two-year course, and Cambridge International AS Level is typically one year. Some subjects can be started as a Cambridge International AS Level and extended to a Cambridge International A Level.

There are three possible assessment approaches for Cambridge International AS & A Level:

Option one

Cambridge International AS Level
(standalone AS)

Learners take the Cambridge International AS Level only. The syllabus content for Cambridge International AS Level is half of a Cambridge International A Level programme.

Option two

Cambridge International A Level
(remainder of A Level)

Cambridge International AS Level
(AS is first half of A Level)

Learners take the Cambridge International AS Level in Year 1 and in Year 2 complete the Cambridge International A Level.

Option three

Cambridge International A Level

Learners take all papers of the Cambridge International A Level course in the same examination series, usually at the end of the second year of study.

Every year thousands of learners with Cambridge International AS & A Levels gain places at leading universities worldwide. Cambridge International AS & A Levels are accepted and valued by top universities around the world including those in the UK, US (including Ivy League universities), European nations, Australia, Canada and New Zealand. Learners should check the university website for specific entry requirements before applying.

Did you know?

In some countries universities accept Cambridge International AS Levels in their own right as qualifications counting towards entry to courses in the same or other related subjects. Many learners who take Cambridge International AS Levels also choose to progress to Cambridge International A Level.

Learn more

For more details go to **www.cie.org.uk/recognition**

Why Cambridge International AS & A Level Chemistry?

Universities value learners who have a thorough understanding of key concepts in chemistry, an in-depth knowledge of chemistry's most important themes and strong practical skills. Cambridge International AS and A Level Chemistry helps learners develop the knowledge and skills that will prepare them for successful university study.

Our learners also develop lifelong skills of scientific enquiry, confidence in technology, and communication and teamwork skills.

Key concepts

The key concepts on which this syllabus is built are set out below. These key concepts can help teachers think about how to approach each syllabus topic in order to encourage learners to make links between topics and develop a deep overall understanding of the subject. The teaching support package gives teachers guidance on integrating the key concepts into their teaching. See page 7 for more information on our teacher support.

As a teacher, you will refer to these concepts again and again to help unify the subject and make sense of it. If mastered, learners can use the concepts to solve problems or to understand unfamiliar subject-related material.

- 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.
- Patterns in chemical behaviour and reactions
  By identifying patterns in chemical behaviour we can predict the properties of substances and how they can be transformed into new substances by chemical reactions. This allows us to design new materials of use to society.
- Chemical bonds
  The understanding of how chemical bonds are made and broken by the movement of electrons allows us to predict patterns of reactivity.
- Energy changes
  The energy changes that take place during chemical reactions can be used to predict both the extent and the rate of such reactions.

Guided learning hours

Guided learning hours give an indication of the amount of contact time teachers need to have with learners to deliver a particular course. Our syllabuses are designed around 180 guided learning hours for Cambridge International AS Level, and around 360 guided learning hours for Cambridge International A Level.

These figures are for guidance only. The number of hours needed to gain the qualification may vary depending on local practice and the learners' previous experience of the subject.

Prior learning

We recommend that learners who are beginning this course should have previously completed a Cambridge O Level or Cambridge IGCSE® course, or the equivalent, in Chemistry or in Co-ordinated Science.

Progression

Cambridge International A Level Chemistry provides a suitable foundation for the study of chemistry or related courses in higher education. It is equally suitable for candidates intending to pursue careers or further study in the chemical sciences, or as part of a course of general education.

Cambridge International AS Level Chemistry is the first half of Cambridge International A Level Chemistry. Depending on local university entrance requirements, the qualification may permit or assist progression directly to university courses in Chemistry or some other subjects.

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

How can I find out more?

If you are already a Cambridge school

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

If you are not yet a Cambridge school

Learn more about the benefits of becoming a Cambridge school from our website at **www.cie.org.uk/startcambridge**

Email us at **info@cie.org.uk** to find out how your organisation can register to become a Cambridge school.

Cambridge AICE

Cambridge AICE Diploma is the group award of the Cambridge International AS & A Level. It gives schools the opportunity to benefit from offering a broad and balanced curriculum by recognising the achievements of candidates who pass examinations from different curriculum groups.

Learn more

For more details go to **www.cie.org.uk/aice**

> “Our research has shown that students who came to the university with a Cambridge AICE background performed better than anyone else that came to the university. That really wasn’t surprising considering the emphasis they have on critical research and analysis, and that’s what we require at university.”
>
> **John Barnhill, Assistant Vice President for Enrollment Management, Florida State University, USA**

Teacher support

We offer a wide range of practical and innovative support to help teachers plan and deliver our programmes and qualifications confidently.

The support package for our Cambridge International AS & A Levels will help teachers integrate key concepts into their teaching, showing how they fit into the overall syllabus and suggesting ways to teach them within each topic. It also gives teachers access to a worldwide teaching community enabling them to connect with other teachers, swap ideas and share best practice.

Cambridge International AS & A Level support for teachers

Teaching and learning

- Support materials provide teachers with ideas and planning resources for their lessons.
- Endorsed textbooks, ebooks and digital resources are produced by leading publishers. We have quality checked these materials to make sure they provide a high level of support for teachers and learners.
- Resource lists to help support teaching, including textbooks and websites.

Exam preparation

- Past question papers and mark schemes so teachers can give learners the opportunity to practise answering different questions.
- Example candidate responses help teachers understand exactly what examiners are looking for.
- Principal examiner reports describing learners' overall performance on each part of the papers. The reports give insight into common misconceptions shown by learners, which teachers can address in lessons.

Professional development

Face-to-face training

We hold workshops around the world to support teachers in delivering Cambridge syllabuses and developing their skills.

Online training

We offer self-study and tutor-led online training courses via our virtual learning environment. A wide range of syllabus-specific courses and skills courses is available. We also offer training via video conference and webinars.

Qualifications

We offer a wide range of practice-based qualifications at Certificate and Diploma level, providing a framework for continuing professional development.

Learn more

Find out more about support for this syllabus at **www.cie.org.uk/alevel**

Visit our online resource bank and community forum at **https://teachers.cie.org.uk**

Useful links

Customer Services	**www.cie.org.uk/help**
LinkedIn	**http://linkd.in/cambridgeteacher**
Twitter	**@cie_education**
Facebook	**www.facebook.com/cie.org.uk**

1 Syllabus overview

1.1 Content

Physical chemistry

1 Atoms, molecules and stoichiometry
2 Atomic structure
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 An introduction to the chemistry of transition elements
13 Nitrogen and sulfur

Organic chemistry and analysis

14 An introduction to organic chemistry
15 Hydrocarbons
16 Halogen derivatives
17 Hydroxy compounds
18 Carbonyl compounds
19 Carboxylic acids and derivatives
20 Nitrogen compounds
21 Polymerisation
22 Analytical techniques
23 Organic synthesis

All candidates study practical skills.

1.2 Assessment

Candidates for Advanced Subsidiary (AS) certification take Papers 1, 2 and 3 (either Advanced Practical Skills 1 or Advanced Practical Skills 2) in a single examination series.

Candidates who, having received AS certification, wish to continue their studies to the full Advanced Level qualification may carry their AS marks forward and take Papers 4 and 5 in the examination series in which they require certification.

Candidates taking the full Advanced Level qualification at the end of the course take all five papers in a single examination series.

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

Candidates may not enter for single papers either on the first occasion or for resit purposes.

All components are externally assessed.

Component	Weighting	
	AS Level	A Level
Paper 1 Multiple Choice **1 hour** This paper consists of 40 multiple choice questions, 30 of the direct choice type and 10 of the multiple completion type, all with four options. All questions will be based on the AS Level syllabus content. Candidates will answer all questions. Candidates will answer on an answer sheet. [40 marks]	31%	15.5%
Paper 2 AS Level Structured Questions **1 hour 15 minutes** This paper consists of a variable number of questions of variable mark value. All questions will be based on the AS Level syllabus content. Candidates will answer all questions. Candidates will answer on the question paper. [60 marks]	46%	23%
Paper 3 Advanced Practical Skills **2 hours** This paper requires candidates to carry out practical work in timed conditions. Candidates will be expected to collect, record and analyse data so that they can answer questions related to the activity. The paper will consist of two or three experiments drawn from different areas of chemistry. Candidates will answer all questions. Candidates will answer on the question paper. [40 marks]	23%	11.5%
Paper 4 A Level Structured Questions **2 hours** This paper consists of a variable number of free response style questions of variable mark value. All questions will be based on the A Level syllabus but may require knowledge of material first encountered in the AS Level syllabus. Candidates will answer all questions. Candidates will answer on the question paper. [100 marks]	–	38.5%
Paper 5 Planning, Analysis and Evaluation **1 hour 15 minutes** This paper consists of a variable number of questions of variable mark value based on the practical skills of planning, analysis and evaluation. The context of the questions may be outside the syllabus content, but candidates will be assessed on their practical skills of planning, analysis and evaluation rather than their knowledge of theory. Candidates will answer all questions. Candidates will answer on the question paper. [30 marks]	–	11.5%

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

Data Booklet

A *Data Booklet* is mandatory for use in Papers 1, 2 and 4. The booklet is reprinted towards the back of the syllabus. Copies of the booklet can be ordered from Cambridge Publications.

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 is 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.

Availability

This syllabus is examined in the June and November examination series. This syllabus is also available for examination in March for India only.

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

Detailed timetables are available from **www.cie.org.uk/timetables**

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

Combining this with other syllabuses

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

- syllabuses with the same title at the same level.

2 Syllabus aims and assessment objectives

2.1 Syllabus aims

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

1. provide, through well designed studies of experimental and practical chemistry, a worthwhile educational experience for all learners, whether or not they go on to study science beyond this level and, in particular, to enable them to acquire sufficient understanding and knowledge to:
    - become confident citizens in a technological world, able to take or develop an informed interest in scientific matters
    - recognise the usefulness, and limitations, of scientific method and appreciate its applicability in other disciplines and in everyday life
    - be suitably prepared for employment and/or further studies beyond Cambridge International A Level in Chemistry.
2. develop abilities and skills that:
    - are relevant to the study and practice of science
    - are useful in everyday life
    - encourage efficient and safe practice
    - encourage the presentation of information and ideas appropriate for different audiences and purposes
    - develop self-motivation and the ability to work in a sustained fashion.
3. develop attitudes relevant to science such as:
    - a concern for accuracy and precision
    - objectivity
    - integrity
    - a spirit of enquiry
    - initiative
    - insight.
4. stimulate interest in, and care for, the environment.
5. promote an awareness that:
    - the study and practice of science are co-operative and cumulative activities, and are subject to social, economic, technological, ethical and cultural influences and limitations
    - the applications of chemistry may be both beneficial and detrimental to the individual, the community and the environment.
6. stimulate learners and create a sustained interest in chemistry so that the study of the subject is enjoyable and satisfying.

2.2 Assessment objectives

The assessment objectives listed below reflect those parts of the syllabus aims that will be assessed in the examination.

AO1 Knowledge with understanding

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

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

The subject content defines the factual knowledge that candidates may be required to recall and explain. Questions testing these assessment objectives will often begin with one of the following words: *define*, *state*, *describe*, *explain* or *outline* (see Glossary of command words on page 69).

AO2 Handling, applying and evaluating information

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

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

These assessment objectives cannot be precisely specified in the subject content because questions testing such skills may be based on information which is unfamiliar to the candidate. In answering such questions, candidates are required to use principles and concepts that are within the syllabus and apply them in a logical, reasoned or deductive manner to a new situation. Questions testing these objectives will often begin with one of the following words: *predict*, *suggest*, *construct*, *calculate* or *determine* (see Glossary of command words on page 69).

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 data to reach conclusions
- evaluate methods and quality of data, and suggest improvements.

2.3 Relationship between assessment objectives and components

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

The table shows the assessment objectives (AO) as a percentage of each component.

Component	AO1 %	AO2 %	AO3 %
Paper 1	55	45	0
Paper 2	55	45	0
Paper 3	0	0	100
Paper 4	55	45	0
Paper 5	0	0	100

2.4 Relationship between assessment objectives and qualifications

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

The table shows the assessment objectives (AO) as a percentage of each qualification.

Assessment objective	Weighting in AS Level %	Weighting in A Level %
AO1	42	42
AO2	35	35
AO3	23	23

Teachers should note that there is a greater weighting of 58 per cent for skills (including handling information, solving problems, practical, experimental and investigative skills) compared to the 42 per cent for knowledge and understanding. Teachers' schemes of work and the sequence of learning activities should reflect this balance so that the aims of the syllabus are met and the candidates prepared for the assessment.

3 Syllabus content

3.1 Structure of the syllabus

The table shows which parts of the syllabus contain AS Level material and which contain additional material that is examined only in the full A Level.

Section	Topic	AS Level	A Level
Physical chemistry	1 Atoms, molecules and stoichiometry	✓	
	2 Atomic structure	✓	✓
	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 An introduction to the chemistry of transition elements		✓
	13 Nitrogen and sulfur	✓	
Organic chemistry and analysis	14 An introduction to organic chemistry	✓	✓
	15 Hydrocarbons	✓	✓
	16 Halogen derivatives	✓	
	17 Hydroxy compounds	✓	✓
	18 Carbonyl compounds	✓	
	19 Carboxylic acids and derivatives	✓	✓
	20 Nitrogen compounds		✓
	21 Polymerisation		✓
	22 Analytical techniques	✓	✓
	23 Organic synthesis		✓

3.2 Subject content

Teachers should incorporate social, environmental, economic and technological aspects of chemistry, where relevant, throughout the syllabus (see Aims 4 and 5). Some examples are included in the syllabus, and learners should be encouraged to apply the principles of these examples to other situations introduced during the course.

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

The **additional** learning outcomes that will be assessed only in the full A Level qualification are shown in **bold** type.

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

Physical chemistry

1 Atoms, molecules and stoichiometry

This topic illustrates how quantitative relationships can be established when different substances react. (The term *relative formula mass* or M_r will be used for all compounds including ionic compounds.)

	Learning outcomes Candidates should be able to:
1.1 Relative masses of atoms and molecules	a) define and use the terms *relative atomic*, *isotopic*, *molecular* and *formula masses*, based on the ^{12}C scale
1.2 The mole and the Avogadro constant	a) define and use the term *mole* in terms of the Avogadro constant
1.3 The determination of relative atomic masses, A_r	a) analyse mass spectra in terms of isotopic abundances (knowledge of the working of the mass spectrometer is not required) b) calculate the relative atomic mass of an element given the relative abundances of its isotopes, or its mass spectrum
1.4 The calculation of empirical and molecular formulae	a) define and use the terms *empirical* and *molecular formula* b) calculate empirical and molecular formulae, using combustion data or composition by mass
1.5 Reacting masses and volumes (of solutions and gases)	a) write and construct balanced equations b) perform calculations, including use of the mole concept, involving: (i) reacting masses (from formulae and equations) (ii) volumes of gases (e.g. in the burning of hydrocarbons) (iii) volumes and concentrations of solutions When performing calculations, candidates' answers should reflect the number of significant figures given or asked for in the question. When rounding up or down, candidates should ensure that significant figures are neither lost unnecessarily nor used beyond what is justified (see also Practical Assessment, Paper 3, Display of calculation and reasoning on page 51). c) deduce stoichiometric relationships from calculations such as those in 1.5(b)

2 Atomic structure

This topic describes the type, number and distribution of the fundamental particles which make up an atom and the impact of this on some atomic properties.

	Learning outcomes Candidates should be able to:
2.1 Particles in the atom	a) identify and describe protons, neutrons and electrons in terms of their relative charges and relative masses b) deduce the behaviour of beams of protons, neutrons and electrons in electric fields c) describe the distribution of mass and charge within an atom d) deduce the numbers of protons, neutrons and electrons present in both atoms and ions given proton and nucleon numbers (atomic and mass numbers) and charge
2.2 The nucleus of the atom	a) describe the contribution of protons and neutrons to atomic nuclei in terms of proton (atomic) number and nucleon (mass) number b) distinguish between isotopes on the basis of different numbers of neutrons present c) recognise and use the symbolism ${}^{x}_{y}A$ for isotopes, where ^{x} is the nucleon (mass) number and ${}_{y}$ is the proton (atomic) number
2.3 Electrons: energy levels, atomic orbitals, ionisation energy, electron affinity	a) describe the number and relative energies of the s, p and d orbitals for the principal quantum numbers 1, 2 and 3 and also the 4s and 4p orbitals b) describe and sketch the shapes of s and p orbitals c) state the electronic configuration of atoms and ions given the proton (atomic) number and charge, using the convention $1s^2 2s^2 2p^6$, etc. d) (i) explain and use the term *ionisation energy* (ii) explain the factors influencing the ionisation energies of elements (iii) explain the trends in ionisation energies across a period and down a group of the Periodic Table (see also Section 9.1) e) deduce the electronic configurations of elements from successive ionisation energy data f) interpret successive ionisation energy data of an element in terms of the position of that element within the Periodic Table **g) explain and use the term *electron affinity***

3 Chemical bonding

This topic introduces the different ways by which chemical bonding occurs and the effect this can have on physical properties.

	Learning outcomes Candidates should be able to:
3.1 Ionic bonding	a) describe ionic bonding, using the examples of sodium chloride, magnesium oxide and calcium fluoride, including the use of 'dot-and-cross' diagrams
3.2 Covalent bonding and co-ordinate (dative covalent) bonding including shapes of simple molecules	a) describe, including the use of 'dot-and-cross' diagrams: (i) covalent bonding, in molecules such as hydrogen, oxygen, chlorine, hydrogen chloride, carbon dioxide, methane, ethene (ii) co-ordinate (dative covalent) bonding, such as in the formation of the ammonium ion and in the Al_2Cl_6 molecule b) describe covalent bonding in terms of orbital overlap, giving σ and π bonds, including the concept of hybridisation to form sp, sp^2 and sp^3 orbitals (see also Section 14.3) c) explain the shapes of, and bond angles in, molecules by using the qualitative model of electron-pair repulsion (including lone pairs), using as simple examples BF_3 (trigonal planar), CO_2 (linear), CH_4 (tetrahedral), NH_3 (pyramidal), H_2O (non-linear), SF_6 (octahedral), PF_5 (trigonal bipyramidal) d) predict the shapes of, and bond angles in, molecules and ions analogous to those specified in 3.2(c) (see also Section 14.3)
3.3 Intermolecular forces, electronegativity and bond properties	a) describe hydrogen bonding, using ammonia and water as simple examples of molecules containing N–H and O–H groups b) understand, in simple terms, the concept of electronegativity and apply it to explain the properties of molecules such as bond polarity (see also Section 3.3(c)), the dipole moments of molecules (3.3(d)) and the behaviour of oxides with water (9.2(c)) c) explain the terms *bond energy*, *bond length* and *bond polarit*y and use them to compare the reactivities of covalent bonds (see also Section 5.1(b)(ii)) d) describe intermolecular forces (van der Waals' forces), based on permanent and induced dipoles, as in, for example, $CHCl_3$(l); Br_2(l) and the liquid Group 18 elements
3.4 Metallic bonding	a) describe metallic bonding in terms of a lattice of positive ions surrounded by delocalised electrons
3.5 Bonding and physical properties	a) describe, interpret and predict the effect of different types of bonding (ionic bonding, covalent bonding, hydrogen bonding, other intermolecular interactions, metallic bonding) on the physical properties of substances b) deduce the type of bonding present from given information c) show understanding of chemical reactions in terms of energy transfers associated with the breaking and making of chemical bonds

4 States of matter

The study of the particles in solids, liquids and gases and the interactions between them is important in understanding the physical properties of substances.

	Learning outcomes Candidates should be able to:
4.1 The gaseous state: ideal and real gases and $pV = nRT$	a) state the basic assumptions of the kinetic theory as applied to an ideal gas b) explain qualitatively in terms of intermolecular forces and molecular size: (i) the conditions necessary for a gas to approach ideal behaviour (ii) the limitations of ideality at very high pressures and very low temperatures c) state and use the general gas equation $pV = nRT$ in calculations, including the determination of M_r
4.2 The liquid state	a) describe, using a kinetic-molecular model, the liquid state, melting, vaporisation and vapour pressure
4.3 The solid state: lattice structures	a) describe, in simple terms, the lattice structure of a crystalline solid which is: (i) ionic, as in sodium chloride and magnesium oxide (ii) simple molecular, as in iodine and the fullerene allotropes of carbon (C_{60} and nanotubes only) (iii) giant molecular, as in silicon(IV) oxide and the graphite, diamond and graphene allotropes of carbon (iv) hydrogen-bonded, as in ice (v) metallic, as in copper b) discuss the finite nature of materials as a resource and the importance of recycling processes c) outline the importance of hydrogen bonding to the physical properties of substances, including ice and water (for example, boiling and melting points, viscosity and surface tension) d) suggest from quoted physical data the type of structure and bonding present in a substance

5 Chemical energetics

Enthalpy changes and entropy changes accompany chemical reactions. This topic demonstrates why some reactions and processes are spontaneous and others are not.

Learning outcomes
Candidates should be able to:

5.1 Enthalpy change, ΔH

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

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

c) calculate enthalpy changes from appropriate experimental results, including the use of the relationship $\Delta H = -mc\Delta T$

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

5.2 Hess' Law, including Born-Haber cycles

a) apply Hess' Law to construct simple energy cycles, and carry out calculations involving such cycles and relevant energy terms, with particular reference to:
  (i) determining enthalpy changes that cannot be found by direct experiment, e.g. an enthalpy change of formation from enthalpy changes of combustion
  (ii) average bond energies
  (iii) the formation of a simple ionic solid and of its aqueous solution
  (iv) Born-Haber cycles (including ionisation energy and electron affinity)

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

5.3 Entropy change, ΔS

a) explain that entropy is a measure of the 'disorder' of a system, and that a system becomes more stable when its energy is spread out in a more disordered state

b) explain the entropy changes that occur:

- **(i) during a change in state e.g. (s) → (l); (l) → (g); (s) → (aq)**
- **(ii) during a temperature change**
- **(iii) during a reaction in which there is a change in the number of gaseous molecules**

c) predict whether the entropy change for a given process is positive or negative

d) calculate the entropy change for a reaction, ΔS, given the standard entropies, S, of the reactants and products

5.4 Gibbs free energy change, ΔG

a) define the standard Gibbs free energy change of reaction by means of the equation $\Delta G = \Delta H - T\Delta S$

b) calculate ΔG for a reaction using the equation $\Delta G = \Delta H - T\Delta S$

c) state whether a reaction or process will be spontaneous/feasible by using the sign of ΔG

d) predict the effect of temperature change on the spontaneity/feasibility of a reaction, given standard enthalpy and entropy changes

6 Electrochemistry

This topic illustrates the relationship between electricity and chemical changes. Chemical reactions can be investigated by looking at electrode potentials.

	Learning outcomes Candidates should be able to:
6.1 Redox processes: electron transfer and changes in oxidation number (oxidation state)	a) calculate oxidation numbers of elements in compounds and ions b) describe and explain redox processes in terms of electron transfer and changes in oxidation number c) use changes in oxidation numbers to help balance chemical equations
6.2 Electrolysis	**a) state and apply the relationship $F = Le$ between the Faraday constant, the Avogadro constant and the charge on the electron** **b) predict the identity of the substance liberated during electrolysis from the state of electrolyte (molten or aqueous), position in the redox series (electrode potential) and concentration** **c) calculate:** **(i) the quantity of charge passed during electrolysis** **(ii) the mass and/or volume of substance liberated during electrolysis, including those in the electrolysis of H_2SO_4(aq) and of Na_2SO_4(aq)** **d) describe the determination of a value of the Avogadro constant by an electrolytic method**

6.3 Standard electrode potentials $E^\ominus$; standard cell potentials $E^\ominus_{\text{cell}}$ and the Nernst equation	a) define the terms: (i) *standard electrode (reduction) potential* (ii) *standard cell potential* b) describe the standard hydrogen electrode c) describe methods used to measure the standard electrode potentials of: (i) metals or non-metals in contact with their ions in aqueous solution (ii) ions of the same element in different oxidation states d) calculate a standard cell potential by combining two standard electrode potentials e) use standard cell potentials to: (i) explain/deduce the direction of electron flow in a simple cell (ii) predict the spontaneity/feasibility of a reaction f) deduce from $E^\ominus$ values the relative reactivity of elements of Group 17 (the halogens) as oxidising agents g) construct redox equations using the relevant half-equations (see also Section 12.2(d)) h) predict qualitatively how the value of an electrode potential varies with the concentrations of the aqueous ions i) 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 $Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$, $Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$, $Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-(aq)$
6.4 Batteries and fuel cells	a) state the possible advantages of developing other types of cell, e.g. the H_2/O_2 fuel cell and the nickel-metal hydride and lithium-ion rechargeable batteries

7 Equilibria

This topic illustrates that many chemical reactions are reversible and involve an equilibrium process. The consideration of the many factors that can affect an equilibrium is an important aspect of physical chemistry.

	Learning outcomes Candidates should be able to:
7.1 Chemical equilibria: reversible reactions, dynamic equilibrium	a) explain, in terms of rates of the forward and reverse reactions, what is meant by a *reversible reaction* and *dynamic equilibrium* b) state Le Chatelier's principle and apply it to deduce qualitatively (from appropriate information) the effects of changes in temperature, concentration or pressure on a system at equilibrium c) state whether changes in temperature, concentration or pressure or the presence of a catalyst affect the value of the equilibrium constant for a reaction d) deduce expressions for equilibrium constants in terms of concentrations, K_c, and partial pressures, K_p (treatment of the relationship between K_p and K_c is not required) e) calculate the values of equilibrium constants in terms of concentrations or partial pressures from appropriate data f) calculate the quantities present at equilibrium, given appropriate data (such calculations will *not* require the solving of quadratic equations) g) describe and explain the conditions used in the Haber process and the Contact process, as examples of the importance of an understanding of chemical equilibrium in the chemical industry

7.2 Ionic equilibria	a) show understanding of, and use, the Brønsted-Lowry theory of acids and bases, including the use of the conjugate acid, conjugate base (acid-I base-I, acid-II base-II) concept b) explain qualitatively the differences in behaviour between strong and weak acids and bases and the pH values of their aqueous solutions in terms of the extent of dissociation **c) explain the terms pH, K_a, pK_a and K_w and use them in calculations** **d) calculate [H^+(aq)] and pH values for strong and weak acids and strong bases** **e) explain the choice of suitable indicators for acid-base titrations, given appropriate data** **f) describe the changes in pH during acid-base titrations and explain these changes in terms of the strengths of the acids and bases** **g) (i) explain how buffer solutions control pH** **(ii) describe and explain the uses of buffer solutions, including the role of HCO_3^- in controlling pH in blood** **h) calculate the pH of buffer solutions, given appropriate data** **i) show understanding of, and use, the concept of solubility product, K_{sp}** **j) calculate K_{sp} from concentrations and vice versa** **k) show understanding of the common ion effect**
7.3 Partition coefficients	**a) state what is meant by a partition coefficient K_{pc}; calculate and use a partition coefficient for a system in which the solute is in the same physical state in the two solvents**

8 Reaction kinetics

The investigation of the factors that affect the rate of a chemical reaction is important in the study of physical chemistry. The temperature and the addition of a catalyst can both affect the progression of a chemical reaction.

	Learning outcomes Candidates should be able to:
8.1 Simple rate equations, orders of reaction and rate constants	a) explain and use the term *rate of reaction* b) explain qualitatively, in terms of collisions, the effect of concentration changes on the rate of a reaction **c) explain and use the terms *rate equation, order of reaction, rate constant, half-life of a reaction, rate-determining step*** **d) construct and use rate equations of the form rate = $k[\mathrm{A}]^m[\mathrm{B}]^n$ (for which m and n are 0, 1 or 2), including:** **(i) deducing the order of a reaction, or the rate equation for a reaction, from concentration-time graphs or from experimental data relating to the initial rates method and half-life method** **(ii) interpreting experimental data in graphical form, including concentration-time and rate-concentration graphs** **(iii) calculating an initial rate using concentration data** **(integrated forms of rate equations are not required)** **e) (i) show understanding that the half-life of a first-order reaction is independent of concentration** **(ii) use the half-life of a first-order reaction in calculations** **f) calculate the numerical value of a rate constant, for example by using the initial rates or half-life method** **g) for a multi-step reaction:** **(i) suggest a reaction mechanism that is consistent with the rate equation and the equation for the overall reaction** **(ii) predict the order that would result from a given reaction mechanism and vice versa** **h) devise a suitable experimental technique for studying the rate of a reaction, from given information**
8.2 Effect of temperature: on reaction rates and rate constants and the concept of activation energy	a) explain and use the term *activation energy*, including reference to the Boltzmann distribution b) explain qualitatively, in terms both of the Boltzmann distribution and of collision frequency, the effect of temperature change on the rate of a reaction **c) explain qualitatively the effect of temperature change on the rate constant and hence the rate of a reaction**

8.3 Homogeneous and heterogeneous catalysts including enzymes

a) explain and use the term *catalysis*

b) explain that catalysts can be homogeneous or heterogeneous

c) (i) explain that, in the presence of a catalyst, a reaction has a different mechanism, i.e. one of lower activation energy
   (ii) interpret this catalytic effect in terms of the Boltzmann distribution

d) describe enzymes as biological catalysts (proteins) which may have specificity

e) outline the different characteristics and modes of action of homogeneous, heterogeneous and enzyme catalysts, including:
   (i) the Haber process
   (ii) the catalytic removal of oxides of nitrogen from the exhaust gases of car engines (see also Section 15.3(b)(i))
   (iii) the catalytic role of atmospheric oxides of nitrogen in the oxidation of atmospheric sulfur dioxide (see also Section 13.1(f))
   (iv) the catalytic role of Fe^{2+} or Fe^{3+} in the $I^-/S_2O_8^{2-}$ reaction
   (v) the catalytic role of enzymes (including the explanation of specificity using a simple lock and key model but excluding inhibition)

Inorganic chemistry

9 The Periodic Table: chemical periodicity

This topic illustrates the regular patterns in chemical and physical properties of the elements in the Periodic Table.

	Learning outcomes Candidates should be able to:
9.1 Periodicity of physical properties of the elements in Period 3	a) describe qualitatively (and indicate the periodicity in) the variations in atomic radius, ionic radius, melting point and electrical conductivity of the elements (see the *Data Booklet*) b) explain qualitatively the variation in atomic radius and ionic radius c) interpret the variation in melting point and electrical conductivity in terms of the presence of simple molecular, giant molecular or metallic bonding in the elements d) explain the variation in first ionisation energy (see the *Data Booklet*) e) explain the strength, high melting point and electrical insulating properties of ceramics in terms of their giant structure; to include magnesium oxide, aluminium oxide and silicon dioxide
9.2 Periodicity of chemical properties of the elements in Period 3	a) describe the reactions, if any, of the elements with oxygen (to give Na_2O, MgO, Al_2O_3, P_4O_{10}, SO_2, SO_3), chlorine (to give $NaCl$, $MgCl_2$, Al_2Cl_6, $SiCl_4$, PCl_5) and water (Na and Mg only) b) state and explain the variation in oxidation number of the oxides (sodium to sulfur only) and chlorides (sodium to phosphorus only) in terms of their outer shell (valence shell) electrons c) describe the reactions of the oxides with water (treatment of peroxides and superoxides is *not* required) d) describe and explain the acid/base behaviour of oxides and hydroxides including, where relevant, amphoteric behaviour in reactions with acids and bases (sodium hydroxide only) e) describe and explain the reactions of the chlorides with water f) interpret the variations and trends in 9.2(b), (c), (d) and (e) in terms of bonding and electronegativity g) suggest the types of chemical bonding present in chlorides and oxides from observations of their chemical and physical properties
9.3 Chemical periodicity of other elements	a) predict the characteristic properties of an element in a given group by using knowledge of chemical periodicity b) 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

The physical and chemical properties of the elements of Group 2 (the alkaline Earth metals) are introduced in this topic.

	Learning outcomes Candidates should be able to:
10.1 Similarities and trends in the properties of the Group 2 metals, magnesium to barium, and their compounds	a) describe the reactions of the elements with oxygen, water and dilute acids
	b) describe the behaviour of the oxides, hydroxides and carbonates with water and dilute acids
	c) describe the thermal decomposition of the nitrates and carbonates
	d) interpret, and make predictions from, the trends in physical and chemical properties of the elements and their compounds
	e) state the variation in the solubilities of the hydroxides and sulfates
	f) interpret and explain qualitatively the trend in the thermal stability of the nitrates and carbonates in terms of the charge density of the cation and the polarisability of the large anion
	g) interpret and explain qualitatively the variation in solubility of the hydroxides and sulfates in terms of relative magnitudes of the enthalpy change of hydration and the corresponding lattice energy
10.2 Some uses of Group 2 compounds	a) describe and explain the use of calcium hydroxide and calcium carbonate (powdered limestone) in agriculture

11 Group 17

The physical and chemical properties of the elements of Group 17 (the halogens) are introduced in this topic.

	Learning outcomes Candidates should be able to:
11.1 Physical properties of the Group 17 elements	a) describe the colours and the trend in volatility of chlorine, bromine and iodine b) interpret the volatility of the elements in terms of van der Waals' forces
11.2 The chemical properties of the elements and their hydrides	a) describe the relative reactivity of the elements as oxidising agents (see also Section 6.3(f)) b) describe and explain the reactions of the elements with hydrogen c) (i) describe and explain the relative thermal stabilities of the hydrides (ii) interpret these relative stabilities in terms of bond energies
11.3 Some reactions of the halide ions	a) describe and explain the reactions of halide ions with: (i) aqueous silver ions followed by aqueous ammonia (ii) concentrated sulfuric acid
11.4 The reactions of chlorine with aqueous sodium hydroxide	a) describe and interpret, in terms of changes of oxidation number, the reaction of chlorine with cold and with hot aqueous sodium hydroxide and recognise this as a disproportionation reaction
11.5 Some important uses of the halogens and of halogen compounds	a) explain the use of chlorine in water purification b) state the industrial importance and environmental significance of the halogens and their compounds (e.g. for bleaches, PVC, halogenated hydrocarbons as solvents, refrigerants and in aerosols. See also Section 16.2).

12 An introduction to the chemistry of transition elements

The physical and chemical properties of the transition elements are introduced in this topic.

	Learning outcomes Candidates should be able to:
12.1 General physical properties of the first row of transition elements, titanium to copper	a) explain what is meant by a *transition element*, in terms of d-block elements forming one or more stable ions with incomplete d orbitals b) sketch the shape of a d orbital c) state the electronic configuration of each of the first row transition elements and of their ions d) contrast, qualitatively, the melting points and densities of the transition elements with those of, for example, calcium as a typical s-block element e) describe the tendency of transition elements to have variable oxidation states f) predict from a given electronic configuration, the likely oxidation states of a transition element
12.2 General characteristic chemical properties of the first set of transition elements, titanium to copper	a) 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 b) (i) 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 including monodentate, bidentate and polydentate ligands (ii) define the term *complex* as a molecule or ion formed by a central metal atom / ion surrounded by one or more ligands (iii) describe the geometry of transition metal complexes as linear, octahedral, tetrahedral or square planar (iv) state what is meant by co-ordination number and predict the formula and charge of a complex ion, given the metal ion, its charge, the ligand and its co-ordination number c) explain qualitatively that ligand exchange can occur, including the complexes of copper(II) ions with water and ammonia molecules and hydroxide and chloride ions d) describe and explain the use of Fe^{3+}/Fe^{2+}, MnO_4^-/Mn^{2+} and $Cr_2O_7^{2-}/Cr^{3+}$ as examples of redox systems (see also Section 6.3) e) predict, using $E^\ominus$ values, the likelihood of redox reactions

12.3 Colour of complexes	a) describe the splitting of degenerate d orbitals into two energy levels in octahedral and tetrahedral complexes b) explain the origin of colour in transition element complexes resulting from the absorption of light energy as an electron moves between two non-degenerate d orbitals c) describe, in qualitative terms, the effects of different ligands on absorption, and hence colour, using the complexes of copper(II) ions with water and ammonia molecules and hydroxide and chloride ions as examples d) apply the above ideas of ligands and complexes to other metals, given information
12.4 Stereoisomerism in transition element complexes	a) describe the types of stereoisomerism shown by complexes, including those associated with bidentate ligands: (i) cis-trans isomerism, e.g. cis- and trans-platin, $[Pt(NH_3)_2Cl_2]$ (ii) optical isomerism, e.g. $[Ni(NH_2CH_2CH_2NH_2)_3]^{2+}$ b) describe the use of cisplatin as an anticancer drug and its action by binding to DNA in cancer cells, preventing cell division
12.5 Stability constants, K_{stab}	a) describe and explain ligand exchanges in terms of competing equilibria (also see Section 7) b) state that the stability constant, K_{stab}, of a complex is the equilibrium constant for the formation of the complex ion in a solvent from its constituent ions or molecules c) deduce and use expressions for the stability constant of a ligand exchange d) explain ligand exchange in terms of K_{stab} and understand that a large K_{stab} is due to the formation of a stable complex ion

13 Nitrogen and sulfur

This topic introduces some of the chemistry associated with nitrogen and sulfur.

	Learning outcomes Candidates should be able to:
13.1 Nitrogen	a) explain the lack of reactivity of nitrogen b) describe and explain: (i) the basicity of ammonia (see also Section 7.2) (ii) the structure of the ammonium ion and its formation by an acid-base reaction (iii) the displacement of ammonia from its salts c) state the industrial importance of ammonia and nitrogen compounds derived from ammonia d) state and explain the environmental consequences of the uncontrolled use of nitrate fertilisers e) 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 f) explain why atmospheric oxides of nitrogen are pollutants, including their catalytic role in the oxidation of atmospheric sulfur dioxide (see also Section 8.3(e)(iii))
13.2 Sulfur: the formation of atmospheric sulfur dioxide, its role in acid rain	a) describe the formation of atmospheric sulfur dioxide from the combustion of sulfur-contaminated fossil fuels b) state the role of sulfur dioxide in the formation of acid rain and describe the main environmental consequences of acid rain

Organic chemistry and analysis

14 An introduction to organic chemistry

Organic chemistry involves the study of a large class of chemical compounds containing carbon. This topic introduces naming conventions, organic reaction terminology and structures of organic molecules.

	Learning outcomes Candidates should be able to:
14.1 Formulae, functional groups and the naming of organic compounds	a) interpret and use the general, structural, displayed and skeletal formulae of the following classes of compound: (i) alkanes, alkenes **and arenes** (ii) halogenoalkanes **and halogenoarenes** (iii) alcohols (including primary, secondary and tertiary) **and phenols** (iv) aldehydes and ketones (v) carboxylic acids, esters **and acyl chlorides** (vi) amines (primary only), nitriles, **amides and amino acids** (Candidates are expected to recognise the shape of the benzene ring when it is present in organic compounds. Knowledge of benzene or its compounds is *not* required for AS Level.) b) understand and use systematic nomenclature of simple aliphatic organic molecules with functional groups detailed in 14.1(a), up to six carbon atoms (six plus six for esters and amides, straight chains only) **c) understand and use systematic nomenclature of simple aromatic molecules with one benzene ring and one or more simple substituents, for example 3-nitrobenzoic acid, 2,4,6-tribromophenol** d) deduce the possible isomers for an organic molecule of known molecular formula e) deduce the molecular formula of a compound, given its structural, displayed or skeletal formula
14.2 Characteristic organic reactions	a) interpret and use the following terminology associated with types of organic reactions: (i) functional group (ii) homolytic and heterolytic fission (iii) free radical, initiation, propagation, termination (iv) nucleophile, electrophile (v) addition, substitution, elimination, hydrolysis, condensation (vi) oxidation and reduction (in equations for organic redox reactions, the symbols [O] and [H] are acceptable for oxidising and reducing agents)

14.3 Shapes of organic molecules; σ and π bonds	a) (i) describe and explain the shape of, and bond angles in, the ethane, ethene **and benzene** molecules in terms of σ and π bonds (ii) predict the shapes of, and bond angles in, other related molecules
14.4 Isomerism: structural and stereoisomerism	a) describe structural isomerism and its division into chain, positional and functional group isomerism b) describe stereoisomerism and its division into geometrical (cis-trans) and optical isomerism (use of E, Z nomenclature is acceptable but is *not* required) c) describe geometrical (cis-trans) isomerism in alkenes, and explain its origin in terms of restricted rotation due to the presence of π bonds d) explain what is meant by a chiral centre and that such a centre normally gives rise to optical isomerism (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.) e) identify chiral centres and geometrical (cis-trans) isomerism in a molecule of given structural formula

15 Hydrocarbons

Compounds containing only carbon and hydrogen are called hydrocarbons. This class of compound can be subdivided into alkanes, alkenes and arenes.

Learning outcomes
Candidates should be able to:

15.1 Alkanes

a) understand the general unreactivity of alkanes, including towards polar reagents

b) describe the chemistry of alkanes as exemplified by the following reactions of ethane:
   - (i) combustion
   - (ii) substitution by chlorine and by bromine

c) describe the mechanism of free-radical substitution at methyl groups with particular reference to the initiation, propagation and termination reactions

d) explain the use of crude oil as a source of both aliphatic and aromatic hydrocarbons

e) suggest how cracking can be used to obtain more useful alkanes and alkenes of lower M_r from larger hydrocarbon molecules

15.2 Alkenes

a) describe the chemistry of alkenes as exemplified, where relevant, by the following reactions of ethene and propene (including the Markovnikov addition of asymmetric electrophiles to alkenes using propene as an example):
   - (i) addition of hydrogen, steam, hydrogen halides and halogens
   - (ii) oxidation by cold, dilute, acidified manganate(VII) ions to form the diol
   - (iii) oxidation by hot, concentrated, acidified manganate(VII) ions leading to the rupture of the carbon–carbon double bond in order to determine the position of alkene linkages in larger molecules
   - (iv) polymerisation (see also Section 21)

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

c) describe and explain the inductive effects of alkyl groups on the stability of cations formed during electrophilic addition

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

e) deduce the repeat unit of an addition polymer obtained from a given monomer

f) identify the monomer(s) present in a given section of an addition polymer molecule

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

15.3 Hydrocarbons as fuels	a) describe and explain how the combustion reactions of alkanes make them suitable to be used as fuels in industry, in the home and in transport b) recognise the environmental consequences of: (i) carbon monoxide, oxides of nitrogen and unburnt hydrocarbons arising from the internal combustion engine and of their catalytic removal (ii) gases that contribute to the enhanced greenhouse effect c) outline the use of infra-red spectroscopy in monitoring air pollution (see also Section 22.2)
15.4 Arenes	**a) describe the chemistry of arenes as exemplified by the following reactions of benzene and methylbenzene:** **(i) substitution reactions with chlorine and with bromine** **(ii) nitration** **(iii) Friedel-Crafts alkylation and acylation** **(iv) complete oxidation of the side-chain to give a benzoic acid** **(v) hydrogenation of the benzene ring to form a cyclohexane ring** **b) (i) describe the mechanism of electrophilic substitution in arenes, as exemplified by the formation of nitrobenzene and bromobenzene** **(ii) suggest the mechanism of other electrophilic substitution reactions, given data** **(iii) describe the effect of the delocalisation of electrons in arenes in such reactions** **c) interpret the difference in reactivity between chlorobenzene and chloroalkanes** **d) predict whether halogenation will occur in the side-chain or in the aromatic ring in arenes depending on reaction conditions** **e) apply knowledge relating to position of substitution in the electrophilic substitution of arenes (see the *Data Booklet* Table 9)**

16 Halogen derivatives

The inclusion of a halogen atom within an organic molecule affects its reactivity. The reactions of halogenoalkanes are very important in organic chemistry.

Learning outcomes

Candidates should be able to:

16.1 Halogenoalkanes

a) recall the chemistry of halogenoalkanes as exemplified by:
  (i) the following nucleophilic substitution reactions of bromoethane: hydrolysis, formation of nitriles, formation of primary amines by reaction with ammonia
  (ii) the elimination of hydrogen bromide from 2-bromopropane
b) describe the S_N1 and S_N2 mechanisms of nucleophilic substitution in halogenoalkanes including the inductive effects of alkyl groups (see Section 15.2(c))
c) 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

16.2 Relative strength of the C–Hal bond

a) interpret the different reactivities of halogenoalkanes (with particular reference to hydrolysis and to the relative strengths of the C–Hal bonds)
b) explain the uses of fluoroalkanes and fluorohalogenoalkanes in terms of their relative chemical inertness
c) recognise the concern about the effect of chlorofluoroalkanes on the ozone layer

17 Hydroxy compounds

This topic introduces the chemistry of a versatile class of organic compounds, hydroxy compounds, which contain an R–OH group.

Learning outcomes
Candidates should be able to:

17.1 Alcohols

a) recall the chemistry of alcohols, exemplified by ethanol, in the following reactions:
   - (i) combustion
   - (ii) substitution to halogenoalkanes
   - (iii) reaction with sodium
   - (iv) oxidation to carbonyl compounds and carboxylic acids
   - (v) dehydration to alkenes
   - (vi) formation of esters by esterification with carboxylic acids
   - **(vii) formation of esters by acylation with acyl chlorides using ethyl ethanoate and phenyl benzoate as examples**

b) (i) classify hydroxy compounds into primary, secondary and tertiary alcohols
   - (ii) suggest characteristic distinguishing reactions, e.g. mild oxidation

c) deduce the presence of a $CH_3CH(OH)$– group in an alcohol from its reaction with alkaline aqueous iodine to form tri-iodomethane

17.2 Phenol

a) recall the chemistry of phenol, as exemplified by the following reactions:
   - **(i) with bases**
   - **(ii) with sodium**
   - **(iii) with diazonium salts (see also Section 20.1)**
   - **(iv) nitration of, and bromination of, the aromatic ring**

b) describe and explain the relative acidities of water, phenol and ethanol

18 Carbonyl compounds

This topic introduces the chemistry of the carbonyl compounds, aldehydes and ketones.

	Learning outcomes Candidates should be able to:
18.1 Aldehydes and ketones	a) describe: (i) the formation of aldehydes and ketones from primary and secondary alcohols respectively using $Cr_2O_7^{2-}/H^+$ (ii) the reduction of aldehydes and ketones, e.g. using $NaBH_4$ or $LiAlH_4$ (iii) the reaction of aldehydes and ketones with HCN and NaCN or KCN b) describe the mechanism of the nucleophilic addition reactions of hydrogen cyanide with aldehydes and ketones c) describe the use of 2,4-dinitrophenylhydrazine (2,4-DNPH) to detect the presence of carbonyl compounds d) deduce the nature (aldehyde or ketone) of an unknown carbonyl compound from the results of simple tests (Fehling's and Tollens' reagents; ease of oxidation) e) describe the reaction of $CH_3CO–$ compounds with alkaline aqueous iodine to give tri-iodomethane

19 Carboxylic acids and derivatives

This topic introduces the chemistry of carboxylic acids and their derivatives.

	Learning outcomes Candidates should be able to:
19.1 Carboxylic acids	a) describe the formation of carboxylic acids from alcohols, aldehydes and nitriles b) describe the reactions of carboxylic acids in the formation of: (i) salts, by the use of reactive metals, alkalis or carbonates (ii) alkyl esters (iii) alcohols, by the use of $LiAlH_4$ **(iv) acyl chlorides** **c) recognise that some carboxylic acids can be further oxidised:** **(i) the oxidation of methanoic acid, HCO_2H, with Fehling's and Tollens' reagents** **(ii) the oxidation of ethanedioic acid, HO_2CCO_2H, with warm, acidified manganate(VII)** **d) explain the relative acidities of carboxylic acids, phenols and alcohols** **e) use the concept of electronegativity to explain the acidities of chlorine-substituted ethanoic acids**
19.2 Acyl chlorides	**a) describe the hydrolysis of acyl chlorides** **b) describe the reactions of acyl chlorides with alcohols, phenols, ammonia and primary amines** **c) explain the relative ease of hydrolysis of acyl chlorides, alkyl chlorides and aryl chlorides including the condensation (addition-elimination) mechanism for the hydrolysis of acyl chlorides**
19.3 Esters	a) describe the acid and base hydrolysis of esters b) state the major commercial uses of esters, e.g. solvents, perfumes, flavourings

20 Nitrogen compounds

Many biological molecules contain nitrogen. This topic introduces the chemistry of a variety of organic compounds that contain nitrogen.

	Learning outcomes Candidates should be able to:
20.1 Primary amines	**a) describe the formation of alkyl amines such as ethylamine (by the reaction of ammonia with halogenoalkanes; the reduction of amides with $LiA\ell H_4$; the reduction of nitriles with $LiA\ell H_4$ or H_2 / Ni) and of phenylamine (by the reduction of nitrobenzene with tin/ concentrated $HC\ell$)** **b) describe and explain the basicity of amines** **c) explain the relative basicities of ammonia, ethylamine and phenylamine in terms of their structures** **d) describe the reaction of phenylamine with:** **(i) aqueous bromine** **(ii) nitrous acid to give the diazonium salt and phenol** **e) describe the coupling of benzenediazonium chloride and phenol and the use of similar reactions in the formation of dyes**
20.2 Amides	**a) describe the formation of amides from the reaction between NH_3 or RNH_2 and $R'COC\ell$** **b) recognise that amides are neutral** **c) (i) describe amide hydrolysis on treatment with aqueous alkali or acid** **(ii) describe the reduction of amides with $LiA\ell H_4$**
20.3 Amino acids	**a) describe the acid / base properties of amino acids and the formation of zwitterions** **b) describe the formation of peptide bonds between amino acids to give di- and tripeptides** **c) describe simply the process of electrophoresis and the effect of pH, using peptides and amino acids as examples**

21 Polymerisation

This topic illustrates how small molecules join together to form polymers and how their properties are useful in everyday life.

	Learning outcomes Candidates should be able to:
21.1 Condensation polymerisation	**a) describe the formation of polyesters and polyamides** **b) describe the characteristics of condensation polymers:** **(i) in polyesters as exemplified by *Terylene*** **(ii) in polyamides as exemplified by polypeptides, proteins, nylon 6, nylon 6,6 and *Kevlar*** **c) deduce the repeat unit of a condensation polymer obtained from a given monomer or pair of monomers** **d) identify the monomer(s) present in a given section of a condensation polymer molecule**
21.2 Predicting the type of polymerisation	**a) predict the type of polymerisation reaction for a given monomer or pair of monomers** **b) deduce the type of polymerisation reaction which produces a given section of a polymer molecule**
21.3 Properties of polymers	**a) discuss the properties and structure of polymers based on their methods of formation (addition or condensation, see also Section 15.2)** **b) discuss how the presence of side-chains and intermolecular forces affect the properties of polymeric materials (e.g. poly(alkenes), PTFE (*Teflon*), *Kevlar*)** **c) explain the significance of hydrogen bonding in the pairing of bases in DNA in relation to the replication of genetic information** **d) distinguish between the primary, secondary (α-helix and β-sheet) and tertiary structures of proteins and explain the stabilisation of secondary structure (through hydrogen bonding between C=O and N–H bonds of peptide groups) and tertiary structure (through interactions between R-groups)** **e) describe how polymers act as:** **(i) non-solvent based adhesives, e.g. epoxy resins and *Super Glues*** **(ii) conducting polymers, e.g. polyacetylene**
21.4 Degradable polymers	**a) recognise that poly(alkenes) are chemically inert and can therefore be difficult to biodegrade** **b) recognise that some polymers can be degraded by the action of light** **c) recognise that polyesters and polyamides are biodegradable by hydrolysis** **d) describe the hydrolysis of proteins**

22 Analytical techniques

Analytical techniques are important tools for investigating compounds.

	Learning outcomes Candidates should be able to:
22.1 Chromatography	**a) explain and use the terms *R_f value* in thin-layer chromatography and *retention time* in gas / liquid chromatography** **b) interpret gas / liquid chromatograms in terms of the percentage composition of a mixture**
22.2 Infra-red spectroscopy	a) analyse an infra-red spectrum of a simple molecule to identify functional groups (see the *Data Booklet* for the functional groups required)
22.3 Mass spectrometry	**a) deduce the molecular mass of an organic molecule from the molecular ion peak in a mass spectrum** **b) deduce the number of carbon atoms in a compound using the M+1 peak** **c) deduce the presence of bromine and chlorine atoms in a compound using the M+2 peak** **d) suggest the identity of molecules formed by simple fragmentation in a given mass spectrum**
22.4 Carbon-13 NMR spectroscopy	**a) analyse a carbon-13 NMR spectrum of a simple molecule to deduce:** **(i) the different environments of the carbon atoms present** **(ii) the possible structures for the molecule** **b) predict the number of peaks in a carbon-13 NMR spectrum for a given molecule**
22.5 Proton (^{1}H) NMR spectroscopy	**a) analyse and interpret a proton (^{1}H) NMR spectrum of a simple molecule to deduce:** **(i) the different types of proton present using chemical shift values** **(ii) the relative numbers of each type of proton present from relative peak areas** **(iii) 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** **(iv) the possible structures for the molecule** **b) predict the chemical shifts and splitting patterns of the protons in a given molecule** **c) describe the use of tetramethylsilane, TMS, as the standard for chemical shift measurements** **d) state the need for deuterated solvents, e.g. $CDCl_3$, when obtaining an NMR spectrum** **e) describe the identification of O–H and N–H protons by proton exchange using D_2O**

23 Organic synthesis

This topic introduces the strategies used in the synthesis of organic molecules.

	Learning outcomes Candidates should be able to:
23.1 Synthesis of chiral drug molecules	**a) state that chiral drugs extracted from natural sources often contain only a single optical isomer** **b) state reasons why the synthetic preparation of drug molecules often requires the production of a single optical isomer, e.g. better therapeutic activity, fewer side effects**
23.2 Synthetic routes	**a) for an organic molecule containing several functional groups:** **(i) identify organic functional groups using the reactions in the syllabus** **(ii) predict properties and reactions** **b) devise multi-stage synthetic routes for preparing organic molecules using the reactions in the syllabus** **c) analyse a given synthetic route in terms of type of reaction and reagents used for each step of it, and possible by-products**

4 Practical assessment

4.1 Introduction

Teachers should ensure that learners practise experimental skills throughout the whole period of their course of study. As a guide, learners should expect to 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 teacher demonstrations of experiments.

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

- provide learning opportunities so that learners 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 interplay of experiment and theory in scientific method
- prove 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 rather than their knowledge of theory. Where appropriate, candidates will be told exactly what to do and how to do it: only knowledge of theory and experimental skills within the syllabus will be expected.

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

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

4.2 Paper 3

In some examination series, two versions of the Advanced Practical Skills paper will be available, identified as Advanced Practical Skills 1 and Advanced Practical Skills 2. In other series only Advanced Practical Skills 1 will be available. These papers will contain different questions, but will be equivalent in the skills assessed and in the level of demand. Each candidate should take one of these papers.

Where two versions of the paper are offered, some Centres may wish to divide their candidates so that some are entered for Advanced Practical Skills 1 and the others are entered for Advanced Practical Skills 2; other Centres may wish to enter all of their candidates for the same paper. Each of these papers will be timetabled on a different day.

Paper 3 will be a timetabled, laboratory-based practical paper focusing on the following experimental skills:

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

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

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

The other question or questions will be quantitative: either volumetric analysis or measurement of a quantity, e.g. the enthalpy change of a reaction, mass change on heating, changing the rate of a reaction or measuring a gas volume. Candidates will be expected to draw suitable tables, graphs and other appropriate means of presenting the data. 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 in the Confidential Instructions. The Confidential Instructions should be followed very carefully. If there is any doubt about how the practical examination should be set up or if a particular chemical is impossible to obtain or not permitted for use in schools, it is vital that Centres contact Cambridge as soon as possible.

4.2.1 Mark scheme for Paper 3

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

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

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

4.2.2 Expectations for each mark category (Paper 3)

Manipulation, measurement and observation

Successful collection of data and observations

Candidates should be able to:

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

Systematic analysis and knowledge of traditional methods of separation will not be required.

It will be assumed that candidates will be familiar with the following qualitative analysis reactions

(i) the reactions of the following cations: NH_4^+, Mg^{2+}, Al^{3+}, Ca^{2+}, Cr^{3+}, Mn^{2+}, Fe^{2+}, Fe^{3+}, Cu^{2+}, Zn^{2+}, Ba^{2+}
(ii) the reactions of the following anions: CO_3^{2-}, NO_3^-, NO_2^-, SO_4^{2-}, SO_3^{2-}, Cl^-, Br^-, I^-
(iii) tests for the following gases: NH_3, CO_2, Cl_2, H_2, O_2.

Qualitative analysis notes are printed at the end of the question paper and are reproduced in Section 5.5 of this syllabus.

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

Candidates should not attempt tests on substances other than those specified, except when it is appropriate to test for a gas.

Exercises requiring a knowledge of simple organic reactions, e.g. test-tube reactions indicating the presence of functional groups given in the AS Level syllabus, may also be set. This would be for the testing of observational skills and drawing general conclusions only.

A knowledge of volumetric determinations using the materials listed in Section 4.2.4 will be expected. This list is not exhaustive, and simple titrations involving other reagents may also be set. Sufficient working details will be given if appropriate.

Candidates should normally record burette readings to the nearest $0.05\,cm^3$. When using a thermometer calibrated at 1 °C intervals, temperature readings should be recorded to the nearest 0.5 °C.

Quality of measurements or observations

Candidates should be able to:

- make accurate and consistent measurements and observations.

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

Marks will be awarded for consistency and accuracy of readings. In some cases, the candidate's data or observations may be compared with information supplied by the Supervisor or known to the Examiners; in other cases, the award of the mark may be based on the scatter of points on a graph. Candidates are expected to work to the precision of the apparatus and materials provided. Allowances will be made where the quality of data is limited by the experimental method required or by the apparatus and materials used.

Decisions relating to measurements or observations

Candidates should be able to:

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

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

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

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
- draw an appropriate table in advance of taking readings/making observations, so that they do not have to copy their results
- include in the table of results, if necessary, columns for raw data, for calculated values and for analyses or conclusions
- use column headings that include both the quantity and the unit and that conform to accepted scientific conventions
- record raw readings of a quantity to the same degree of precision, and observations to the same level of detail.

As an example of accepted practice in column headings, if the quantity being measured is volume in cm^3, then 'volume/cm^3' would be the usual way to write the column heading, but 'volume in cm^3' or 'volume (cm^3)' would be allowed. Headings such as 'volume cm^3' or just 'cm^3' are not acceptable. The quantity or the unit or both may be written in words, or appropriate symbols may be used provided that their meaning is clear and unambiguous in the context (e.g. avoid t, since it may be used for time and for temperature).

Conventional symbols or abbreviations, such as ΔH for enthalpy change or ppt. for precipitate, may be used without explanation.

In recording data and observations, if one measurement of mass in a column of raw data is given as 0.06 g, then all the masses in that column should be given to the nearest 0.01 g. The degree of precision recorded should be compatible with the measuring instrument used, e.g. a measuring cylinder calibrated at 1.0 cm^3 should normally be read to the nearest 0.5 cm^3. 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 3 minutes' or 'paler green than with 0.2 mol dm^{-3}'.

Display of calculation and reasoning

Candidates should be able to:

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

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

Calculated quantities should be given to the same number of significant figures as (or one more than) the measured quantity of least accuracy. For example, if titre volume is measured to four significant figures, e.g. 23.45 cm^3, then the corresponding molar concentrations 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:

- choose a suitable and clear method of presenting the data, e.g. tabulations, graphs or a mixture of methods of presentation
- use the appropriate presentation method to produce a clear presentation of the data
- plot appropriate variables on appropriate, clearly labelled *x*- and *y*-axes
- choose suitable scales for graph axes
- plot all points or bars to an appropriate accuracy
- draw straight lines of best fit or curves to show the trend of a graph.

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

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

Analysis, conclusions and evaluation

Interpretation of data or observations and identifying sources of error

Candidates should be able to:

- describe the patterns and trends shown by data in tables and graphs
- describe and summarise the key points of a set of observations
- find an unknown value by using co-ordinates or intercepts on a graph
- calculate other quantities from data, or calculate the mean from repeated values, or make other appropriate calculations
- determine the gradient of a straight-line graph
- evaluate the effectiveness of control variables
- identify the most significant sources of error in an experiment
- estimate, quantitatively, the uncertainty in a quantitative measurement and express such uncertainty in a measurement as an actual or percentage error
- show an understanding of the distinction between systematic errors and random errors.

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

Candidates should have experience of looking at experiments and assessing the relative importance of errors in measurement or in making observations so that they can judge which sources of error are most important. They should be familiar with simple ways of estimating error, such as the errors intrinsic in measuring devices or in experiments where limitations of the method introduce errors (e.g. heat loss when trying to assess enthalpy change). 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. They should be able to express these errors in standard forms such as length = 73 ± 1 mm, or temperature increase = 14 ± 4 °C.

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

Drawing conclusions

Candidates should be able to:

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

Hypotheses that are being tested will be given to the candidates, although hypothesis formulation is in Assessment Objective 2, and so may be tested in the theory components. Candidates may be required to prove or disprove hypotheses, using deductions from the data, observations or calculated values. Simple scientific explanations form a part of such conclusions and therefore form a part of this practical assessment: 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.

Suggesting improvements

Candidates should be able to:

- suggest 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
- describe such modifications clearly in words or diagrams.

Candidate's suggestions should be realistic, so that in principle they are achievable in practice, although they may include the use of apparatus that is not available to the candidate (e.g. a colorimeter). The suggestions may relate to the apparatus used, to the experimental procedure followed, to the nature of the observations or how they were made. Candidates may include improvements that they have actually made while carrying out the experiment, such as repeating readings. The suggested modifications may relate to sources of error identified by the candidate or to other sources of error. Extensions of the investigation should only be proposed in order to permit the answering of a specified new question.

4.2.3 Administration of Paper 3

Detailed regulations on the administration of Cambridge 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 if they believe the Confidential Instructions have not been received.

It is the responsibility of Centres to provide the apparatus and chemicals required for practical examinations. Cambridge is not able to supply apparatus or chemicals directly, or provide advice on local suppliers.

Access to the Question Paper itself is not permitted in advance of the examination.

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

The Confidential Instructions describe information required by the Examiners. This will include a set of numerical results for the experiments, which the Supervisor should obtain out of sight of the candidates. A Supervisor's Report is included in the Confidential Instructions. Centres must complete this and enclose a copy in each envelope of scripts. The marking process may be delayed and candidates may be disadvantaged if the Supervisor's Report or sample results are missing or do not contain the information required.

If there is any doubt about the interpretation of the Confidential Instructions or the suitability of the apparatus available, enquiries should be sent to Cambridge, using either email (**info@cie.org.uk**), fax (+44 1223 553558) or telephone (+44 1223 553554).

The hazard codes have been updated to maintain consistency with changes in global regulations regarding chemical labelling.[1]

The new hazard codes will be used where relevant and in accordance with information provided by CLEAPSS.[2]

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

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

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[1] United Nations Global Harmonised System (GHS) for hazard classification and compatible labelling

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

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

Guidance for the preparation of reagents for qualitative analysis and indicators

Hazard	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.
[C]	**dilute nitric acid**	2.0 mol dm^{-3} HNO_3	Dilute 128 cm^3 of concentrated (70%) nitric acid **[C] [O]** to 1 dm^3.
[MH]	**dilute sulfuric acid**	1.0 mol dm^{-3} H_2SO_4	Cautiously pour 55 cm^3 of concentrated (98%) sulfuric acid **[C]** into 500 cm^3 of distilled water with continuous stirring. Make the solution up to 1 dm^3 with distilled water. **Care**: *concentrated* H_2SO_4 *is very corrosive.*
[C] [MH] [N]	**aqueous ammonia**	2.0 mol dm^{-3} NH_3	Dilute 112 cm^3 of concentrated (35%) ammonia **[C] [MH] [N]** to 1 dm^3.
[C]	**aqueous sodium hydroxide**	2.0 mol dm^{-3} NaOH	Dissolve 80.0 g of NaOH **[C]** in each dm^3 of solution. **Care**: *the process of solution is exothermic and any concentrated solution is very corrosive.*
	0.1 mol dm^{-3} barium chloride **or** **0.1 mol dm^{-3} barium nitrate**	0.1 mol dm^{-3} barium chloride or 0.1 mol dm^{-3} barium nitrate	Dissolve 24.4 g of $BaCl_2.2H_2O$ **[T]** in each dm^3 of solution, or dissolve 26.1 g of $Ba(NO_3)_2$ **[HH] [O]** in each dm^3 of solution.
[N]	**0.05 mol dm^{-3} silver nitrate**	0.05 mol dm^{-3} silver nitrate	Dissolve 8.5 g of $AgNO_3$ **[C] [O] [N]** in each dm^3 of solution.
[MH]	**limewater**	saturated aqueous calcium hydroxide, $Ca(OH)_2$	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.
	0.1 mol dm^{-3} potassium iodide	0.1 mol dm^{-3} KI	Dissolve 16.6 g of KI in each dm^3 of solution.
	0.02 mol dm^{-3} potassium manganate(VII)	0.02 mol dm^{-3} $KMnO_4$	Dissolve 3.16 g of $KMnO_4$ **[O] [MH] [N]** in each dm^3 of solution.

Hazard	Label	Identity	Instructions
	starch indicator	freshly prepared aqueous starch indicator (approx 2% solution w/v)	Mix 2 g of **soluble** starch with a little cold water until a smooth paste is obtained. Add 100 cm^3 boiling water and stir. Boil until a clear solution is obtained (about 5 minutes).
[F] [HH] [MH]	**methyl orange indicator**	methyl orange indicator (pH range 2.9 to 4.6)	Use commercially produced solution or dissolve 0.4 g of solid indicator **[T]** in 200 cm^3 of ethanol (IMS) **[F] [HH] [MH]** and make up to 1 dm^3 with distilled water.
[F] [HH] [MH]	**bromophenol blue indicator**	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.
[F] [HH] [MH]	**thymol blue indicator**	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.
[F] [HH] [MH]	**thymolphthalein indicator**	thymolphthalein indicator (pH range 9.3 to 10.5)	Dissolve 2.0 g of the solid indicator in 1 dm^3 of ethanol (IMS) **[F] [HH] [MH]**.
[MH]	**acidified aqueous potassium manganate(VII)**	0.01 $mol\,dm^{-3}$ $KMnO_4$ 0.5 $mol\,dm^{-3}$ sulfuric acid	Mix equal volumes of 0.02 $mol\,dm^{-3}$ $KMnO_4$ and 1.0 $mol\,dm^{-3}$ H_2SO_4 **[MH]**.

4.2.4 Apparatus and materials list

The list given below gives guidance to schools concerning the apparatus and materials that are expected to be generally available for examination purposes (Paper 3 Advanced Practical Skills 1 and Advanced Practical Skills 2). The list is not intended to be exhaustive: in particular, items (such as Bunsen burners, tripods, glass tubing) that are commonly regarded as standard equipment in a chemical laboratory are not included. Unless otherwise stated, the rate of allocation is 'per candidate'. Centres **should keep these in stock** and candidates should be accustomed to using these. To provide some variation in the questions set, some additional items of equipment or materials may be required.

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

two burettes, 50 cm^3 (ISO385 or grade B)
two pipettes, 25 cm^3 (ISO648 or grade B)
one pipette, 10 cm^3 (ISO648 or grade B)
teat/dropping pipettes
one pipette filler
conical flasks: two within range 150 cm^3 to 250 cm^3
one-mark graduated volumetric flask, 250 cm^3 (ISO1042 or grade B)
measuring cylinders, 25 cm^3 and 50 cm^3 (ISO6706 or ISO4788 or grade B)
measuring cylinder, 250 cm^3 (glass or plastic)
side-arm conical flask or third conical flask with suitable bung and delivery tube
tub suitable for acting as a trough (for collecting gas over water)
wash bottle
two filter funnels
two porcelain crucibles, approximately 15 cm^3, with lids
one pipe-clay triangle
one evaporating basin, at least 30 cm^3
beakers, squat form with lip: 100 cm^3, 250 cm^3
one thermometer: –10 °C to +110 °C at 1 °C
two foamed plastic (expanded polystyrene) cups approximately 150 cm^3
test-tubes (some of which should be Pyrex or hard-glass) approximately 125 mm × 16 mm
boiling tubes, approximately 150 mm × 25 mm
clocks to measure to an accuracy of 1 s (where clocks are specified, candidates may use their own wrist watches if they prefer.)
balance, single-pan, direct reading, **minimum** accuracy 0.1 g (1 per 8–12 candidates) weighing to 200 g
stand and clamp suitable for a burette

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

For quantitative analysis

This list is not exhaustive. Other chemicals may be used in a practical examination.

Acid-base titration

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

Manganate(VII) titration

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

Gravimetric, thermometric, rates and gas collection

copper(II) sulfate
Group 2 carbonates
iron, magnesium, zinc metals
potassium iodide
potassium peroxydisulfate
sodium thiosulfate
solid hydrated barium chloride and magnesium sulfate

For qualitative analysis

This list is not exhaustive. Other chemicals may be used in a practical examination.

Bench reagents and equipment

aqueous ammonia (approximately 2.0 mol dm^{-3})

aqueous sodium hydroxide (approximately 2.0 mol dm^{-3})

hydrochloric acid (approximately 2.0 mol dm^{-3})

nitric acid (approximately 2.0 mol dm^{-3})

sulfuric acid (approximately 1.0 mol dm^{-3})

aqueous barium nitrate or barium chloride (approximately 0.1 mol dm^{-3})

aqueous silver nitrate (approximately 0.05 mol dm^{-3})

aqueous potassium iodide (approximately 0.1 mol dm^{-3})

aqueous potassium manganate(VII) (approximately 0.02 mol dm^{-3})

acidified aqueous potassiuim manganate(VII)

limewater (a saturated solution of calcium hydroxide) and the equipment normally used by the Centre to test for carbon dioxide

aqueous iodine (approximately 0.01 mol dm^{-3} in 0.2 mol dm^{-3} potassium iodide)

sodium carbonate or sodium hydrogencarbonate

starch indicator

aluminium foil

red and blue litmus paper

pH indicator paper

Universal Indicator (paper or solution)

For inorganic analysis

the carbonates (where they exist), sulfates, nitrates and chlorides of the cations listed in the Qualitative Analysis Notes (page 72)

the sodium and potassium salts of the anions listed in the Qualitative Analysis Notes (page 73)

For organic analysis

alcohols (primary, secondary, tertiary)

aldehydes and ketones (N.B. Tests for aldehydes may be performed by substituting glucose for the aldehyde.)

carboxylic acids and esters

halogenoalkanes

4.2.5 Safety in the laboratory

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

Associations

CLEAPSS is an advisory service providing support in practical science and technology.
www.cleapss.org.uk

The Association for Science Education promotes excellence in science teaching and learning.
www.ase.org.uk

Publications

Safeguards in the School Laboratory, ASE, 11th edition, 2006
Topics in Safety, ASE, 3rd edition, 2001
CLEAPSS Laboratory Handbook, updated annually (available to CLEAPSS members only)
CLEAPSS Hazcards, updated annually (available to CLEAPSS members only)
Hazardous Chemicals, an interactive manual for science education, SSERC, 2002 (CD)

UK Regulations

Control of Substances Hazardous to Health Regulations (COSHH) 2002
www.legislation.gov.uk/uksi/2002/2677/contents/made

A brief guide may be found at:
www.hse.gov.uk/pubns/indg136.pdf

European Regulations

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

4.3 Paper 5

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

- planning
- analysis, conclusions and evaluation

This examination will not require laboratory facilities.

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

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

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

This requires many hours of laboratory-based work and careful supervision from teachers to ensure that experiments are performed safely.

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

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

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

There will be activities in which candidates will be given some experimental data and will be required to analyse, evaluate and draw conclusions from them.

Some questions on Paper 5 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 the syllabus. Information that candidates are not expected to know will be provided in the examination paper.

4.3.1 Mark scheme for Paper 5

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

Skill	Minimum mark allocation*	Breakdown of skills	Minimum mark allocation*
Planning	12 marks	Defining the problem	4 marks
		Methods	8 marks
Analysis, conclusions and evaluation	12 marks	Dealing with data	6 marks
		Evaluation	4 marks
		Conclusions	2 marks

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

4.3.2 Expectations for each mark category (Paper 5)

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
- assess the risks of their proposed experiment
- identify the independent variable in an experiment or investigation
- identify the dependent variable in an experiment or investigation
- express the aim 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.

Candidates will be provided with information about the aims of the investigation or experiment, and some background information relating to it. They should be able to make use of this information to identify the key variables in the investigation.

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

Candidates may be asked to express their prediction in a variety of ways.

Methods

Candidates should be able to:

- describe the method to be used when carrying out the experiment
- describe the arrangement of apparatus and the steps in the procedure to be followed
- suggest appropriate volumes and concentrations of reagents
- describe precautions that should be taken to keep risks to a minimum
- describe how to vary the independent variable and how the dependent variable is to be measured
- 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 tables for data that they might wish to record
- describe how the data might be used in order to reach a conclusion.

The overall method suggested should be workable. It should be possible to collect any data required without undue difficulty if the apparatus were assembled as described. Words and labelled diagrams should be used for describing the apparatus and how to use it. If measuring instruments are required they should be chosen to measure the correct quantity to a suitable precision. Control experiments may be of the type where all factors are identical to the experimental treatment, except that the value of the independent variable is zero, or they may be of the type used to confirm that, for example, it is a catalyst that is causing a particular effect, where the catalyst is omitted or inactivated.

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

Analysis, conclusions and evaluation

Dealing with data

Candidates should be able to:

- identify the calculations and means of presentation of data that are necessary to be able to draw conclusions from provided data
- use calculations to enable simplification or explanation of data
- use tables and graphs to draw attention to the key points in quantitative data, including the variability of data
- analyse qualitative data to draw appropriate conclusions
- analyse data from provided spectra or other published data to reach appropriate conclusions.

Candidates should know how to choose and carry out calculations required to simplify data or make them comparable. These calculations might include the mean, median, mode, percentage and percentage gain or loss. Candidates should also know how to choose and construct appropriate data tables, including columns for calculated values, and headings including quantity and unit where appropriate.

Similarly, they should be able to construct suitable graphs displaying the independent variable on the *x*-axis and dependent variable on the *y*-axis, and fulfilling the criteria laid out in the Paper 3 section on page 52.

Candidates should be able to recognise and understand the significance of observations made from qualitative tests and use them to identify the functional groups within a molecule.

Candidates should also be able to identify peaks obtained from spectra and use these to determine the structures of molecules. Candidates should be able to use chemical data from other sources (e.g. melting points, optical isomer rotation, etc.) in context.

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 within familiar contexts
- identify the extent to which provided readings have been adequately replicated, and describe the adequacy of the range of data provided
- use provided information to assess the extent to which selected variables have been effectively controlled
- use these evaluations and provided information to make informed judgements on the confidence with which conclusions may be drawn
- 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
- explain the consequences that the incorrect use of apparatus might have on the results obtained.

In a table or graph of data, candidates should be able to identify values which are clearly anomalous, and suggest strategies for dealing with such anomalies, including repeating the experiment or omitting the affected replicate. Where investigations are set in familiar contexts, which it is expected that candidates will have explored during the course, candidates may be asked to suggest possible causes for such anomalies (above and beyond 'investigator error'), and will be rewarded for answers derived from their own experience of problems intrinsic in the particular investigation.

Candidates should be able to describe and explain how a change in the experimental conditions or procedures would affect the results obtained. Candidates will be expected to have a knowledge of the advantages of replication of data, and the practical limitations. Candidates will be expected to be able to identify instances where it would have been sensible for additional readings to have been taken during the experiment in order to give a more comprehensive range of values.

Candidates may be provided with information that will permit them to assess the extent to which particular variables have been effectively controlled (e.g. the temperature recorded within each of a number of samples in which it is supposed to be the same). Candidates will be expected to be able to draw together all this information to permit them to make judgements about the reliability of the investigation and the trustworthiness of its outcomes.

They should be able to state whether the data will support or refute a prediction, or whether it is of such poor quality that it cannot be used successfully to test the prediction.

Conclusions

Candidates should be able to:

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

Key points of any observations, raw data, graphical representations of them and calculated values should be given, leading to a clear indication of the strength or weakness of any conclusion reached. Such conclusions require detailed scientific explanations, the knowledge and understanding of which should be gained by candidates during the A Level course.

Where appropriate, candidates may be given the opportunity to ask questions based on their conclusions and thus to derive further predictions. Within familiar contexts and in relation to the evaluations they have made, candidates may be offered the opportunity to suggest how the investigation may be improved in order to increase the confidence in drawing conclusions.

5 General syllabus requirements and information

5.1 Mathematical requirements

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

- perform calculations involving addition, subtraction, multiplication and division of quantities
- make approximate evaluations of numerical expressions
- express fractions as percentages, and *vice versa*
- calculate an arithmetic mean
- convert numbers in decimal notation to standard form notation (scientific notation)
- use tables or calculators to evaluate logarithms (for pH calculations), squares, square 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
- understand and use the symbols/notations $<$, $>$, $\approx$, $/$, Δ, $\equiv$, $\bar{x}$ (or x)
- 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' linear model for a set of data presented graphically
- 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
- understand how to perform calculations so that significant figures are neither lost unnecessarily nor used beyond what is justified
- estimate orders of magnitude
- set up simple algebraic equations as mathematical models, e.g. construct a rate equation, and identify limitations of such models.

Calculators

If calculators are to be used, it is suggested that they should have the following functions:
$+$, $-$, $\times$, $\div$, $\sqrt{x}$, x^2, x^y, $\lg x$.

A memory function may be useful but is not essential.

5.2 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		
acid dissociation constant	K_a	as appropriate
atomic mass	m_a	kg
Avogadro constant	L	mol^{-1}
bond energy	–	kJ mol^{-1}
concentration	c	mol dm^{-3}
density	ρ	kg m^{-3}, g dm^{-3}, g cm^{-3}
electric potential difference	V	V
electromotive force (e.m.f.)	E	V
electron affinity	–	kJ mol^{-1}
enthalpy change of reaction	ΔH	J, kJ
entropy	S	J K^{-1}
equilibrium constant	K, K_p, K_c	as appropriate
Faraday constant	F	C mol^{-1}
frequency	ν, f	Hz
Gibbs free energy	G	J mol^{-1}
half-life	$T_{\frac{1}{2}}$, $t_{\frac{1}{2}}$	s
ionic product of water	K_w	$\text{mol}^2\,\text{dm}^{-6}$
ionic product	K, K_{sp}	as appropriate
ionisation energy	I	kJ mol^{-1}
lattice energy	ΔH_{latt}	kJ mol^{-1}
molar gas constant	R	$\text{J K}^{-1}\,\text{mol}^{-1}$

Quantity	Usual symbols	Usual unit
molar mass	M	kg mol^{-1}
mole fraction	x	–
molecular mass	m	kg
neutron number	N	–
nucleon (mass) number	A	–
number of molecules	N	–
number of molecules per unit volume	n	m^{-3}
order of reaction	n, m	–
partition coefficient	K_{pc}	–
pH	pH	–
Planck constant	h	J s
pressure	p	Pa
proton (atomic) number	Z	–
rate constant	k	as appropriate
relative atomic {isotopic} mass	A_r	–
relative molecular mass	M_r	–
solubility product	K_{sp}	as appropriate
speed of electromagnetic waves	c	m s^{-1}
(standard) electrode (reduction) potential	($E^\ominus$) E	V
standard enthalpy change of reaction	$\Delta H^\ominus$	J mol^{-1}, kJ mol^{-1}
temperature	θ, t	°C
volume	V, v	m^3, dm^3
wavelength	λ	m, mm, nm

5.3 Glossary of command words

This glossary should prove helpful to candidates as a guide, although it is not exhaustive and it has deliberately been kept brief. Candidates should understand that the meaning of a term must depend in part on its context. The number of marks allocated for any part of a question is a guide to the depth required for the answer.

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

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

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

In diagrams, *sketch* implies that a simple, freehand drawing is acceptable though care should be taken over proportions and the clear exposition of important details.

18 *Construct* is often used in relation to chemical equations where a candidate is expected to write a balanced equation, not by factual recall but by analogy or by using information in the question.

19 *Compare* requires candidates to provide both the similarities and differences between things or concepts.

20 *Classify* requires candidates to group things based on common characteristics.

5.4 Organic chemistry and analysis requirements

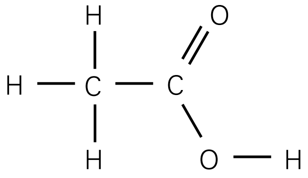
This section gives details of the terminology used when referring to organic structures, reactions and mechanisms.

Structural formulae

In candidates' answers, an acceptable response to a request for a structural formula will be to give the minimal detail, using conventional groups, for an unambiguous structure, e.g. $CH_3CH_2CH_2OH$ for propan-1-ol, not C_3H_7OH, and $CH_3CHCHCH_3$ for but-2-ene, not C_4H_8.

Displayed formulae

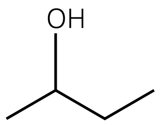
A displayed formula should show both the relative placing of atoms and the number of bonds between them, for example ethanoic acid below.

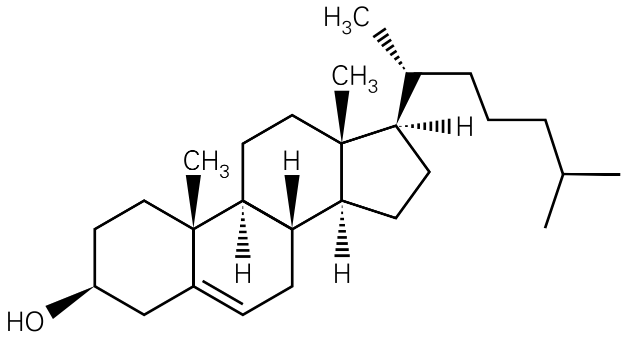


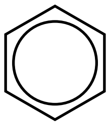
Skeletal formulae

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 below.

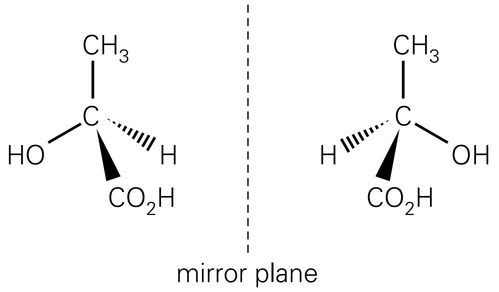




The  convention for representing the aromatic ring is preferred.

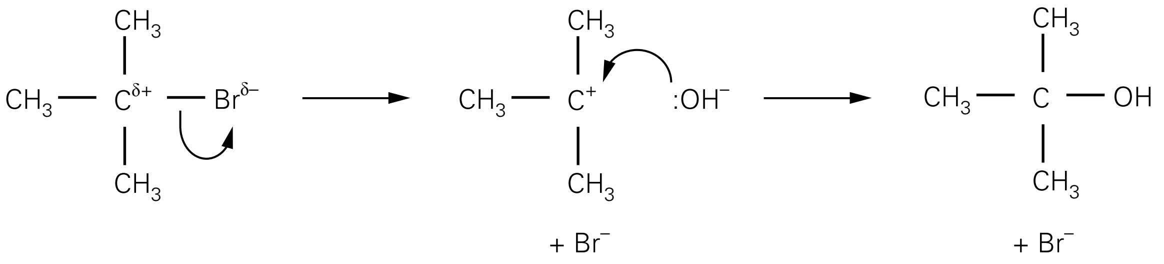
Optical isomers

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



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 below.



Reagents and conditions

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

5.5 Qualitative analysis notes

[Key: ppt. = precipitate]

1 Reactions of aqueous cations

cation	reaction with	
	$NaOH(aq)$	$NH_3(aq)$
aluminium, $Al^{3+}(aq)$	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, $NH_4^+(aq)$	no ppt. ammonia produced on heating	–
barium, $Ba^{2+}(aq)$	faint white ppt. is nearly always observed unless reagents are pure	no ppt.
calcium, $Ca^{2+}(aq)$	white ppt. with high $[Ca^{2+}(aq)]$	no ppt.
chromium(III), $Cr^{3+}(aq)$	grey-green ppt. soluble in excess	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

ion	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 ppt. with $Ag^+(aq)$ (partially soluble in $NH_3(aq)$)
iodide, $I^-(aq)$	gives yellow ppt. with $Ag^+(aq)$ (insoluble in $NH_3(aq)$)
nitrate, $NO_3^-(aq)$	NH_3 liberated on heating with $OH^-(aq)$ and Al foil
nitrite, $NO_2^-(aq)$	NH_3 liberated on heating with $OH^-(aq)$ and Al foil;
sulfate, $SO_4^{2-}(aq)$	gives white ppt. with $Ba^{2+}(aq)$ (insoluble in excess dilute strong acids)
sulfite, $SO_3^{2-}(aq)$	gives white ppt. with $Ba^{2+}(aq)$ (soluble in excess dilute strong acids)

3 Tests for gases

gas	test and test result
ammonia, NH_3	turns damp red litmus paper blue
carbon dioxide, CO_2	gives a white ppt. with limewater (ppt. dissolves with excess CO_2)
chlorine, Cl_2	bleaches damp litmus paper
hydrogen, H_2	'pops' with a lighted splint
oxygen, O_2	relights a glowing splint

5.6 Data Booklet

Pages 75 to 92 show the information that will be made available to candidates for papers 1, 2 and 4 in the Data Booklet.

Cambridge
International
AS & A Level

Data
Booklet

Cambridge International Advanced Subsidiary and Advanced Level in Chemistry (9701)

For use from 2016 in all papers for the above syllabus, except practical examinations.

CST314

8982009131

CAMBRIDGE
International Examinations

Contents: Tables of Chemical data

1 Important values, constants and standards

molar gas constant	$R = 8.31\ \mathrm{J\,K^{-1}\,mol^{-1}}$
the Faraday constant	$F = 9.65 \times 10^{4}\ \mathrm{C\,mol^{-1}}$
the Avogadro constant	$L = 6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
the Planck constant	$h = 6.63 \times 10^{-34}\ \mathrm{J\,s}$
speed of light in a vacuum	$c = 3.00 \times 10^{8}\ \mathrm{m\,s^{-1}}$
rest mass of proton, $^{1}_{1}\mathrm{H}$	$m_p = 1.67 \times 10^{-27}\ \mathrm{kg}$
rest mass of neutron, $^{1}_{0}\mathrm{n}$	$m_n = 1.67 \times 10^{-27}\ \mathrm{kg}$
rest mass of electron, $^{0}_{-1}\mathrm{e}$	$m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$
electronic charge	$e = -1.60 \times 10^{-19}\ \mathrm{C}$
molar volume of gas	$V_m = 22.4\ \mathrm{dm^{3}\,mol^{-1}}$ at s.t.p $V_m = 24.0\ \mathrm{dm^{3}\,mol^{-1}}$ under room conditions (where s.t.p. is expressed as 101 kPa, approximately, and 273 K (0 °C))
ionic product of water	$K_w = 1.00 \times 10^{-14}\ \mathrm{mol^{2}\,dm^{-6}}$ (at 298 K (25 °C))
specific heat capacity of water	$= 4.18\ \mathrm{kJ\,kg^{-1}\,K^{-1}}$ $(= 4.18\ \mathrm{J\,g^{-1}\,K^{-1}})$

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

	Proton number	First	Second	Third	Fourth
H	1	1310	–	–	–
He	2	2370	5250	–	–
Li	3	519	7300	11800	–
Be	4	900	1760	14800	21000
B	5	799	2420	3660	25000
C	6	1090	2350	4610	6220
N	7	1400	2860	4590	7480
O	8	1310	3390	5320	7450
F	9	1680	3370	6040	8410
Ne	10	2080	3950	6150	9290
Na	11	494	4560	6940	9540
Mg	12	736	1450	7740	10500
Al	13	577	1820	2740	11600
Si	14	786	1580	3230	4360
P	15	1060	1900	2920	4960
S	16	1000	2260	3390	4540
Cl	17	1260	2300	3850	5150
Ar	18	1520	2660	3950	5770
K	19	418	3070	4600	5860
Ca	20	590	1150	4940	6480
Sc	21	632	1240	2390	7110
Ti	22	661	1310	2720	4170
V	23	648	1370	2870	4600
Cr	24	653	1590	2990	4770
Mn	25	716	1510	3250	5190
Fe	26	762	1560	2960	5400
Co	27	757	1640	3230	5100
Ni	28	736	1750	3390	5400
Cu	29	745	1960	3350	5690
Zn	30	908	1730	3828	5980
Ga	31	577	1980	2960	6190
Br	35	1140	2080	3460	4850

	Proton number	First	Second	Third	Fourth
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
D–D	442
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$\overset{\cdots}{-}$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)

For ease of reference, two tables are given:

(a) an extended list in alphabetical order

(b) a shorter list in decreasing electrode potential, i.e. a redox series.

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

Electrode reaction	$E^\ominus$/V
$Ag^+ + e^- \rightleftharpoons Ag$	+0.80
$Al^{3+} + 3e^- \rightleftharpoons Al$	–1.66
$Ba^{2+} + 2e^- \rightleftharpoons Ba$	–2.90
$Br_2 + 2e^- \rightleftharpoons 2Br^-$	+1.07
$Ca^{2+} + 2e^- \rightleftharpoons Ca$	–2.87
$Cl_2 + 2e^- \rightleftharpoons 2Cl^-$	+1.36
$2HOCl + 2H^+ + 2e^- \rightleftharpoons Cl_2 + 2H_2O$	+1.64
$ClO^- + H_2O + 2e^- \rightleftharpoons Cl^- + 2OH^-$	+0.89
$Co^{2+} + 2e^- \rightleftharpoons Co$	–0.28
$Co^{3+} + e^- \rightleftharpoons Co^{2+}$	+1.82
$[Co(NH_3)_6]^{2+} + 2e^- \rightleftharpoons Co + 6NH_3$	–0.43
$Cr^{2+} + 2e^- \rightleftharpoons Cr$	–0.91
$Cr^{3+} + 3e^- \rightleftharpoons Cr$	–0.74
$Cr^{3+} + e^- \rightleftharpoons Cr^{2+}$	–0.41
$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O$	+1.33
$Cu^+ + e^- \rightleftharpoons Cu$	+0.52
$Cu^{2+} + 2e^- \rightleftharpoons Cu$	+0.34
$Cu^{2+} + e^- \rightleftharpoons Cu^+$	+0.15
$[Cu(NH_3)_4]^{2+} + 2e^- \rightleftharpoons Cu + 4NH_3$	–0.05
$F_2 + 2e^- \rightleftharpoons 2F^-$	+2.87
$Fe^{2+} + 2e^- \rightleftharpoons Fe$	–0.44
$Fe^{3+} + 3e^- \rightleftharpoons Fe$	–0.04
$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$	+0.77
$[Fe(CN)_6]^{3-} + e^- \rightleftharpoons [Fe(CN)_6]^{4-}$	+0.36
$Fe(OH)_3 + e^- \rightleftharpoons Fe(OH)_2 + OH^-$	–0.56
$2H^+ + 2e^- \rightleftharpoons H_2$	0.00
$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^-$	–0.83
$I_2 + 2e^- \rightleftharpoons 2I^-$	+0.54
$K^+ + e^- \rightleftharpoons K$	–2.92

Electrode reaction	$E^{\ominus}/V$
$Li^+ + e^- \rightleftharpoons Li$	–3.04
$Mg^{2+} + 2e^- \rightleftharpoons Mg$	–2.38
$Mn^{2+} + 2e^- \rightleftharpoons Mn$	–1.18
$Mn^{3+} + e^- \rightleftharpoons Mn^{2+}$	+1.49
$MnO_2 + 4H^+ + 2e^- \rightleftharpoons Mn^{2+} + 2H_2O$	+1.23
$MnO_4^- + e^- \rightleftharpoons MnO_4^{2-}$	+0.56
$MnO_4^- + 4H^+ + 3e^- \rightleftharpoons MnO_2 + 2H_2O$	+1.67
$MnO_4^- + 8H^+ + 5e^- \rightleftharpoons Mn^{2+} + 4H_2O$	+1.52
$NO_3^- + 2H^+ + e^- \rightleftharpoons NO_2 + H_2O$	+0.81
$NO_3^- + 3H^+ + 2e^- \rightleftharpoons HNO_2 + H_2O$	+0.94
$NO_3^- + 10H^+ + 8e^- \rightleftharpoons NH_4^+ + 3H_2O$	+0.87
$Na^+ + e^- \rightleftharpoons Na$	–2.71
$Ni^{2+} + 2e^- \rightleftharpoons Ni$	–0.25
$[Ni(NH_3)_6]^{2+} + 2e^- \rightleftharpoons Ni + 6NH_3$	–0.51
$H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O$	+1.77
$HO_2^- + H_2O + 2e^- \rightleftharpoons 3OH^-$	+0.88
$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O$	+1.23
$O_2 + 2H_2O + 4e^- \rightleftharpoons 4OH^-$	+0.40
$O_2 + 2H^+ + 2e^- \rightleftharpoons H_2O_2$	+0.68
$O_2 + H_2O + 2e^- \rightleftharpoons HO_2^- + OH^-$	–0.08
$Pb^{2+} + 2e^- \rightleftharpoons Pb$	–0.13
$Pb^{4+} + 2e^- \rightleftharpoons Pb^{2+}$	+1.69
$PbO_2 + 4H^+ + 2e^- \rightleftharpoons Pb^{2+} + 2H_2O$	+1.47
$SO_4^{2-} + 4H^+ + 2e^- \rightleftharpoons SO_2 + 2H_2O$	+0.17
$S_2O_8^{2-} + 2e^- \rightleftharpoons 2SO_4^{2-}$	+2.01
$S_4O_6^{2-} + 2e^- \rightleftharpoons 2S_2O_3^{2-}$	+0.09
$Sn^{2+} + 2e^- \rightleftharpoons Sn$	–0.14
$Sn^{4+} + 2e^- \rightleftharpoons Sn^{2+}$	+0.15
$V^{2+} + 2e^- \rightleftharpoons V$	–1.20
$V^{3+} + e^- \rightleftharpoons V^{2+}$	–0.26
$VO^{2+} + 2H^+ + e^- \rightleftharpoons V^{3+} + H_2O$	+0.34
$VO_2^+ + 2H^+ + e^- \rightleftharpoons VO^{2+} + H_2O$	+1.00
$VO_3^- + 4H^+ + e^- \rightleftharpoons VO^{2+} + 2H_2O$	+1.00
$Zn^{2+} + 2e^- \rightleftharpoons Zn$	–0.76

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

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

(a selection only – see also the extended alphabetical list on the previous pages)

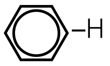
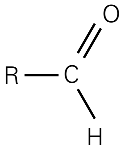
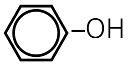
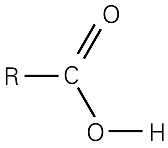
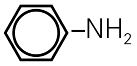
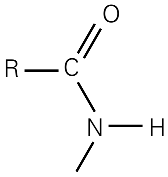
Electrode reaction			$E^\ominus$/V
$F_2 + 2e^-$	$\rightleftharpoons$	$2F^-$	+2.87
$S_2O_8^{2-} + 2e^-$	$\rightleftharpoons$	$2SO_4^{2-}$	+2.01
$H_2O_2 + 2H^+ + 2e^-$	$\rightleftharpoons$	$2H_2O$	+1.77
$MnO_4^- + 8H^+ + 5e^-$	$\rightleftharpoons$	$Mn^{2+} + 4H_2O$	+1.52
$PbO_2 + 4H^+ + 2e^-$	$\rightleftharpoons$	$Pb^{2+} + 2H_2O$	+1.47
$Cl_2 + 2e^-$	$\rightleftharpoons$	$2Cl^-$	+1.36
$Cr_2O_7^{2-} + 14H^+ + 6e^-$	$\rightleftharpoons$	$2Cr^{3+} + 7H_2O$	+1.33
$O_2 + 4H^+ + 4e^-$	$\rightleftharpoons$	$2H_2O$	+1.23
$Br_2 + 2e^-$	$\rightleftharpoons$	$2Br^-$	+1.07
$ClO^- + H_2O + 2e^-$	$\rightleftharpoons$	$Cl^- + 2OH^-$	+0.89
$NO_3^- + 10H^+ + 8e^-$	$\rightleftharpoons$	$NH_4^+ + 3H_2O$	+0.87
$NO_3^- + 2H^+ + e^-$	$\rightleftharpoons$	$NO_2 + H_2O$	+0.81
$Ag^+ + e^-$	$\rightleftharpoons$	Ag	+0.80
$Fe^{3+} + e^-$	$\rightleftharpoons$	Fe^{2+}	+0.77
$I_2 + 2e^-$	$\rightleftharpoons$	$2I^-$	+0.54
$O_2 + 2H_2O + 4e^-$	$\rightleftharpoons$	$4OH^-$	+0.40
$Cu^{2+} + 2e^-$	$\rightleftharpoons$	Cu	+0.34
$SO_4^{2-} + 4H^+ + 2e^-$	$\rightleftharpoons$	$SO_2 + 2H_2O$	+0.17
$Sn^{4+} + 2e^-$	$\rightleftharpoons$	Sn^{2+}	+0.15
$S_4O_6^{2-} + 2e^-$	$\rightleftharpoons$	$2S_2O_3^{2-}$	+0.09
$2H^+ + 2e^-$	$\rightleftharpoons$	H_2	0.00
$Pb^{2+} + 2e^-$	$\rightleftharpoons$	Pb	–0.13
$Sn^{2+} + 2e^-$	$\rightleftharpoons$	Sn	–0.14
$Fe^{2+} + 2e^-$	$\rightleftharpoons$	Fe	–0.44
$Zn^{2+} + 2e^-$	$\rightleftharpoons$	Zn	–0.76
$2H_2O + 2e^-$	$\rightleftharpoons$	$H_2 + 2OH^-$	–0.83
$V^{2+} + 2e^-$	$\rightleftharpoons$	V	–1.20
$Mg^{2+} + 2e^-$	$\rightleftharpoons$	Mg	–2.38
$Ca^{2+} + 2e^-$	$\rightleftharpoons$	Ca	–2.87
$K^+ + e^-$	$\rightleftharpoons$	K	–2.92

5 Atomic and ionic radii

(a) Period 1	**atomic/nm**		**ionic/nm**			
single covalent	H	0.037	H^-	0.208		
van der Waals	He	0.140				
(b) Period 2						
metallic	Li	0.152	Li^+	0.060		
	Be	0.112	Be^{2+}	0.031		
single covalent	B	0.080	B^{3+}	0.020		
	C	0.077	C^{4+}	0.015	C^{4-}	0.260
	N	0.074			N^{3-}	0.171
	O	0.073			O^{2-}	0.140
	F	0.072			F^-	0.136
van der Waals	Ne	0.160				
(c) Period 3						
metallic	Na	0.186	Na^+	0.095		
	Mg	0.160	Mg^{2+}	0.065		
	Al	0.143	Al^{3+}	0.050		
single covalent	Si	0.117	Si^{4+}	0.041	Si^{4-}	0.271
	P	0.110			P^{3-}	0.212
	S	0.104			S^{2-}	0.184
	Cl	0.099			Cl^-	0.181
van der Waals	Ar	0.190				
(d) Group 2						
metallic	Be	0.112	Be^{2+}	0.031		
	Mg	0.160	Mg^{2+}	0.065		
	Ca	0.197	Ca^{2+}	0.099		
	Sr	0.215	Sr^{2+}	0.113		
	Ba	0.217	Ba^{2+}	0.135		
	Ra	0.220	Ra^{2+}	0.140		

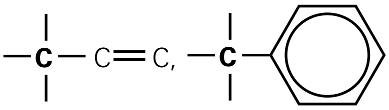
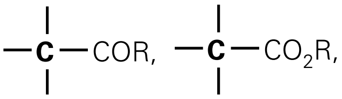
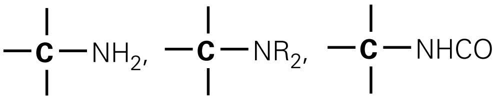
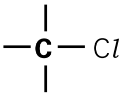
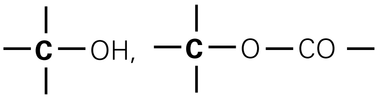
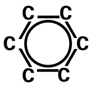
(e) Group 14	**atomic/nm**		**ionic/nm**			
single covalent	C	0.077				
	Si	0.117	Si^{4+}	0.041		
	Ge	0.122	Ge^{2+}	0.093		
metallic	Sn	0.162	Sn^{2+}	0.112		
	Pb	0.175	Pb^{2+}	0.120		
(f) Group 17						
single covalent	F	0.072	F^{-}	0.136		
	Cl	0.099	Cl^{-}	0.181		
	Br	0.114	Br^{-}	0.195		
	I	0.133	I^{-}	0.216		
	At	0.140				
(g) First row d-block elements						
metallic	Sc	0.164			Sc^{3+}	0.081
	Ti	0.146	Ti^{2+}	0.090	Ti^{3+}	0.067
	V	0.135	V^{2+}	0.079	V^{3+}	0.064
	Cr	0.129	Cr^{2+}	0.073	Cr^{3+}	0.062
	Mn	0.132	Mn^{2+}	0.067	Mn^{3+}	0.062
	Fe	0.126	Fe^{2+}	0.061	Fe^{3+}	0.055
	Co	0.125	Co^{2+}	0.078	Co^{3+}	0.053
	Ni	0.124	Ni^{2+}	0.070	Ni^{3+}	0.056
	Cu	0.128	Cu^{2+}	0.073		
	Zn	0.135	Zn^{2+}	0.075		

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

Type of proton	Environment of proton	Example structures	Chemical shift range (δ)
C–H	alkane	$-CH_3$, $-CH_2-$, $>CH-$	0.9–1.7
	alkyl next to C=O	$CH_3-C=O$, $-CH_2-C=O$, $>CH-C=O$	2.2–3.0
	alkyl next to aromatic ring	CH_3-Ar, $-CH_2-Ar$, $>CH-Ar$	2.3–3.0
	alkyl next to electronegative atom	CH_3-O, $-CH_2-O$, $-CH_2-Cl$, $>CH-Br$	3.2–4.0
	attached to alkyne	$\equiv C-H$	1.8–3.1
	attached to alkene	$=CH_2$, $=CH-$	4.5–6.0
	attached to aromatic ring		6.0–9.0
	aldehyde		9.3–10.5
O–H (see note below)	alcohol	RO–H	0.5–6.0
	phenol		4.5–7.0
	carboxylic acid		9.0–13.0
N–H (see note below)	alkyl amine	R–NH–	1.0–5.0
	aryl amine		3.0–6.0
	amide		5.0–12.0

Note: δ values for O–H and N–H protons can vary depending on solvent and concentration.

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

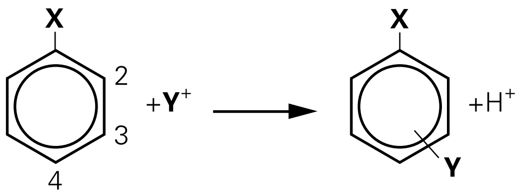
Hybridisation of the carbon atom	Environment of carbon atom	Example structures	Chemical shift range (δ)
sp^3	alkyl	$\mathbf{C}H_3-$, $\mathbf{C}H_2-$, $-\mathbf{C}H<$, $>\mathbf{C}<$	0–50
sp^3	next to alkene/arene	 $-\overset{\vert}{\underset{\vert}{\mathbf{C}}}-C{=}C$,	10–40
sp^3	next to carbonyl/carboxyl	 $-\overset{\vert}{\underset{\vert}{\mathbf{C}}}-COR$, $-\overset{\vert}{\underset{\vert}{\mathbf{C}}}-CO_2R$,	25–50
sp^3	next to nitrogen	 $-\overset{\vert}{\underset{\vert}{\mathbf{C}}}-NH_2$, $-\overset{\vert}{\underset{\vert}{\mathbf{C}}}-NR_2$, $-\overset{\vert}{\underset{\vert}{\mathbf{C}}}-NHCO$	30–65
sp^3	next to chlorine ($-CH_2-Br$ and $-CH_2-I$ are in the same range as alkyl)	 $-\overset{\vert}{\underset{\vert}{\mathbf{C}}}-Cl$	30–60
sp^3	next to oxygen	 $-\overset{\vert}{\underset{\vert}{\mathbf{C}}}-OH$, $-\overset{\vert}{\underset{\vert}{\mathbf{C}}}-O-CO-$	50–70
sp^2	alkene or arene	$>\mathbf{C}{=}\mathbf{C}<$, 	110–160
sp^2	carboxyl	$R-\mathbf{C}O_2H$, $R-\mathbf{C}O_2R$	160–185
sp^2	carbonyl	$R-\mathbf{C}HO$, $R-\mathbf{C}O-R$	190–220
sp	alkyne	$R-\mathbf{C}{\equiv}\mathbf{C}-$	65–85
sp	nitrile	$R-\mathbf{C}{\equiv}N$	100–125

8 Characteristic infra-red absorption frequencies for some selected bonds

Bond	Functional groups containing the bond	Absorption range (in wavenumbers)/cm^{-1}	Appearance of peak (*s = strong, w = weak*)
C–O	alcohols, ethers, esters	1040–1300	***s***
C=C	aromatic compounds, alkenes	1500–1680	***w*** unless conjugated
C=O	amides ketones and aldehydes carboxylic acids esters	1640–1690 1670–1740 1680–1730 1710–1750	***s*** ***s*** ***s*** ***s***
C≡C	alkynes	2150–2250	***w*** unless conjugated
C≡N	nitriles	2200–2250	***w***
C–H	alkanes, CH_2–H alkenes/arenes, =C–H	2850–2950 3000–3100	***s*** ***w***
N–H	amines, amides	3300–3500	***w***
O–H	carboxylic acids, RCO_2–H H-bonded alcohol, RO–H free alcohol, RO–H	2500–3000 3200–3600 3580–3650	***s*** and very broad ***s*** ***s*** and sharp

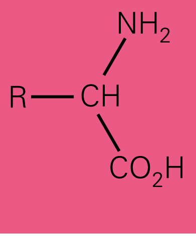
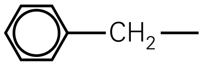
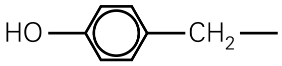
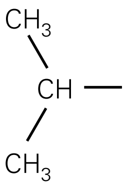
9 The orientating effect of groups in aromatic substitution reactions.

The position of the incoming group, **Y**, is determined by the nature of the group, **X**, already bonded to the ring, and not by the nature of the incoming group **Y**.



X– groups that direct the incoming Y group to the 2– or 4– positions	X– groups that direct the incoming Y group to the 3– position
$–NH_2$, –NHR or $–NR_2$	$–NO_2$
–OH or –OR	$–NH_3^+$
–NHCOR	–CN
$–CH_2$, –alkyl	–CHO, –COR
–C*l*	$–CO_2H$, $–CO_2R$

10 Names, structures and abbreviations of some amino acids

Name	**3-letter abbreviation**	**1-letter symbol**	**structure of side chain R– in** 
alanine	Ala	A	CH_3–
aspartic acid	Asp	D	HO_2CCH_2–
cysteine	Cys	C	$HSCH_2$–
glutamic acid	Glu	E	$HO_2CCH_2CH_2$–
glycine	Gly	G	H–
lysine	Lys	K	$H_2NCH_2CH_2CH_2CH_2$–
phenylalanine	Phe	F	
serine	Ser	S	$HOCH_2$–
tyrosine	Tyr	Y	
valine	Val	V	

The Periodic Table of Elements

Key

atomic number
atomic symbol
name
relative atomic mass

Group

1	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 –		114 Fl flerovium –		116 Lv livermorium –		

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 –

6 Other information

Equality and inclusion

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

The standard assessment arrangements may present unnecessary barriers for candidates with disabilities or learning difficulties. Arrangements can be put in place for these candidates to enable them to access the assessments and receive recognition of their attainment. Access arrangements will not be agreed if they give candidates an unfair advantage over others or if they compromise the standards being assessed. Candidates who are unable to access the assessment of any component may be eligible to receive an award based on the parts of the assessment they have taken.

Information on access arrangements is found in the *Cambridge Handbook*, which can be downloaded from the website **www.cie.org.uk/examsofficers**

Language

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

Grading and reporting

Cambridge International A Level results are shown by one of the grades A*, A, B, C, D or E, indicating the standard achieved, A* being the highest and E the lowest. 'Ungraded' indicates that the candidate's performance fell short of the standard required for grade E. 'Ungraded' will be reported on the statement of results but not on the certificate. The letters Q (result pending), X (no result) and Y (to be issued) may also appear on the statement of results but not on the certificate.

Cambridge International AS Level results are shown by one of the grades a, b, c, d or e, indicating the standard achieved, 'a' being the highest and 'e' the lowest. 'Ungraded' indicates that the candidate's performance fell short of the standard required for grade 'e'. 'Ungraded' will be reported on the statement of results but not on the certificate. The letters Q (result pending), X (no result) and Y (to be issued) may also appear on the statement of results but not on the certificate.

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

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

Entry option codes

To maintain the security of our examinations, we produce question papers for different areas of the world, known as 'administrative zones'. Where the entry option code has two digits, the first digit is the component number given in the syllabus. The second digit is the location code, specific to an administrative zone.

Entry option codes and instructions for making entries can be found in the *Cambridge Guide to Making Entries*. Other exams administration documents, including timetables and administrative instructions, can be found at **www.cie.org.uk/examsofficers**

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