

Cambridge Pre-U Syllabus

Cambridge  
**Pre-U**

Cambridge International Level 3  
Pre-U Certificate in  
**CHEMISTRY**

For examination in 2013, 2014 and 2015



UNIVERSITY of CAMBRIDGE  
International Examinations



# Chemistry (9791)

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

For examination in 2013, 2014 and 2015

**QN 500/3683/X**

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**Cambridge International Level 3 Pre-U Certificate**

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**Chemistry****9791****Contents**

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## Introduction

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Cambridge Pre-U syllabuses aim to equip students with the skills required to make a success of their subsequent studies at university, involving not only a solid grounding in each specialist subject at an appropriate level, but also the ability to undertake independent and self-directed learning and to think laterally, critically and creatively. The Cambridge Pre-U curriculum is underpinned by a core set of educational principles:

- A programme of study which supports the development of well-informed, open and independent-minded individuals, capable of applying their skills to meet the demands of the world as they will find it and over which they may have influence.
- A curriculum which retains the integrity of subject specialisms and which can be efficiently, effectively and reliably assessed, graded and reported to meet the needs of universities.
- A curriculum which is designed to recognise a wide range of individual talents, interests and abilities and which provides the depth and rigour required for a university degree course.
- A curriculum which encourages the acquisition of specific skills and abilities, in particular the skills of problem solving, creativity, critical thinking, team working and effective communication.
- The encouragement of 'deep understanding' in learning – where that deep understanding is likely to involve higher order cognitive activities.
- The development of a perspective which equips young people to understand a range of different cultures and ideas and to respond successfully to the opportunity for international mobility.

All Cambridge Pre-U Principal Subject syllabuses are linear. A candidate taking a Principal Subject must take all the components together at the end of the course in one examination session.

Reflecting the constantly advancing state of scientific knowledge, Cambridge Pre-U science syllabuses have been designed to allow incorporation of cutting-edge science. Students will be able to bring with them, and build on, the knowledge and understanding gained in their earlier science courses.

Cambridge Pre-U science syllabuses aim to develop and nurture in students a philosophy of evidence-based thinking and instil in them a notion of inquisitiveness and delight in exploring a topic further on their own. The assessments foster practical approaches to problem solving that engender an appreciation of the need for accuracy and precision when working with data.

In summary, the Cambridge Pre-U science suite should invoke in students a passion for science, and encourage reflection on the nature, history and philosophy of science.

Chemistry, being the central science and being a mature science, has largely become a collaborative subject for the emerging fields of molecular genetics, biotechnology, materials, semiconductors and nanotechnology. As such, chemists are often needed to solve problems and synthesise molecules in these areas, and it is in this light that chemistry should be taught in schools – problem solving in varied contexts. Chemists need to be able to do things and solve problems (practical and theoretical). Hence the need for the learning of key concepts in the course, so that students are equipped with the necessary skills to characterise molecules, make meaningful predictions or calculate useful quantities. While students should be exposed to modern applications in the teaching of chemistry, it should not be the aim simply to learn

them. With the rate of new developments in science, it is imperative to know the fundamentals on which future breakthroughs will be based, rather than just learning facts about what is current.

Chemistry is too often seen as a large body of facts that defies straightforward rationalisation. Such ideas can be reinforced by modular examination questions that concentrate on the particular without relation to the wider subject. This course, which is written with progression to university chemistry in mind, highlights the principles that unify the subject and seeks to examine them through their application to chemical situations.

By introducing the student to the big ideas of chemistry and some modern applications, the framework allows the interested and independent candidate to take the subject further with confidence. The subject content has also been chosen to facilitate the setting of substantial chemical problems to solve. These problems should serve to motivate students as well as to discriminate between them.

This course places an emphasis on the appreciation of three-dimensional structure. It is an intellectual challenge that is worth pursuing if one is truly to appreciate the way chemical systems work. It is fundamental to the subject at so many levels and brings to life some of the abstractions that are met in theory.

Chemistry is a practical subject and the acquisition of practical skills must be central to any course. These skills are most rigorously and fairly tested in a practical examination. Microscale practical work is becoming increasingly relevant and has many advantages; its introduction to students in some of their experimental work during the course is encouraged. It is not compulsory and will not be examined.

It is not the intention of this course to prescribe how teachers must teach: that is left to their professional judgement. It is also not the intention to fix the context in which the chemistry is presented, since teachers will have their own preferred applications. The main intention is to provide interesting and challenging questions, which demand problem-solving skills and genuine chemical skills. Context and applications, and the associated teaching resources will be provided in resources prepared for the course.

In realising the aims of the course it has been necessary to introduce new approaches and material not covered by other qualifications into the syllabus. This material provides an essential framework for appreciating the subject as a whole and furnishes the student with valuable methods for solving chemical problems. Some of this material may be unfamiliar to teachers first encountering this course. An explanation of why this material was chosen and its importance to the study of chemistry at this level is given in Curriculum content under the title Totally new topics. Resource material explaining these topics and how they may be taught will be provided separately.

### **Prior knowledge and progression**

The syllabus builds on the knowledge, understanding and skills typically gained by candidates taking Level 2 (IGCSE, GCSE, O Level) qualifications in Chemistry, Dual Award Science or Additional Science.

It is recommended that candidates have attained communication and literacy skills at a level equivalent to IGCSE/GCSE/O Level Grade C in English.

The course will equip candidates with a coherent theoretical and practical base of transferable skills and key knowledge suitable for future study and employment in chemistry and related fields (e.g. medicine, engineering, applied sciences) whilst providing thought-provoking material that may appeal to those who do not wish to pursue a scientific career.



## Aims

The purpose of this syllabus is to enable Centres to develop courses that will:

- Equip students with the principles with which they can make sense of the large body of chemical knowledge and enable them to develop an understanding of and insight into chemical reactions and structure.
- Develop students' skills in solving chemical problems and rationalising unfamiliar material.
- Expose students to modern applications of the subject, as determined by the teacher to be most relevant to their environment and interests.
- Develop students' understanding of the link between theory and experiment and foster the development of skills required for the design and evaluation of experiments.
- Instil in students a sense of safe laboratory practice and equip them with the necessary laboratory skills to pursue the subject beyond this course.
- Foster the development of attitudes relevant to science, such as a concern for accuracy and precision, objectivity, integrity and the skills of enquiry, initiative and inventiveness.
- Promote an awareness of the use and development of scientific models.
- Provide the tools for students to learn and analyse independently, and to develop an informed interest in major scientific issues.
- Develop transferable skills applicable to the study and communication of science.
- Develop an understanding of the links between chemistry and other scientific and technological subjects.
- Promote an awareness that chemistry is a cooperative and cumulative activity, subject to technological, economic, historical, cultural, social and ethical factors.
- Promote the value of chemistry to society and stimulate interest in, and care for, the environment in relation to the impact of chemical science and its applications.

## Scheme of assessment

For the Principal Cambridge Pre-U qualification in Chemistry, candidates take four components in the same session.

| Component | Component title                 | Duration              | Weighting (%) | Type of assessment                           |
|-----------|---------------------------------|-----------------------|---------------|--|
| 1         | Part A<br>Multiple choice paper | 1 hour                | 15            | Externally set and marked                    |
| 2         | Part A Written paper            | 2 hours<br>15 minutes | 35            | Externally set and marked                    |
| 3         | Part B Written paper            | 2 hours<br>15 minutes | 35            | Externally set and marked                    |
| 4         | Practical assessment            | 2 hours               | 15            | Practical exam,<br>externally set and marked |

## Assessment objectives

|            |  |
|------------|--|
| <b>AO1</b> | <b>Knowledge with understanding</b> <p>Candidates will be expected to demonstrate knowledge and understanding in relation to:</p> <ul style="list-style-type: none"><li>• Chemical phenomena, principles, concepts, laws, theories, models, relationships, facts, quantities and definitions.</li><li>• Chemistry vocabulary, terminology, conventions, symbols and units.</li><li>• Chemistry laboratory apparatus and its use.</li></ul> <p>The curriculum content of the syllabus defines the factual knowledge that candidates may be required to recall and explain.</p>  |
| <b>AO2</b> | <b>Analysis and application</b> <p>Candidates will be expected to:</p> <ul style="list-style-type: none"><li>• Handle and interpret unfamiliar information.</li><li>• Translate information from one form into another.</li><li>• Identify patterns, report trends, draw inferences, construct arguments and report conclusions from unfamiliar data.</li><li>• Use skills, knowledge and understanding from different areas of chemistry to solve problems in unfamiliar contexts or to explain chemical phenomena.</li><li>• Demonstrate competence in processing numbers, mathematical functions and algebraic quantities.</li></ul> <p>This assessment objective relates primarily to unfamiliar data, phenomena or situations which, by definition, cannot be listed in the curriculum content of the syllabus.</p> |
| <b>AO3</b> | <b>Practical skills</b> <p>Candidates will be expected to:</p> <ul style="list-style-type: none"><li>• Make predictions and hypotheses.</li><li>• Plan investigations.</li><li>• Use practical techniques skilfully and safely.</li><li>• Make and record observations and estimates methodically and with due regard for precision, accuracy and units.</li><li>• Manipulate and analyse raw data, including by graphical methods.</li><li>• Draw appropriate conclusions supported by evidence.</li><li>• Evaluate experimental method and suggest improvements.</li></ul>   |

## Relationship between scheme of assessment and assessment objectives

The table gives the approximate number of marks allocated to each assessment objective in each paper and the percentage of marks allocated to each assessment objective across the whole assessment.

| Assessment objective | Component 1 (marks) | Component 2 (marks) | Component 3 (marks) | Component 4 (marks) | Whole assessment (%) |
|----------------------|---------------------|---------------------|---------------------|---------------------|----------------------|
| <b>AO1</b>           | 20                  | 40                  | 50                  | 0                   | 40                   |
| <b>AO2</b>           | 20                  | 40                  | 50                  | 0                   | 40                   |
| <b>AO3</b>           | 0                   | 20                  | 0                   | 40                  | 20                   |
| <b>Total</b>         | 40                  | 100                 | 100                 | 40                  | 280 / 100            |

## Description of components

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### Contexts for questions in written papers

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

### Written papers

Component 1 is a multiple choice paper consisting of 40 questions which will involve choosing a single correct answer from a choice of four.

Component 2 involves long structured questions totalling 100 marks. The questions will contain many parts, most parts involving short answers or calculations with some longer answers. Candidates should expect the questions to cross the boundaries of the different fields of chemistry covered in Part A of the Curriculum content, to require application of Part A knowledge and skills to unfamiliar contexts, and to require an appreciation of the practical side of the subject. One or more questions will require candidates to plan practical work, manipulate and evaluate experimental data and show insight into laboratory procedures.

Component 3 involves long structured questions totalling 100 marks, i.e. the questions will contain many parts, most parts involving short answers or calculations with some longer answers. The questions will focus on Part B topics but will cross the boundaries of the different fields of chemistry and potentially cover the entire syllabus.

The Data booklet (see Appendix 3) will be available to candidates for all three written components.

### Practical assessment

Component 4 will involve a question on qualitative analysis and one or more questions on quantitative analysis, totalling 40 marks. The latter may involve a volumetric problem requiring titration, the measurement of enthalpy changes or reaction rate, thermometric titration or a gravimetric exercise. The Data booklet (Appendix 3), which includes Qualitative analysis notes, will be available to candidates. As well as manipulative skills, candidates will be assessed on how they record observations, manipulate and analyse their experimental data, and evaluate experimental technique. Further details can be found in Appendix 1.

There will be a practical component to the Component 2, which will involve planning an experiment, manipulating and evaluating data, and showing insight into laboratory procedures.

## Nomenclature

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

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

## Curriculum content

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The sections of the syllabus are divided into Part A and Part B topics, which indicate whether the material is examined in Papers 1 and 2 (Part A) or in Paper 3 (Parts A and B).

### Totally new topics

Attention is drawn to a number of totally new topics within the syllabus, which have not been examined at this level before. These new topics should allow candidates to develop an important insight into chemical processes and should help to rationalise new and unfamiliar compounds and reactions. **Resource materials will be provided especially for these topics.**

- **Van Arkel diagrams.** These diagrams put all binary compounds, be they ionic, covalent, giant covalent, metallic or semiconducting, on a single graph which explains their bonding type in terms of the difference in electronegativity and the average electronegativity of their constituent elements. It thus unifies all the chemical bonding types through an easily comprehensible concept.
- **Functional group level.** This idea provides a simple framework through which a vast number of organic reactions can be understood: simply the number of bonds from a carbon atom to an electronegative element. Functional groups can be classified very simply by this scheme and so reactions between functional groups can thus immediately be understood as reduction, oxidation, or a reaction within a level, such as substitution, hydrolysis or condensation.
- **Carbon-13 NMR.** This is the best technique with which to approach NMR since the spectra are routinely decoupled, and chemical shift values are predictable. As a result, questions can consider more complex and interesting molecules, where a greater emphasis can be placed on equivalent environments in molecules. Protons will be considered on an equal footing with other spin  $\frac{1}{2}$  nuclei such as  $^{19}\text{F}$  (given sufficient information in questions).
- **Antibonding molecular orbitals.** These high-energy orbitals are introduced at the simplest possible level: that the associated electron density lies outside the internuclear region and that therefore their occupancy weakens the bonding. There is no requirement to appreciate their formation from the linear combination of atomic orbitals. An appreciation that these vacant orbitals exist is vital for a proper understanding of molecular electronic spectroscopy and for understanding mechanism in further study. There is, however, little scope for examining this concept at this level.

## 1. Physical chemistry

### Preamble

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

It is recommended that candidates apply ideas from this section to the following or other relevant contexts:

- unfamiliar atoms and molecules, from which information about structure and physical properties may be inferred
- the discovery of new elements
- spectacularly exothermic reactions such as those propelling rockets
- indirect determination of enthalpy changes, e.g. photosynthesis
- hydrogen bonding and surface tension – walking on water
- equilibrium conditions in large-scale industrial processes
- catalysts in large-scale industrial processes – lowering of energy consumption
- everyday catalysts, e.g. catalytic converters, washing powders
- immobilisation of enzymes to increase efficiency, e.g. lactose hydrolysis in cat-milk manufacture
- commercial batteries and fuel cells

Note that candidates are provided with the relevant equations in the Data booklet.

### Part A

#### A1.0 Assumed knowledge

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

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

**A1.1 Atomic structure****Content**

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

Candidates should be able to:

- (a) recall the relationship between shell number and number of subshells
- (b) recognise an orbital as a mathematical function giving rise to a probability distribution, as illustrated by orbitals such as 1s, 2s, 2p<sub>x</sub> etc. (no knowledge of orbitals from f or higher subshells is required.)
- (c) draw the approximate shapes of the s, p and d orbitals
- (d) describe qualitatively the relative energies of the s, p, d and f subshells within a principal shell and describe the concept of shielding in multi-electron atoms
- (e) recall that all electrons possess spin and that electrons are spin-paired in orbitals
- (f) apply the aufbau principle
- (g) state the ground state electronic configurations of the first 36 elements and any common ion using conventional notation and shorthand (e.g. [Ar] 4s<sup>2</sup> for Ca) given proton number and charge
- (h) describe the ground state configuration of electrons in a subshell using electron-in-box notation
- (i) explain the variation of atomic radii, ionic radii, first ionisation energies and electronegativities down groups and across the third period in terms of shell number, nuclear charge and shielding; explain the effect of ionisation on atomic radius
- (j) understand and use the relationship between group number and successive ionisation energies; write equations for successive ionisation energies.

**A1.2 Chemical forces****Content**

- molecular bonding and antibonding orbitals
- $\sigma$  and  $\pi$  bonds, bond order
- molecular shape and bond angles
- intermolecular forces

Candidates should be able to:

- (a) use dot-cross diagrams to describe ionic and covalent bonding, including dative covalent bonding
- (b) understand that electrons occupy orbitals in molecules as well as atoms; understand that putting electrons into a bonding orbital leads to the nuclei being held together (i.e. bonded) whereas putting electrons into an antibonding orbital weakens bonding by pulling the nuclei apart from one another (as these orbitals lie outside the internuclear region)
- (c) understand that the strength of the covalent bond can be related to the extent to which the energy of the bonding molecular orbital is lowered relative to the atomic orbitals
- (d) understand how  $\sigma$  and  $\pi$  bonds result from overlap of atomic orbitals
- (e) appreciate the relative strengths of  $\sigma$  and  $\pi$  bonds



- (f) understand the concept of bond order and its qualitative relationship to bond length and strength
- (g) deduce the shapes and bond angles of simple molecules and ions (typified by examples such as  $\text{BF}_3$ ,  $\text{CH}_4$ ,  $\text{NH}_3$ ,  $\text{H}_2\text{O}$ ,  $\text{CO}_2$ ,  $\text{C}_2\text{H}_4$ ,  $\text{CH}_3^+$ ) and hypervalent species (typified by examples such as  $\text{PCl}_5$ ,  $\text{SF}_6$ ,  $\text{IF}_7$ ,  $\text{XeO}_4$ ,  $\text{PCl}_4^+$ ) using the VSEPR model
- (h) deduce changes in geometry and bond angle during chemical reaction, e.g. protonation of ammonia, addition to double bonds
- (i) describe the concept of electronegativity and its use in predicting bond dipoles
- (j) describe van der Waals forces (all intermolecular forces weaker than hydrogen-bonds) in terms of instantaneous, permanent and induced dipoles and the increase of these forces with polarisability
- (k) describe hydrogen bonding as a special case of a dipole-dipole interaction and its influence on the structure of ice and the anomalous properties of water; outline its importance in base-pairing in the double helix of DNA (structure of DNA bases is not required)
- (l) understand the importance of van der Waals forces and hydrogen bonding in determining protein structure (recall of alpha helix and beta sheet structures is not required).

### A1.3 Energy changes

#### Content

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

Candidates should be able to:

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

## Part B

**B1.4 Free energy and entropy****Content**

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

Candidates should be able to:

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

**B1.5 Equilibrium****Content**

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

Candidates should be able to:

- state Le Chatelier's principle and apply it to deduce qualitatively the effects of changes in temperature, concentration or pressure on a system at equilibrium
- describe weak acids and alkalis in terms of equilibria; describe the Brønsted-Lowry theory of acids, including conjugate pairs; describe the Lewis theory of acids and bases
- understand that equilibrium constant expressions take the form outlined in Equation 4 of the Data booklet, and apply this to  $K_c$
- understand that in the case of  $K_p$  only gas phase constituents are included in the equilibrium constant expression, that in the case of  $K_{sp}$  solids are omitted, and that in the case of  $K_a$  and  $K_w$  the solvent is omitted
- calculate quantities based on equilibrium constant expressions

- (f) define pH and determine pH for strong and weak acids (solving of quadratic equations not required); understand how  $pK_a$  is a measure of acid strength
- (g) describe and explain the change in pH during strong/weak acid-base titrations and explain the choice of indicator
- (h) understand and explain how simple buffer solutions work; calculate the pH of buffer solutions
- (i) calculate quantities of substances involved during electrolysis using the Faraday constant (given in the Data Booklet)
- (j) understand the concept of redox with reference to oxidation number; deduce unfamiliar half-equations and construct redox equations from the relevant half-equations
- (k) understand the concept of standard electrode potential and describe the standard hydrogen electrode
- (l) describe methods used to measure standard electrode potentials of: (i) metals or non-metals in contact with their ions in aqueous solution, and (ii) ions of the same element in different oxidation states
- (m) calculate standard cell potential from standard electrode potentials
- (n) understand the link between the standard cell potential and the standard Gibbs energy change and use Equation 5 in the Data booklet
- (o) deduce the direction of electron flow in an electrochemical cell and therefore the feasible direction of reaction using cell potentials
- (p) understand how the cell potential changes from its standard value during the course of a reaction in an electrochemical cell and approaches zero as equilibrium is approached; interpret the variation of the cell potential as the concentrations of the solutions change using Le Chatelier's principle (knowledge of the Nernst equation is not required)
- (q) describe the hydrogen/oxygen fuel cell.

## B1.6 Gases and kinetics

### Content

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

Candidates should be able to:

- (a) state the assumptions of the kinetic theory applied to an ideal gas and understand their limitations
- (b) state Boyle's law and Charles's law and use the ideal gas equation,  $pV=nRT$  (Equation 6 in the Data booklet)
- (c) explain the dependence of the rate of reaction on the activation energy of the reaction and temperature in terms of the Boltzmann distribution of molecular energies
- (d) rationalise the rate constant as the product of collision frequency (per unit concentration), the steric factor and a Boltzmann term; use the Arrhenius equation (Equation 7 in the Data booklet)
- (e) describe the homogeneous and heterogeneous modes of catalytic activity and that it is the shape of the active site in enzymes that is central to their function and makes them highly specific

- (f) understand how rate equations are based on experimental data; deduce the orders and overall order of reaction from a rate equation; deduce the molecularity of a given step; deduce the units of rate of reaction, and of rate constants for different orders of reaction
- (g) interpret simple multi-step reactions in terms of a series of elementary steps with a rate-determining step; predict orders and overall order of reaction from a given mechanism
- (h) suggest a mechanism that is consistent with a given rate equation
- (i) deduce rate equations using initial rates data; interpret rate-concentration graphs
- (j) understand that only first order reactions have a constant half life; use the equation for the concentration-time dependence for first order reactions (Equation 8 in the Data booklet) to calculate the first order rate constant from provided data.

### B1.7 Chemical models and evidence

#### Content

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

Candidates should be able to:

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

## 2. Inorganic chemistry

### Preamble

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

It is recommended that candidates apply ideas from this section to the following or other relevant contexts:

- novel materials whose bonding may be predicted using the van Arkel triangle
- the scrubbing of inorganic pollutants in industry
- hydrogen peroxide in early rocketry; ozone as a replacement for chlorine in swimming pools
- novel and notorious fluorine compounds ( $\text{SF}_6$ ,  $\text{UF}_6$ , HF, magic acid, sarin)
- formation of nitrogen oxides in car engines
- properties of water and the search for liquid water on other planets
- semiconductors
- geometrical isomerism in square planar transition metal complexes – *cis*-platin, CO detectors

**Part A****A2.1 Periodic Table****Content**

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

Candidates should be able to:

- (a) appreciate that the elements can be divided into metals, metalloids and non-metals and the locations of these regions on the Periodic Table
- (b) appreciate that elemental structures can be divided into simple and giant
- (c) understand the variation of melting and boiling points and electrical conductivity of elements across period 3 in terms of structure and bonding
- (d) predict the bonding type and hence properties in elements and compounds using electronegativity values and the van Arkel triangle; plot points on a template van Arkel triangle
- (e) understand and apply the concept of oxidation number (including use in nomenclature) and appreciate that the maximum oxidation states of elements are found in compounds with oxygen and fluorine
- (f) describe the reactivity of period 3 elements with oxygen and water
- (g) describe the reactivity of period 3 oxides with water, and the acid-base character of the oxides as the periodic table is crossed
- (h) describe the reactivity of period 3 chlorides with water, including reactions of  $\text{SiCl}_4$  and  $\text{PCl}_5$  with water in terms of replacement of  $-\text{Cl}$  with  $-\text{OH}$  and subsequent dehydration; analogy with dehydration of unstable hydroxyl group in organic chemistry
- (i) appreciate that there is a thermodynamic preference of bonds to oxygen compared to chlorine, as illustrated by the natural occurrence of mineral oxides.

**A2.2 Main group chemistry (except Group 14)****Content**

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

Candidates should be able to:

- (a) describe the thermal decomposition reactions of carbonates, and explain the trends in thermal stability in terms of the charge density of the cation and the polarisability of the anion
- (b) recall and compare the structures of nitrogen and white phosphorus
- (c) explain why nitrogen is unreactive
- (d) describe the acid-base behaviour of ammonia and the ammonium ion
- (e) recall the allotropes of oxygen
- (f) describe the redox properties of hydrogen peroxide

- (g) describe the formation of sulfur oxides in the atmosphere from carbon fuels containing sulfur, and the removal of  $\text{SO}_2$  from power station emissions
- (h) describe sulfuric acid as a strong involatile acid, oxidising agent, dehydrating agent and catalyst; understand the importance of sulfuric acid as an industrial chemical
- (i) recall the trends in volatility and colour, and understand the trend in oxidising power of the halogens, including fluorine
- (j) explain the trend in bond energy of the halogens, with the reason for  $\text{F}_2$  being exceptional
- (k) explain the trend in acidity of the hydrogen halides in terms of the bond energy, including HF being a weak acid
- (l) recall the reaction of halides with conc.  $\text{H}_2\text{SO}_4$  and explain the trend towards oxidation
- (m) recall the reaction of iodine with sodium thiosulfate and its use in analysis
- (n) recall the reactions of the halogens with cold  $\text{NaOH}(\text{aq})$  in terms of disproportionation
- (o) state reasons for the anomalous reactivity of fluorine (see above), and understand why elements can form high oxidation state fluorides, such as  $\text{UF}_6$ ,  $\text{SF}_6$ .

## Part B

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

#### Content

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

Candidates should be able to:

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

### B2.4 Transition elements

#### Content

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

Candidates should be able to:

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

## B2.5 Crystal structures

### Content

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

Candidates should be able to:

- describe and recognise the cubic close-packed (CCP) and hexagonal close-packed (HCP) structures in metals, including the ABC and AB representations of the close-packed structures
- define the unit-cell representation as the simplest repeating unit of the lattice which displays the full symmetry of the crystal
- explain the relationship between neighbouring atoms/ions in a lattice in terms of geometry (limited to tetrahedral and octahedral) and coordination number
- appreciate that there are octahedral and tetrahedral holes in close-packed structures and recall the ratio of holes to atoms in each case
- understand the derivation of lattice structures by occupying holes in a close-packed lattice of ions with counter-ions:  $\text{NaCl}$  by filling all the octahedral holes in the CCP lattice,  $\text{CaF}_2$  from filling all the tetrahedral holes
- explain that lattice energies may be calculated from the crystal structure using electrostatics and the ionic model, and the deficiencies of this method (recall of the Born-Landé equation is **not** required).

### 3. Organic chemistry

#### Preamble

This section is intended to equip candidates with the tools to understand the organic reactions through the framework of the functional group level, to suggest reagents and conditions for the transformations they have studied when encountered in unfamiliar reaction schemes, to consider the 3-dimensional nature of organic reactions, to understand mechanisms of organic reactions and the acid-base properties of organic molecules.

It is recommended that candidates apply ideas from this section to the following or other relevant contexts.

- drug design and synthesis, including:
  - the importance of stereochemistry and interaction with biological molecules
  - natural products as lead compounds
  - design of synthetic routes
- materials design and synthesis, including:
  - organic dyestuffs
  - esters in fragrances and glues
  - design of bio- and photodegradable polymers
  - polymer for strength, flexibility, conductivity
- process chemistry, including the importance of green chemistry
- the twelve principles of green chemistry
- interesting alcohols: antifreeze; glycerol; methanol toxicity; dichromate(VI)/ethanol reaction in breathalyser tests
- interesting aldehydes and ketones: aromas and flavours (e.g. vanilla, cinnamon, spearmint, caraway); formaldehyde in biological preservation; solvents (e.g. nail-varnish remover, perfumes, paints)
- nature's molecules
  - natural polymers – proteins, nucleic acids – their properties and uses
  - natural products – vitamins, polyphenols, pheromones, sugars – their properties and uses

**Greater emphasis is placed on understanding what kind of reagent is required for a chemical transformation, rather than the learning of reagents and conditions for all reactions.** For the reactions listed in the syllabus, candidates will be required to give the kind of reagent required (oxidising agent etc.) and to give an example of each kind of reagent. They should recall and recognise the reagents quoted as examples in the syllabus.



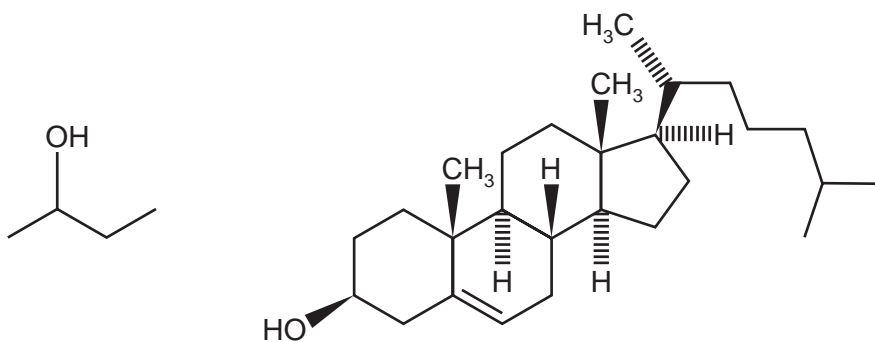
## Formulae and representation

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.  $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$  for propan-1-ol, **not**  $\text{C}_3\text{H}_7\text{OH}$ . A response to a request for a *molecular* formula should not give functional groups separately e.g.  $\text{C}_3\text{H}_8\text{O}$  for propan-1-ol, not  $\text{C}_3\text{H}_7\text{OH}$ .

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

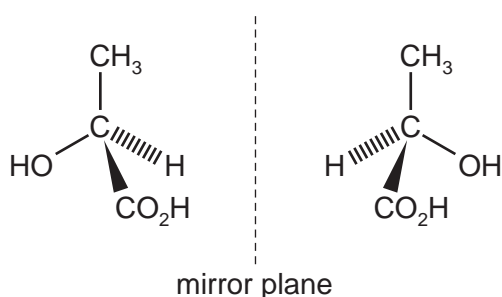
Skeletal or partial-skeletal representations may be used in question papers and are acceptable in candidates' answers where they are unambiguous.

The skeletal formula for butan-2-ol and a partial-skeletal formula for cholesterol are shown below.



The  convention for representing the aromatic ring is preferred.

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



## Part A

## A3.1 Preliminaries

## Content

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

Candidates should be able to:

- appreciate the tetravalent nature of carbon and the shapes of the ethane, ethene and benzene molecules; use this to write structural formulae and predict the shapes of and bond angles in other related organic molecules
- draw carbon backbones (i.e. skeletal formulae), showing realistic geometry (zig zag)
- draw structures and derive molecular formulae from structures (molecular formulae being of the form  $C_aH_bX_cY_d$ , where heteroatoms are listed in atomic number order)
- understand structural (including functional group) and geometric (cis-trans) isomerism
- understand optical isomerism in terms of asymmetric carbons (chiral carbons)
- use hashed and wedged bonds to represent 3D structures
- understand and use nomenclature of molecules with functional groups mentioned in the syllabus, up to six carbon atoms (six plus six for esters)
- use and interpret the terms: *oxidation, reduction, hydrolysis, condensation, isomerisation, substitution, addition, elimination, nucleophile/nucleophilic, electrophile/electrophilic, free-radical, homolytic/heterolytic fission*, as appropriate to part A or part B; recognise such reactions, as appropriate to part A or part B.

## A3.2 Functional group level

## Content

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

Candidates should be able to:

- explain the relative inactivity of C-H and C-C single bonds in terms of the absence of lone pairs and dipole moments
- explain in terms of dipole moments and lone pairs, why heteroatoms (O, N, X, etc.) lead to more diverse chemistry (dipole moments, high energy lone pairs)
- recognise functional groups (limited to the examples in the syllabus, as appropriate to Part A or Part B) present in a given structure; and name simple molecules containing these groups
- use the concept of functional group level of a carbon atom from counting the number of bonds to electronegative atoms on the carbon. (No such bonds is called the Hydrocarbon level; one bond is called

the Alcohol level; two bonds is the Carbonyl level; three bonds the Carboxylic Acid level; and four bonds the Carbon Dioxide level.) Appreciate that functional group level applies to a single carbon atom, not the whole molecule

- (e) state the functional group level of a carbon atom in an unfamiliar example and deduce changes in functional group level in a reaction scheme
- (f) understand that reaction within a level simply swaps one heteroatom for another, e.g. hydrolysis; that moving a carbon atom up a level requires an oxidizing agent, that moving a carbon atom down a level requires a reducing agent or carbanion equivalent; that hydrolysis ultimately yields the functional group after which the level is named
- (g) recognise common examples within the Alcohol level: alcohols, amines, alkyl halides; the Carbonyl level: aldehydes, ketones; the Carboxylic Acid level: carboxylic acids, esters, amides, nitriles; the Carbon Dioxide level: carbon dioxide
- (h) describe what happens when there are unstable groups, e.g. two hydroxyls on the same carbon atom (geminal diol or hydrate) forming aldehyde/ketone; three hydroxyls on one carbon forming a carboxylic acid; four hydroxyl groups on one carbon forming carbonic acid and carbon dioxide.

### A3.3 Lower functional group level reactions – Alcohol level

#### Content

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

Candidates should be able to:

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

**A3.4 Lower functional group level reactions – Carbonyl level****Content**

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

Candidates should be able to:

- appreciate that hydrolysis of any member within the group leads to an aldehyde or ketone, and that this is an example of moving within the level
- understand that addition (where the  $\pi$  bond of the carbonyl breaks) of bisulfite (hydrogensulfate(IV)), is an example of reaction within the level
- understand and recall that oxidation, including use of acidified dichromate(VI) and carboxylic acids from aldehydes with Tollens' reagent, is an example of moving up a level
- understand and recall that addition of hydrogen cyanide, Grignard reagents or metallic hydrides (e.g.  $\text{NaBH}_4$ ), where the  $\pi$  bond of the carbonyl breaks and a new C-C or C-H bond forms, is an example of a carbon atom moving down a level.

**A3.5 Addition and elimination reactions****Content**

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

Candidates should be able to:

- compare C=C and C=O  $\pi$  bonds in terms of dipole moments to explain why there is no nucleophilic attack on C=C
- describe addition reactions to C=C: the reaction with  $\text{H}_3\text{O}^+$ , HBr,  $\text{H}_2$ , and  $\text{Br}_2$
- describe addition polymerisation as an example of an addition reaction and in terms of the repeat unit in the polymer; suggest the monomer given the structure of an addition polymer
- understand that elimination reactions are essentially the reverse of addition reactions and that elimination competes with substitution, the former being favoured by high temperature and high pH
- describe the formation of alkenes by the elimination of HX from alkyl halides or  $\text{H}_2\text{O}$  from alcohols.

**A3.6 Green chemistry****Content**

- atom economy
- reducing environmental impact

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

Candidates should be able to:

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

**Part B****B3.7 Higher functional group level reactions – Carboxylic Acid level****Content**

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

Candidates should be able to:

- appreciate that hydrolysis of any member within the group leads to carboxylic acids, e.g. nitriles, amides, esters, acyl chlorides to carboxylic acids, and that these are examples of moving within the level
- understand that the synthesis of esters from carboxylic acids and alcohols, the reaction of acyl chlorides with alcohols/phenols, the synthesis of amides from acyl chlorides and amines, and the synthesis of acyl chlorides from carboxylic acids are examples of substitution within the level
- understand how condensation polymerisation can occur when there is more than one functional group on reagents, forming, for example, amide links (and peptides from amino acids), ether links (from the condensation of sugars) and ester links
- understand that reductions with metallic hydrides, e.g. esters to alcohols, amides to amines, nitriles to amines, are examples of moving down level(s);  $\text{NaBH}_4$  is capable of reducing aldehydes and ketones to alcohols, whereas the more powerful  $\text{LiAlH}_4$  can affect all the above examples.

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

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

Candidates should be able to:

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

**B3.9 Mechanisms****Content**

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

Candidates should be able to:

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

**B3.10 Aromatic chemistry****Content**

- stability of aromatic systems
- electrophilic substitution reactions
- activation and deactivation of the benzene ring

Candidates should be able to:

- (a) appreciate that enthalpies of hydrogenation and resistance to addition reactions indicate the stability of aromatic systems such as benzene in contrast to alkenes
- (b) describe electrophilic substitution reactions: C=C  $\pi$  bond reacting with electrophiles, limited to NO<sub>2</sub><sup>+</sup>(nitration), Br<sup>+</sup>(bromination), R<sup>+</sup> (Friedel-Crafts alkylation), and RCO<sup>+</sup> (Friedel-Crafts acylation). (Knowledge of the mechanism is **not** required.)
- (c) appreciate that the benzene ring is activated by electron donating groups (-R, -OR, -NR<sub>2</sub>) and deactivated by electron withdrawing groups (-C=O, -NO<sub>2</sub>), as typified by the reactions of phenol, phenylamine and nitrobenzene
- (d) appreciate the utility of aromatic nitro compounds in producing aryl amines.

**B3.11 Acidity and basicity****Content**

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

Candidates should be able to:

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

**B3.12 Stereochemistry****Content**

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

Candidates should be able to:

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

#### 4. Analysis

##### Preamble

This section is intended to give candidates insight into the physical background of spectroscopic techniques, and the skills to interpret spectra without relying on tables of data; an appreciation of molecular symmetry and its importance in carbon-13 NMR in particular; the ability to interpret measurements and observations in classical laboratory analytical techniques.

It is recommended that candidates apply ideas from this section to the following or other relevant contexts.

- analytical techniques employed in detecting drugs in sport
- the application of luminescence to lasers and lighting
- detecting elements in space spectroscopically
- the Mars Viking lander
- spectra of modern pharmaceutical products
- forensic science
- archaeological dating techniques
- environmental monitoring
- NMR in biology and medicine – structure determination; metabolic studies; magnetic resonance imaging

#### Part A

##### A4.1 Qualitative and quantitative analysis

###### Content

- interpreting experimental observations
- performing mole calculations using quantitative data

Candidates should be able to:

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



**A4.2 Mass spectrometry****Content**

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

Candidates should be able to:

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

**A4.3 Electronic spectroscopy****Content**

- the physical process
- explaining line spectra qualitatively

Candidates should be able to:

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

**A4.4 Infra-red****Content**

- the physical process of infra-red spectroscopy
- interpreting spectra, recognising particular stretches and general regions

Candidates should be able to:

- explain the principle of the process: excitation of bond vibrations with resonant electromagnetic radiation
- predict relative frequencies of bond vibrations based on bond strength and atomic masses (recall of Hooke's law is not required), and hence recall that IR stretching frequency increases in the order: single bonds (except those to hydrogen), double bonds, triple bonds, bonds to hydrogen
- recall that the approximate regions in the spectrum of the stretching frequencies are: 2500–3700  $\text{cm}^{-1}$  for bonds to H, 1900–2300  $\text{cm}^{-1}$  for triple bonds, ca. 1500–1900  $\text{cm}^{-1}$  for double bonds and less than 1500  $\text{cm}^{-1}$  for single bond vibrations (except to H) and compound-specific ("fingerprint") absorptions
- interpret IR spectra for simple organic functional groups, recognising the bond stretch regions as specified in (c) and specifically the C=O stretch and O-H stretches in alcohols and carboxylic acids by their characteristic appearances. (Tables of data are **not** provided.)

**A4.5 Carbon-13 NMR****Content**

- predicting the number of peaks in a carbon-13 spectrum
- interpreting spectra, recognising general chemical shift regions

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

Candidates should be able to:

- (a) predict the number of peaks in a decoupled carbon-13 spectrum
- (b) recall that carbon-13 chemical shift values fall in the approximate divisions: C-C (0–50 ppm), C-O (50–100 ppm), C=C (100–150 ppm), C=O (150–200 ppm)
- (c) interpret decoupled carbon-13 NMR spectra considering the number of peaks in each of the approximate divisions only. (Tables of data are **not** provided.)

**Part B****B4.6 NMR of other spin  $\frac{1}{2}$  nuclei****Content**

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

Candidates should be able to:

- (a) describe the physical process: magnetic dipoles interacting with the external field, shielding and coupling
- (b) understand the origin of the delta chemical shift scale
- (c) interpret spin  $\frac{1}{2}$  NMR spectra (proton, fluorine-19, etc.) using spin-spin coupling and signal integrations. (No knowledge is required of proton chemical shift values.)
- (d) appreciate that coupling to  $n$  equivalent nuclei gives  $n+1$  peaks; use Pascal's triangle to predict multiplet intensities; use integrals in proton NMR to give ratios of hydrogens in different environments.

## Appendix 1: Practical assessment

### Introduction

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

Candidates' experimental skills will be formally assessed in the practical exam, Component 4, and in one or more written questions in Component 2. In order to prepare candidates fully for these assessments it is recommended that at least one practical investigation is undertaken during the course of study. This will allow candidates to appreciate fully the experimental process as a coherent whole, from planning, through manipulation, observation and recording and presentation of data, to analysis of results, drawing conclusions and evaluation of methods and conclusions.

### Component 4

Component 4 will be a timetabled, laboratory-based practical paper focusing on the following experimental skills:

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

The questions in the practical paper may include the following:

- a volumetric analysis problem, based on one set of titrations
- an experiment that involves the determination of some quantity, e.g. the enthalpy change of a reaction, or the rate of a reaction; such experiments will depend on the simple manipulation of usual laboratory apparatus
- an observational problem in which the candidate will be asked to investigate, by specified experiments, an unknown substance; the substance may be an element, a compound or a mixture.

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

Candidates are **not** allowed to refer to notebooks, textbooks or any other information in the Practical examination. The Data booklet (see Appendix 3), which includes qualitative analysis notes, will be supplied in addition to the question paper. Candidates may also be required to carry out calculations as detailed in the syllabus.

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

## Mark scheme for Component 4

Component 4 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 session to session.

**Manipulation, measurement and observation****Successful collection of data and observations**

Candidates should be able to:

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

Systematic analysis and a knowledge of traditional methods of separation will not be required. It will be assumed that candidates will be familiar with: (i) the reactions of the following cations:  $\text{NH}_4^+$ ,  $\text{Mg}^{2+}$ ,  $\text{Al}^{3+}$ ,  $\text{Ca}^{2+}$ ,  $\text{Cr}^{3+}$ ,  $\text{Mn}^{2+}$ ,  $\text{Fe}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Zn}^{2+}$ ,  $\text{Ba}^{2+}$ ,  $\text{Pb}^{2+}$ , (ii) the reactions of the following anions:  $\text{CO}_3^{2-}$ ,  $\text{NO}_3^-$ ,

$\text{NO}_2^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{SO}_3^{2-}$ ,  $\text{Cl}^-$ ,  $\text{Br}^-$ ,  $\text{I}^-$ ,  $\text{CrO}_4^{2-}$ , (iii) tests for the following gases:  $\text{NH}_3$ ,  $\text{CO}_2$ ,  $\text{Cl}_2$ ,  $\text{H}_2$ ,  $\text{O}_2$ ,  $\text{SO}_2$ , as detailed in the qualitative analysis notes.

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

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

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

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

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

### 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  $0.10 \text{ cm}^3$ .

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

### Decisions relating to measurements or observations

Candidates should be able to:

- decide how many tests or observations to perform
- make measurements that span a range and have a distribution appropriate to the experiment
- decide how long to leave experiments running before taking readings
- identify where repeated readings or observations are appropriate
- replicate readings or observations as necessary

- identify where confirmatory tests are appropriate and the nature of such tests
- choose reagents to distinguish between given ions.

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

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

### Presentation of data and observations

#### Recording data or observations

Candidates should be able to:

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

As an example of accepted practice in column headings, if the quantity being measured is volume in  $\text{cm}^3$ , then 'volume /  $\text{cm}^3$ ' would be the usual way to write the column heading, but 'volume in  $\text{cm}^3$ ' or 'volume ( $\text{cm}^3$ )' would be allowed. Headings such as 'volume  $\text{cm}^3$ ' or just ' $\text{cm}^3$ ' 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  $\Delta H$  for enthalpy change or ppt. for precipitate, may be used without explanation.

In recording data and observations, if one measurement of volume in a column of raw data is given as  $0.06 \text{ cm}^3$ , then all the volumes in that column should be given to the nearest  $0.01 \text{ cm}^3$ . The degree of precision used should be compatible with the measuring instrument used; it would be inappropriate to record a volume measured on a  $\text{cm}^3$  scale as ' $10 \text{ mm}^3$ '. Where the calibration marks on a measuring instrument are widely spaced, it may be appropriate to interpolate between the marks, but where the calibration marks are close together then the reading should be to the nearest calibration mark. Observations of qualitative variables such as colour should be recorded in simple language such as 'blue' or 'orange'. Where fine discrimination is required, terms such as 'pale' or 'dark' should be used, and comparisons made such as 'darker red than at 3 minutes' or 'paler green than at  $0.2 \text{ mol dm}^{-3}$ ', but darker than at  $0.4 \text{ mol dm}^{-3}$ '.

### Display of calculation and reasoning

Candidates should be able to:

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

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

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

### Data layout

Candidates should be able to:

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

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

The accepted scientific conventions for labelling the axes of a graph are the same as for the column headings in a table of results, with both the quantity and the unit shown (where appropriate). Points should be finely drawn with a sharp pencil, but must still be visible. A fine cross or an encircled dot is suitable; a thick pencil blob is not. Often it is obvious that the data fall on a straight line or smooth curve, and a line of best fit or appropriate curve should be placed on the graph. In some cases candidates may be expected to draw two curves or lines and find the intersection. A line of

best fit should show an even distribution of points on either side of the line along its whole length. Lines should be finely drawn and should not contain kinks or breaks. Candidates will be expected to extrapolate lines to read intercepts with axes or other lines or predict values outside the range of the experiment.

## Analysis, conclusions and evaluation

### Interpretation of data or observations and identifying sources of error

Candidates should be able to:

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

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

Candidates should be used to looking at experiments and assessing the relative importance of errors in measurement or in making observations so that they can judge which sources of error are most important. Candidates should be familiar with simple means of estimating error, such as the errors intrinsic in measuring devices or in the observer's ability to observe, or in experiments where limitations of the method introduce errors (e.g. heat loss when trying to assess enthalpy change). They should be able to express these errors in standard forms such as length = 73 mm  $\pm$  1 mm, or temperature increase = 14 °C  $\pm$  4 °C. Candidates should be able to suggest which of the sources of error described are likely to be systematic errors such as those resulting from thermometers that consistently read 1 °C above actual temperature, or candidates who read volumes to the wrong part of the meniscus, as well as those which are likely to be random errors due to variability of materials, or random variations in room temperature.



### Drawing conclusions

Candidates should be able to:

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

Conclusions may be expressed in terms of support for, or refutation of, hypotheses, or in terms of the deductions or inductions that can logically be made from the data, observations or calculated values. Simple scientific explanations form a part of such conclusions and therefore form a part of this practical assessment, in which the candidates will be expected to refer to knowledge and understanding gained in the theory part of their course in order to provide explanations of their practical conclusions.

### Suggesting improvements

Candidates should be able to:

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

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

## Component 2

One or more questions in Component 2 will assess the higher order practical skills of planning, analysis and evaluation. It should be stressed that candidates cannot be adequately prepared for these questions without the following laboratory experience:

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

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

Candidates may be asked to express a prediction in the form of a written hypothesis linking independent and dependent variables, or in the form of a graph showing the expected outcome. There will be activities in which candidates will be given some experimental data and will be required to analyse, evaluate and draw conclusions from it. These questions also will not be highly structured; candidates will be expected to decide for themselves the means that should be used to analyse, evaluate and conclude.

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

### Planning

#### Defining the problem

Candidates should be able to:

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

Candidates will be provided with information about the aims of the investigation or experiment, and some background information relating to it. They should be able to make use of this information to identify the key variables in the investigation, and to make a quantitative, testable, falsifiable prediction of the likely outcome, based on the information given and their knowledge and understanding of the topic under consideration. Candidates may be asked to express their prediction in the form of a sketch graph showing the expected outcome. A list of key variables to control in order to test the hypothesis effectively is required, and should include variables that might be expected to have some effect on the material involved (e.g. temperature), but not those likely to have a trivial effect (e.g. using the same test-tube).

#### Methods

Candidates should be able to:

- describe the method to be used to vary the independent variable, and the means that they will propose to ensure that they have measured its values accurately
- describe how the dependent variable is to be measured
- describe how each of the other key variables is to be controlled
- explain how any control experiments will be used to verify that it is the independent variable that is affecting the dependent variable and not some other factor
- describe the arrangement of apparatus and the steps in the procedure to be followed
- suggest appropriate volumes and concentrations of reagents
- assess the risks of their proposed methods

- describe precautions that should be taken to keep risks to a minimum
- draw up tables for data that they might wish to record
- describe how the data might be used in order to reach a conclusion.

The overall arrangement should be workable. It should be possible to collect the data required without undue difficulty if the apparatus were assembled as described. Words and labelled diagrams should be used for describing the apparatus and how to use it. The measuring instruments chosen should measure the correct quantity to a suitable precision.

Control experiments may be of the type where all factors are identical to the experimental treatment, except that the value of the independent variable is zero, or they may be of the type used to confirm that, for example, it is a catalyst that is causing a particular effect, where the catalyst is omitted or inactivated.

Candidates should be able to carry out a simple risk assessment of their plan, identifying the areas where accident or injury is most likely and areas where it would be most serious.

They should be able to use this to propose appropriate safety precautions specifically related to the risks that they have identified – e.g. the experiment gives off  $\text{NO}_2$  fumes and should be carried out in a fume hood.

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

## Analysis, conclusions and evaluation

### Dealing with data

Candidates should be able to:

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

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

### Evaluation

Candidates should be able to:

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

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

### Conclusions

Candidates should be able to:

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

Key points of the raw data, graphical representations of it and calculated values should be given, leading to a clear indication of the strength or weakness of any support for or against the hypothesis, or indeed, its proof or refutation. Detailed scientific explanations form a part of such conclusions and therefore form a part of this higher-order practical skill assessment, in which the candidates will be expected to refer to knowledge and understanding gained in their theory part of the course in order to provide explanations of their practical conclusions, for example making detailed reference to the rate

of effective collisions between particles and substrates in explaining the conclusions made about a reaction-rate hypothesis. Where appropriate, candidates may be given the opportunity to ask questions based on their conclusions and thus to derive further predictions and hypotheses. Within familiar contexts, and in relation to the evaluations they have made, candidates may be offered the opportunity to suggest how the investigation may be improved in order to increase the confidence in drawing conclusions.

### Apparatus and materials list

The list given below has been drawn up in order to give guidance to schools concerning the apparatus that is expected to be generally available for examination purposes. 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".

two burettes, 50 cm<sup>3</sup>  
 two pipettes, 25 cm<sup>3</sup>  
 one pipette, 10 cm<sup>3</sup>  
 dropping pipette  
 one pipette filler  
 conical flasks: three within range 150 cm<sup>3</sup> to 250 cm<sup>3</sup>  
 volumetric flask, 250 cm<sup>3</sup>  
 measuring cylinders, 25 cm<sup>3</sup> and 50 cm<sup>3</sup>  
 wash bottle  
 two filter funnels  
 porcelain crucible, approximately 15 cm<sup>3</sup>, with lid  
 evaporating basin, at least 30 cm<sup>3</sup>  
 beakers, squat form with lip, 100 cm<sup>3</sup> and 250 cm<sup>3</sup>  
 thermometers, -10 °C to +110 °C at 1 °C and -5 °C to +50 °C at 0.2 °C  
 plastic beaker, e.g. polystyrene, of approximate capacity 150 cm<sup>3</sup>  
 test-tubes (some of which should be pyrex or hard glass) approximately 125 mm × 16 mm  
 boiling tubes, approximately 150 mm × 25 mm  
 clocks (or wall-clock) to measure to an accuracy of about 1s (where clocks are specified, candidates may use their own wrist watches if they prefer)  
 balance, single-pan, direct reading, minimum accuracy 0.01 g (1 per 8–12 candidates) weighing to 300 g

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

### For titration

#### Acid/base titration

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

#### Manganate titration

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

#### Iodine/thiosulfate titration

potassium manganate(VII)  
potassium dichromate(VI)  
hydrogen peroxide  
potassium iodate(V)  
starch indicator

### For qualitative analysis

#### Bench reagents

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

**Inorganic analysis**

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

**Organic analysis**

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

N.B. tests for aldehydes may be performed by substituting glucose for the aldehyde

Details of the specific requirements for apparatus and materials for a particular examination are given in the Confidential Instructions, which are sent to Centres several weeks prior to the examination. These Instructions also contain advice about colour-blind candidates.

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

The attention of Centres is drawn to the Handbook for Centres which contains a section on science syllabuses, which includes information about arrangements for practical examinations.

**Microscale**

Centres are encouraged to incorporate some microscale chemistry into their laboratory work. Manipulative skills on this small scale are becoming increasingly relevant in modern research. The kit is cheap compared to conventional apparatus, and working with such small quantities of chemicals is money-saving. Experiments take much less time and are much less likely to require the sharing of apparatus between candidates; with all the required materials on a personal palette, microscale work generates quiet independent work. Many health and safety barriers are removed by working on such a small scale – risks are minimised when tiny quantities are involved; the experiments can even be done in classrooms rather than laboratories. Quantitative work that involves mass measurement is less advantageously carried out as microscale though, due to the percentage mass errors. Microscale will not, however, be required for practical exams.

**Safety in the laboratory**

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

**Associations**

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

### Websites

[www.chemsoc.org/networks/learnnet/Safety.htm](http://www.chemsoc.org/networks/learnnet/Safety.htm)

[www.ncbe.reading.ac.uk/NCBE/SAFETY/menu.html](http://www.ncbe.reading.ac.uk/NCBE/SAFETY/menu.html)

[www.microbiologyonline.org.uk/safety.html](http://www.microbiologyonline.org.uk/safety.html)

### Publications

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

Topics in Safety, ASE, 3rd Edition, 2001

CLEAPSS Laboratory Handbook (available to CLEAPSS members only)

CLEAPSS Hazcards (available to CLEAPSS members only)

Safety in Science Education, DfES, HMSO, 1996

Hazardous Chemicals Manual, SSERC, 1997

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

### UK Regulations

Control of Substances Hazardous to Health Regulations (COSHH) 2002,

[www.opsi.gov.uk/SI/si2002/20022677.htm](http://www.opsi.gov.uk/SI/si2002/20022677.htm); a brief guide may be found at

[www.hse.gov.uk/pubns/indg136.pdf](http://www.hse.gov.uk/pubns/indg136.pdf)



## Appendix 2: Textbooks and IT resources

Recommended textbooks include:

Chemistry for Advanced Level by Peter Cann and Peter Hughes, published by Hodder Murray (ISBN 9780719586026)

Chemistry by Dr. Michael A. Thompson, published by Keytones (ISBN 9780980711004)

A supplement covering additional material is being written and will be available online via **www.cie.org.uk**.

Additional material can be found on the Teacher Support Site.

For very useful and comprehensive resource packs:

Philip Allan Teacher Resource Packs: **www.philipallan.co.uk**. Chemistry AS/A level titles are:

- Calculations, Structure and Bonding by Harry Hammond (ISBN 9780860032267)
- Equilibria, Acids and Bases by Rob King (ISBN 9780860032243)
- Organic Chemistry 1 by Eric Sie (ISBN 9780860032221)
- Organic Chemistry 2 by Eric Sie (ISBN 9780860032236)
- The Periodic Table by Rob King (ISBN 9780860032250)
- Thermodynamics and Kinetics by Harry Hammond (ISBN 9780860032274)

For using IT in chemistry teaching:

Using ICT to enhance Teaching and Learning in Chemistry by S Lewis, published by the Royal Society of Chemistry (ISBN 0854043837)

For practical chemistry:

- ILPAC Advanced Practical Chemistry (second edition) by Alec Thompson, published by Hodder Murray (ISBN 0719575079)
- Microscale Chemistry by J Skinner, published by the Royal Society of Chemistry (ISBN 1870343492)
- Classic Chemistry Experiments by K Hutchings, published by the Royal Society of Chemistry (ISBN 0854049193)
- Classic Chemical Demonstrations by T Lister, published by the Royal Society of Chemistry (ISBN 1870343387)
- The Chemistry Video Consortium at the Southampton University Chemistry Department (**www.soton.ac.uk/chemistry/services/services3.html**) has much excellent practical material on video.
- A number of websites offer ideas for and advice on practical investigations. These include **www.chemistry-react.org/go/Topic/Default\_4.html** and **www.york.ac.uk/org/seg/salters/chemistry/ResourceSheets/rsindex.html**

The Royal Society of Chemistry:

The RSC produces many excellent resources at this level, such as:

- Aspirin (2nd edition) by D Lewis (ISBN 0854043888)
- Paracetamol by F Ellis (ISBN 0854043756)

They also produce CD-ROMs on modern analytical techniques, spectroscopic interpretation, industrial processes, practical chemistry and the Periodic Table.

General interest for candidates:

- The University of York journal Chemistry Review: [www.york.ac.uk/depts/chem/chemrev](http://www.york.ac.uk/depts/chem/chemrev)
- The University of Bristol's Molecule of the Month: [www.chm.bris.ac.uk/motm](http://www.chm.bris.ac.uk/motm)

Of interest for teachers:

- Royal Society of Chemistry: [www.rsc.org](http://www.rsc.org)
- Association for Science Education: [www.ase.org.uk](http://www.ase.org.uk)
- Teacher support at CIE: [www.cie.org.uk/profiles/teachers/support](http://www.cie.org.uk/profiles/teachers/support)

## Appendix 3: Data booklet

### Important values and constants

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

### Important equations

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

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

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

$\Delta G^\ominus$  is the standard Gibbs energy change;  $\Delta H^\ominus$  is the standard enthalpy change;  $T$  is thermodynamic temperature;  $\Delta S^\ominus$  is the standard entropy change

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

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

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

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

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

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

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

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

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

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

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

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

(9) Electromagnetic energy:  $E = hf$

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

## The Periodic Table of the Elements

| Group  |           |                      |               |               |            |            |           |               |              |             |          |           |           |            |           |          |         |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
|--|-----------|----------------------|---------------|---------------|------------|------------|-----------|---------------|--------------|-------------|----------|-----------|-----------|------------|-----------|----------|---------|------------|--|----------------------|--|---------------|--|------|--|---------------|--|------|------|------|------|------|------|
| 1  | 2         |                      |               |               |            |            |           |               |              |             |          | 13        | 14        | 15         | 16        | 17       | 18      |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
|  |           |                      |               |               |            |            |           |               |              |             | 1.0      |           |           |            |           |          | 4.0     |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
|  |           |                      |               |               |            |            |           |               |              |             | H        |           |           |            |           |          | He      |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
|  |           |                      |               |               |            |            |           |               |              |             | hydrogen |           |           |            |           |          | helium  |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
|  |           |                      |               |               |            |            |           |               |              |             | 1        |           |           |            |           |          | 2       |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td colspan="2" style="text-align: center;"><b>Key</b></td> <td colspan="2" style="text-align: center;">relative atomic mass</td> <td colspan="2" style="text-align: center;">atomic symbol</td> <td colspan="2" style="text-align: center;">name</td> <td colspan="2" style="text-align: center;">atomic number</td> </tr> </table> |           |                      |               |               |            |            |           |               |              |             |          |           |           |            |           |          |         | <b>Key</b> |  | relative atomic mass |  | atomic symbol |  | name |  | atomic number |  | 10.8 | 12.0 | 14.0 | 16.0 | 19.0 | 20.2 |
| <b>Key</b>   |           | relative atomic mass |               | atomic symbol |            | name       |           | atomic number |              |             |          |           |           |            |           |          |         |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| 6.9  | 9.0       |                      |               |               |            |            |           |               |              |             |          | B         | C         | N          | O         | F        | Ne      |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| Li   | Be        |                      |               |               |            |            |           |               |              |             |          | boron     | carbon    | nitrogen   | oxygen    | fluorine | neon    |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| 3  | 4         |                      |               |               |            |            |           |               |              |             |          | 5         | 6         | 7          | 8         | 9        | 10      |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| 23.0   | 24.3      |                      |               |               |            |            |           |               |              |             |          | 27.0      | 28.1      | 31.0       | 32.1      | 35.5     | 39.9    |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| Na   | Mg        |                      |               |               |            |            |           |               |              |             |          | Al        | Si        | P          | S         | Cl       | Ar      |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| sodium   | magnesium |                      |               |               |            |            |           |               |              |             |          | aluminium | silicon   | phosphorus | sulfur    | chlorine | argon   |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| 11   | 12        | 3                    | 4             | 5             | 6          | 7          | 8         | 9             | 10           | 11          | 12       | 13        | 14        | 15         | 16        | 17       | 18      |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| 39.1   | 40.1      | 45.0                 | 47.9          | 50.9          | 52.0       | 54.9       | 55.8      | 58.9          | 58.7         | 63.5        | 65.4     | 69.7      | 72.6      | 74.9       | 79.0      | 79.9     | 83.8    |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| K  | Ca        | Sc                   | Ti            | V             | Cr         | Mn         | Fe        | Co            | Ni           | Cu          | Zn       | Ga        | Ge        | As         | Se        | Br       | Kr      |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| potassium  | calcium   | scandium             | titanium      | vanadium      | chromium   | manganese  | iron      | cobalt        | nickel       | copper      | zinc     | gallium   | germanium | arsenic    | selenium  | bromine  | krypton |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| 19   | 20        | 21                   | 22            | 23            | 24         | 25         | 26        | 27            | 28           | 29          | 30       | 31        | 32        | 33         | 34        | 35       | 36      |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| 85.5   | 87.6      | 88.9                 | 91.2          | 92.9          | 95.9       | –          | 101       | 103           | 106          | 108         | 112      | 115       | 119       | 122        | 128       | 127      | 131     |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| Rb   | Sr        | Y                    | Zr            | Nb            | Mo         | Tc         | Ru        | Rh            | Pd           | Ag          | Cd       | In        | Sn        | Sb         | Te        | I        | Xe      |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| rubidium   | strontium | yttrium              | zirconium     | niobium       | molybdenum | technetium | ruthenium | rhodium       | palladium    | silver      | cadmium  | indium    | tin       | antimony   | tellurium | iodine   | xenon   |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| 37   | 38        | 39                   | 40            | 41            | 42         | 43         | 44        | 45            | 46           | 47          | 48       | 49        | 50        | 51         | 52        | 53       | 54      |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| 133  | 137       |                      | 178           | 181           | 184        | 186        | 190       | 192           | 195          | 197         | 201      | 204       | 207       | 209        | –         | –        | –       |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| Cs   | Ba        | lanthanides          | Hf            | Ta            | W          | Re         | Os        | Ir            | Pt           | Au          | Hg       | Tl        | Pb        | Bi         | Po        | At       | Rn      |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| caesium  | barium    |                      | hafnium       | tantalum      | tungsten   | rhenium    | osmium    | iridium       | platinum     | gold        | mercury  | thallium  | lead      | bismuth    | polonium  | astatine | radon   |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| 55   | 56        | 57-71                | 72            | 73            | 74         | 75         | 76        | 77            | 78           | 79          | 80       | 81        | 82        | 83         | 84        | 85       | 86      |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| –  | –         |                      | –             | –             | –          | –          | –         | –             | –            | –           |          |           |           |            |           |          |         |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| Fr   | Ra        | actinides            | Rf            | Db            | Sg         | Bh         | Hs        | Mt            | Ds           | Rg          |          |           |           |            |           |          |         |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| francium   | radium    |                      | rutherfordium | dubnium       | seaborgium | bohrium    | hassium   | meitnerium    | darmstadtium | roentgenium |          |           |           |            |           |          |         |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |
| 87   | 88        | 89-103               | 104           | 105           | 106        | 107        | 108       | 109           | 110          | 111         |          |           |           |            |           |          |         |            |  |                      |  |               |  |      |  |               |  |      |      |      |      |      |      |

|             |           |         |              |           |            |           |           |            |           |             |             |         |             |           |            |
|-------------|-----------|---------|--------------|-----------|------------|-----------|-----------|------------|-----------|-------------|-------------|---------|-------------|-----------|------------|
| lanthanides | 139       | 140     | 141          | 144       | –          | 150       | 152       | 157        | 159       | 163         | 165         | 167     | 169         | 173       | 175        |
|             | La        | Ce      | Pr           | Nd        | Pm         | Sm        | Eu        | Gd         | Tb        | Dy          | Ho          | Er      | Tm          | Yb        | Lu         |
|             | lanthanum | cerium  | praseodymium | neodymium | promethium | samarium  | europium  | gadolinium | terbium   | dysprosium  | holmium     | erbium  | thulium     | ytterbium | lutetium   |
|             | 57        | 58      | 59           | 60        | 61         | 62        | 63        | 64         | 65        | 66          | 67          | 68      | 69          | 70        | 71         |
| actinides   | –         | –       | –            | –         | –          | –         | –         | –          | –         | –           | –           | –       | –           | –         | –          |
|             | Ac        | Th      | Pa           | U         | Np         | Pu        | Am        | Cm         | Bk        | Cf          | Es          | Fm      | Md          | No        | Lr         |
|             | actinium  | thorium | protactinium | uranium   | neptunium  | plutonium | americium | curium     | berkelium | californium | einsteinium | fermium | mendelevium | nobelium  | lawrencium |
|             | 89        | 90      | 91           | 92        | 93         | 94        | 95        | 96         | 97        | 98          | 99          | 100     | 101         | 102       | 103        |

## Qualitative Analysis Notes

[Key: ppt. = precipitate]

## 1 Reactions of aqueous cations

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

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

## 2 Reactions of anions

| <i>ion</i>                                      | <i>reaction</i>  |
|---|--|
| carbonate,<br>$\text{CO}_3^{2-}$                | $\text{CO}_2$ liberated by dilute acids  |
| chromate(VI),<br>$\text{CrO}_4^{2-}(\text{aq})$ | yellow solution turns orange with $\text{H}^+(\text{aq})$ ;<br>gives yellow ppt. with $\text{Ba}^{2+}(\text{aq})$ ;<br>gives bright yellow ppt. with $\text{Pb}^{2+}(\text{aq})$                 |
| chloride,<br>$\text{Cl}^-(\text{aq})$           | gives white ppt. with $\text{Ag}^+(\text{aq})$ (soluble in $\text{NH}_3(\text{aq})$ );<br>gives white ppt. with $\text{Pb}^{2+}(\text{aq})$  |
| bromide,<br>$\text{Br}^-(\text{aq})$            | gives cream ppt. with $\text{Ag}^+(\text{aq})$ (partially soluble in $\text{NH}_3(\text{aq})$ );<br>gives white ppt. with $\text{Pb}^{2+}(\text{aq})$  |
| iodide,<br>$\text{I}^-(\text{aq})$              | gives yellow ppt. with $\text{Ag}^+(\text{aq})$ (insoluble in $\text{NH}_3(\text{aq})$ );<br>gives yellow ppt. with $\text{Pb}^{2+}(\text{aq})$  |
| nitrate,<br>$\text{NO}_3^-(\text{aq})$          | $\text{NH}_3$ liberated on heating with $\text{OH}^-(\text{aq})$ and Al foil   |
| nitrite,<br>$\text{NO}_2^-(\text{aq})$          | $\text{NH}_3$ liberated on heating with $\text{OH}^-(\text{aq})$ and Al foil;<br>$\text{NO}$ liberated by dilute acids<br>(colourless $\text{NO} \rightarrow$ (pale) brown $\text{NO}_2$ in air) |
| sulfate,<br>$\text{SO}_4^{2-}(\text{aq})$       | gives white ppt. with $\text{Ba}^{2+}(\text{aq})$ or with $\text{Pb}^{2+}(\text{aq})$ (insoluble in excess dilute strong acids)  |
| sulfite,<br>$\text{SO}_3^{2-}(\text{aq})$       | $\text{SO}_2$ liberated with dilute acids;<br>gives white ppt. with $\text{Ba}^{2+}(\text{aq})$ (soluble in excess dilute strong acids)  |

## 3 Tests for gases

| <i>gas</i>                    | <i>test and test result</i>  |
|-------------------------------|--|
| ammonia, $\text{NH}_3$        | turns damp red litmus paper blue   |
| carbon dioxide, $\text{CO}_2$ | gives a white ppt. with limewater<br>(ppt. dissolves with excess $\text{CO}_2$ ) |
| chlorine, $\text{Cl}_2$       | bleaches damp litmus paper   |
| hydrogen, $\text{H}_2$        | "pops" with a lighted splint   |
| oxygen, $\text{O}_2$          | relights a glowing splint  |
| sulfur dioxide, $\text{SO}_2$ | turns acidified potassium dichromate(VI) (aq) from orange to green               |

## Appendix 4: Mathematical requirements

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

- (a) make calculations involving addition, subtraction, multiplication and division of quantities
- (b) make approximate evaluations of numerical expressions
- (c) express small fractions as percentages, and vice versa
- (d) calculate an arithmetic mean
- (e) transform decimal notation to power of ten notation (standard form)
- (f) use tables or calculators to evaluate logarithms (for pH calculations), squares, square roots and reciprocals
- (g) change the subject of an equation (most such equations involve only the simpler operations but may include positive and negative indices and square roots)
- (h) substitute physical quantities into an equation using consistent units so as to calculate one quantity; check the dimensional consistency of such calculations, e.g. the units of a rate constant  $k$
- (i) solve simple algebraic equations
- (j) comprehend and use the symbols/notations  $<$ ,  $>$ ,  $\approx$ ,  $/$ ,  $\Delta$ ,  $\equiv$
- (k) test tabulated pairs of values for direct proportionality by a graphical method or by constancy of ratio
- (l) select appropriate variables and scales for plotting a graph, especially to obtain a linear graph of the form  $y = mx + c$
- (m) determine and interpret the slope and intercept of a linear graph
- (n) choose by inspection a straight line that will serve as the 'least bad' linear model for a set of data presented graphically
- (o) understand:
  - (i) the slope of a tangent to a curve as a measure of rate of change
  - (ii) the 'area' below a curve where the area has physical significance, e.g. Boltzmann distribution curves
- (p) comprehend how to handle numerical work so that significant figures are neither lost unnecessarily nor used beyond what is justified
- (q) estimate orders of magnitude
- (r) formulate simple algebraic equations as mathematical models, e.g. construct a rate equation, and identify failures of such models

### Calculators

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

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



## Appendix 5: Grade descriptors

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The following grade descriptors indicate the level of attainment characteristic of the middle of the given grade. They give a general indication of the required standard at each specified grade. The descriptors should be interpreted in relation to the content outlined in the syllabus; they are not designed to define that content.

The grade awarded will depend in practice upon the extent to which the candidate has met the assessment objectives overall. Shortcomings in some aspects of the examination may be balanced by better performance in others.

### Distinction (D2)

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

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

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

### Merit (M2)

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

Candidates apply knowledge and principles of chemistry contained within the syllabus in familiar and some unfamiliar contexts. In questions requiring numerical calculations, candidates demonstrate some understanding of the underlying relationships between quantities involved and are usually aware of the

magnitudes of common quantities. Candidates are usually successful in calculations where some structure is provided and can carry out some elements of extended calculations correctly.

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

### **Pass (P2)**

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

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

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

## Appendix 6: Additional information

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### Guided learning hours

It is intended that each Principal Subject should be delivered through 380 hours of guided learning. This is a notional measure of the substance of the qualification. It includes an estimate of the time that might be allocated to direct teaching or instruction, together with other structured learning time such as directed assignments or supported individual study and practice. It excludes learner-initiated private study.

### Certification title

This qualification is shown on a certificate as:

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

The qualification is accredited at Level 3 of the UK National Qualifications Framework and provides a solid grounding for candidates to pursue a variety of progression pathways.

### Entries

For entry information please refer to the *UK E3 Booklet*.

### Grading and reporting

The Cambridge International Level 3 Pre-U Certificates in the Principal Subjects are qualifications in their own right. They are acceptable as an alternative to A Level (or other Level 3 qualifications) for entry into higher education or employment. Each individual Principal Subject is graded separately on a scale of nine grades: Distinction 1, Distinction 2, Distinction 3, Merit 1, Merit 2, Merit 3, Pass 1, Pass 2, Pass 3.

Subjects can also be combined with two core components to meet the requirements for eligibility for the Cambridge International Level 3 Pre-U Diploma. More details about the Diploma requirements and the core components can be found in a separate Diploma syllabus. The results of the individual Principal Subjects are reported on a separate certificate to the Diploma result.

### Classification code for UK Centres

In the UK, every syllabus is assigned to a national classification code that indicates the subject area to which it belongs. UK Centres should be aware that candidates who enter for more than one qualification with the same classification code will have only one grade (the highest) counted for the purpose of the School and College Performance Tables.

The classification code for this syllabus is **1110**.

### Language

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

### **Procedures and regulations**

This syllabus complies with the *CIE Code of Practice* and *The Statutory Regulation of External Qualifications 2004*.

Further information about the administration of Cambridge Pre-U qualifications can be found in the *CIE Handbook for UK Centres* available from CIE Publications or by contacting [international@cie.org.uk](mailto:international@cie.org.uk).

### **Spiritual, moral, ethical, social, legislative, economic and cultural issues**

The syllabus provides a number of areas in which candidates may appreciate the moral, social, ethical, economic and cultural issues surrounding chemical industry and research, both on a local and on a global scale. It is expected that candidates will gain a deeper appreciation and understanding of the atomic and molecular workings of the world around them. There are no legislative issues in this syllabus.

### **Sustainable development, health and safety considerations, European developments and international agreements**

Aspects of environmental education and sustainable development occur in relation to reducing the impact of chemical industry and research on the environment, finding benign alternatives to hazardous chemicals and improving efficiency of syntheses.

Aspects of environmental education and sustainable development are covered in sections B1.5, A2.2 and A3.6.

The following health and safety issues feature in this syllabus:

- safe practice in laboratories
- issues associated with the impact of electricity generation, chemical industry and research on the environment.

Health and safety issues are covered in section A2.2, A3.6 and Appendix 1.

There are opportunities in this syllabus to investigate local, national and international contributions to the subject field and to appreciate the global significance and impact of chemical endeavour. For example, section 1: fuel cells, industrial processes; section 2: novel materials, inorganic pollutants; section 3: advances in drug development, polymer chemistry, green chemistry; section 4: pharmaceutical analysis, drug detection.

### **Avoidance of bias**

CIE has taken great care in the preparation of this syllabus and assessment materials to avoid bias of any kind.

## Key Skills

This syllabus provides opportunities for the development of evidence for the Key Skills of: *Communication, Application of Number, Information Technology, Working with Others, Improving Own Learning and Performance* and *Problem Solving* at Levels 2 and/or 3. However, the extent to which this evidence fulfils the Key Skills criteria at these levels will be totally dependent on the style of teaching and learning adopted for each section.

The Key Skills awarding bodies and the regulatory authorities have produced a suite of example portfolios that will help to give candidates and practitioners a clear understanding of the requirements for the Key Skills portfolio. These are available on the QCDA Key Skills website ([www.qcda.org.uk/keyskills](http://www.qcda.org.uk/keyskills)). Full details of the requirements for certification can be obtained from the awarding bodies that are approved to offer Key Skills. For further information about Key Skills assessment, please see the document *The Key Skills Qualifications Standards and Guidance* published by the Qualifications and Curriculum Authority 2004 (ISBN 1 85838 548 2).

The following table indicates where opportunities may exist for at least some coverage of the various Key Skills criteria at Levels 2 and/or 3 for each section.

| Component | Communication | Application of Number | IT | Working with Others | Improving own Learning and Performance | Problem Solving |
|-----------|---------------|-----------------------|----|---------------------|--|-----------------|
| 1         | ✓             | ✓                     | ✓  | ✓                   | ✓                                      | ✓               |
| 2         | ✓             |                       | ✓  | ✓                   | ✓                                      | ✓               |
| 3         | ✓             |                       | ✓  |                     | ✓                                      | ✓               |
| 4         | ✓             | ✓                     | ✓  | ✓                   | ✓                                      | ✓               |

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