

**CHEMISTRY 9701  
GCE A/AS Level  
FOR EXAMINATION IN 2008**

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# CHEMISTRY

## GCE Advanced Subsidiary Level and GCE Advanced Level 9701

### CONTENTS

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|  | <i>Page</i> |
|--|-------------|
| INTRODUCTION   | 1           |
| AIMS   | 1           |
| ASSESSMENT OBJECTIVES                                  | 3           |
| SCHEME OF ASSESSMENT                                   | 5           |
| WEIGHTING OF ASSESSMENT OBJECTIVES                     | 6           |
| STRUCTURE OF THE SYLLABUS                              | 7           |
| SUBJECT CONTENT  | 8           |
| PRACTICAL ASSESSMENT                                   | 33          |
| SAFETY IN THE LABORATORY                               | 46          |
| MATHEMATICAL REQUIREMENTS                              | 47          |
| INFORMATION TECHNOLOGY (IT) USAGE IN A LEVEL CHEMISTRY | 48          |
| GLOSSARY OF TERMS USED IN SYLLABUS/SCIENCE PAPERS      | 52          |
| DATA BOOKLET   | 55          |
| TEXTBOOKS AND IT RESOURCES                             | 65          |

### NOTE

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Attention is drawn to the alterations in the syllabus by black vertical lines on either side of the text.

Copies of syllabuses, past papers and Examiners' Reports are available on CD ROM and can be ordered using the Publications Catalogue, which is available at [www.cie.org.uk](http://www.cie.org.uk) under 'Qualifications & Diplomas' – 'Order Publications'.



## INTRODUCTION

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This syllabus is designed to give greater flexibility both to teachers and to candidates and to place greater emphasis on the understanding and application of scientific concepts and principles and less emphasis on factual material whilst still giving a thorough introduction to the study of Chemistry.

Centres and candidates may choose:

- to take all Advanced Level components in the same examination session leading to the full A Level
- to follow a **staged** assessment route to the Advanced Level by taking the Advanced Subsidiary qualification in an earlier examination session. Subject to satisfactory performance such candidates are then only required to take the final part of the assessment (referred to in this syllabus as A2) leading to the full A Level
- to take the Advanced Subsidiary qualification only

## AIMS

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These are not listed in order of priority.

Many of these Aims are reflected in the Assessment Objectives which follow; others are not readily assessed.

The syllabus aims are to:

- 1 provide, through well designed studies of experimental and practical chemistry, a worthwhile educational experience for all students, whether or not they go on to study science beyond this level and, in particular, to enable them to acquire sufficient understanding and knowledge to
  - 1.1 become confident citizens in a technological world, able to take or develop an informed interest in matters of scientific import;
  - 1.2 recognise the usefulness, and limitations, of scientific method and to appreciate its applicability in other disciplines and in everyday life;
  - 1.3 be suitably prepared for employment and/or further studies beyond A level.
- 2 develop abilities and skills that
  - 2.1 are relevant to the study and practice of science;
  - 2.2 are useful in everyday life;
  - 2.3 encourage efficient and safe practice;
  - 2.4 encourage the presentation of information and ideas appropriate for different audiences and purposes;
  - 2.5 develop self motivation and the ability to work in a sustained fashion.

- 3 develop attitudes relevant to science such as:
  - 3.1 accuracy and precision;
  - 3.2 objectivity;
  - 3.3 integrity;
  - 3.4 enquiry;
  - 3.5 initiative;
  - 3.6 insight.
- 4 stimulate interest in, and care for, the environment.
- 5 promote an awareness that:
  - 5.1 the study and practice of science are co-operative and cumulative activities, and are subject to social, economic, technological, ethical and cultural influences and limitations;
  - 5.2 the applications of science may be both beneficial and detrimental to the individual, the community and the environment.
  - 5.3 the use of information technology is important for communication, as an aid to experiments and as a tool for interpretation of experimental and theoretical results.
- 6 stimulate students, create and sustain their interest in Chemistry, and understand its relevance to society.

## ASSESSMENT OBJECTIVES

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

### A Knowledge with understanding

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

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

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

### B Handling, applying and evaluating information

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

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

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

**C Experimental skills and investigations**

Students should be able to;

1. plan investigations;
2. use techniques, apparatus and materials;
3. make and record observations, measurements and estimates;
4. interpret and evaluate observations and experimental results;
5. select techniques, apparatus and materials;
6. evaluate methods and suggest possible improvements.



## SCHEME OF ASSESSMENT

| Paper | Type of Paper                     | Duration   | Marks | Weighting |         |
|-------|-----------------------------------|------------|-------|-----------|---------|
|       |                                   |            |       | AS Level  | A Level |
| 1     | Multiple-choice                   | 1 h        | 40    | 31%       | 15%     |
| 2     | AS structured questions           | 1 h 15 min | 60    | 46%       | 23%     |
| 3     | Advanced Practical Skills         | 2 h        | 40    | 23%       | 12%     |
| 4     | A2 structured questions           | 1 h 45 min | 100   |           | 38%     |
| 5     | Planning, Analysis and Evaluation | 1 h 15 min | 30    |           | 12%     |

### Paper 1

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

### Paper 2

This paper will consist of a variable number of structured questions of variable mark value. All questions will be based on the AS syllabus. Candidates will answer all questions. Candidates will answer on the question paper.

### Paper 3

This paper will consist of two or three experiments drawn from different areas of chemistry. The examiners will not be restricted by the subject content. Candidates will answer on the question paper.

Two versions of this paper will be set, Paper 31 and Paper 32. The two papers will be equivalent and each candidate will be required to take only one of them. This is to allow large Centres to spread the assessment of candidates' practical skills over two days.

### Paper 4

This paper will consist of two sections.

Section A (70 marks) will consist of questions based on the A2 core.

Section B (30 marks) will consist of questions based on the section "Applications of Chemistry".

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

### Paper 5

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

### Combinations of papers

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

**Candidates may not enter for single papers either on the first occasion or for re-sit purposes. Candidates may only enter for the papers in the combinations indicated above.**

## WEIGHTING OF ASSESSMENT OBJECTIVES

The Assessment Grid below gives a general idea of the allocation of marks to assessment objectives. Whilst the overall allocation of marks to assessment objectives A and B in the theory papers is given, the balance on each paper may vary slightly.

| Assessment Objective                                   | Weighting (%) | Assessment Components |
|--|---------------|-----------------------|
| <b>A Knowledge with understanding</b>                  | 46*           | PAPERS 1, 2, 4        |
| <b>B Handling, applying and evaluating information</b> | 30            | PAPERS 1, 2, 4        |
| <b>C Experimental skills and investigations</b>        | 24            | PAPERS 3, 5           |

\*approximately 27% allocated to recall and 19% to understanding

### **Additional Information**

#### **Data Booklet**

A *Data Booklet* is available for use in Papers 1, 2 and 4. The booklet is reprinted towards the back of the syllabus. Copies of the booklet can be ordered from the Publications Office at UCLES using the appropriate order form.

#### **Nomenclature**

The ASE proposals in *Signs, Symbols and Systematics* and *Chemical Nomenclature, Symbols and Terminology for use in school science* will generally be adopted. In particular, the names sulphite, nitrite, sulphur trioxide, sulphurous acid and nitrous acid will be used in question papers.

## STRUCTURE OF THE SYLLABUS

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The syllabus has been constructed with a compulsory Advanced Subsidiary core. That part of the core syllabus which will be examined only in the full Advanced Level qualification is indicated in **bold** type. A full Advanced Level qualification requires the study of further core material together with section 11, Applications of Chemistry. The Applications of Chemistry section represents about 12% of the full Advanced Level course or 23% of the A2 course.

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

It is intended that candidates should be directed towards the practice of experimental skills throughout the whole period of their course of study. Candidates' experimental skills will be tested in papers 3 and 5. Paper 3 is a practical examination that will test the skills of manipulation of apparatus, presentation of data, analysis and evaluation. Paper 5 is a written examination that will test the higher-order experimental skills of planning, analysis and evaluation. It should be stressed that candidates cannot be adequately prepared for this paper without extensive laboratory work throughout the course of their study.

Section 11, Applications of Chemistry, is designed to allow candidates to use the chemical knowledge gained in the core syllabus to explore key areas of modern chemical science. The course provides opportunities to revise content from the core syllabus as well as introducing candidates to some new chemistry. It focuses on the applications of chemistry in research, industry and everyday life, and raises awareness of the associated ethical issues. It is intended that the teaching of this section will incorporate practical work.

The section has three parts, all of which are compulsory:

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

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

A booklet covering this section can be purchased from CIE.

Specimen papers for papers 3, 4 and 5 will be available in late 2005 via the CIE website [www.cie.org.uk](http://www.cie.org.uk)

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

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

**Aim 5.3** emphasises the importance of Information Technology (IT) in this chemistry course. It is hoped that students will make full use of IT techniques in their practical work. Teachers may also use IT in demonstrations and simulations. Asterisks (\*) placed alongside Learning Outcomes indicate areas where it is anticipated that teachers might use applications of IT, as appropriate. It should be appreciated that the list is not exhaustive.

Appropriate parts of the section **INFORMATION TECHNOLOGY (IT) USAGE IN A LEVEL CHEMISTRY** suggesting appropriate applications of IT, are printed towards the back of the syllabus.

# SUBJECT CONTENT

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- The Learning Outcomes to be studied by AS candidates are in normal type.
- The additional Learning Outcomes to be studied by A2 candidates are shown in **bold** type.

\* An asterisk (\*) placed next to an assessment objective indicates an area where IT might be used.

## PHYSICAL CHEMISTRY

### 1. ATOMS, MOLECULES AND STOICHIOMETRY

#### Content

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

#### Learning Outcomes

[the term relative formula mass or  $M_r$  will be used for ionic compounds]

Candidates should be able to:

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

## 2. ATOMIC STRUCTURE

### Content

- I The nucleus of the atom: neutrons and protons, isotopes, proton and nucleon numbers
- II Electrons: electronic energy levels, ionisation energies, atomic orbitals, extranuclear structure

### Learning Outcomes

Candidates should be able to:

- (a) \*identify and describe protons, neutrons and electrons in terms of their relative charges and relative masses
- (b) \*deduce the behaviour of beams of protons, neutrons and electrons in electric fields
- (c) describe the distribution of mass and charges within an atom
- (d) deduce the numbers of protons, neutrons and electrons present in both atoms and ions given proton and nucleon numbers (and charge)
- (e)
  - (i) describe the contribution of protons and neutrons to atomic nuclei in terms of proton number and nucleon number
  - (ii) distinguish between isotopes on the basis of different numbers of neutrons present
- (f) \*describe the number and relative energies of the s, p and d orbitals for the principal quantum numbers 1, 2 and 3 and also the 4s and 4p orbitals.
- (g) \*describe the shapes of s and p orbitals
- (h) state the electronic configuration of atoms and ions given the proton number (and charge)
- (i)
  - (i) explain and use the term ionisation energy
  - (ii) explain the factors influencing the ionisation energies of elements
  - (iii) \*explain the trends in ionisation energies across a Period and down a Group of the Periodic Table (see also Section 9)
- (j) deduce the electronic configurations of elements from successive ionisation energy data
- (k) \*interpret successive ionisation energy data of an element in terms of the position of that element within the Periodic Table

## 3. CHEMICAL BONDING

### Content

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

**Learning Outcomes**

Candidates should be able to:

- (a) \*describe ionic (electrovalent) bonding, as in sodium chloride and magnesium oxide, including the use of 'dot-and-cross' diagrams
- (b) \*describe, including the use of 'dot-and-cross' diagrams,
  - (i) covalent bonding, as in hydrogen; oxygen; chlorine; hydrogen chloride; carbon dioxide; methane; ethene
  - (ii) co-ordinate (dative covalent) bonding, as in the formation of the ammonium ion and in the  $Al_2Cl_6$  molecule
- (c) \*explain the shapes of, and bond angles in, molecules by using the qualitative model of electron-pair repulsion (including lone pairs), using as simple examples:  $BF_3$  (trigonal);  $CO_2$  (linear);  $CH_4$  (tetrahedral);  $NH_3$  (pyramidal);  $H_2O$  (non-linear);  $SF_6$  (octahedral)
- (d) \*describe covalent bonding in terms of orbital overlap, giving  $\sigma$  and  $\pi$  bonds
- (e) \*explain the shape of, and bond angles in, the ethane, ethene **and benzene** molecules in terms of  $\sigma$  and  $\pi$  bonds (see also Section 10.1)
- (f) predict the shapes of, and bond angles in, molecules analogous to those specified in (c) and (e)
- (g) describe hydrogen bonding, using ammonia and water as simple examples of molecules containing N-H and O-H groups
- (h) explain the terms *bond energy*, *bond length* and *bond polarity* and use them to compare the reactivities of covalent bonds (see also 5b(ii))
- (i) \*describe intermolecular forces (van der Waals' forces), based on permanent and induced dipoles, as in  $CHCl_3(l)$ ;  $Br_2(l)$  and the liquid noble gases
- (j) describe metallic bonding in terms of a lattice of positive ions surrounded by mobile electrons
- (k) \*describe, interpret and/or predict the effect of different types of bonding (ionic bonding; covalent bonding; hydrogen bonding; other intermolecular interactions; metallic bonding) on the physical properties of substances
- (l) deduce the type of bonding present from given information
- (m) show understanding of chemical reactions in terms of energy transfers associated with the breaking and making of chemical bonds

**4. STATES OF MATTER****Content****I The gaseous state:**

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

**II The liquid state**

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

**III The solid state**

Lattice structures



**Learning Outcomes**

Candidates should be able to:

- (a) state the basic assumptions of the kinetic theory as applied to an ideal gas
- (b) explain qualitatively in terms of intermolecular forces and molecular size:
  - (i) the conditions necessary for a gas to approach ideal behaviour
  - (ii) the limitations of ideality at very high pressures and very low temperatures
- (c) state and use the general gas equation  $pV = nRT$  in calculations, including the determination of  $M_r$
- (d) \*describe, using a kinetic-molecular model, the liquid state; melting; vaporisation and vapour pressure
- (e) \*describe, in simple terms, the lattice structure of a crystalline solid which is:
  - (i) ionic, as in sodium chloride, magnesium oxide
  - (ii) simple molecular, as in iodine
  - (iii) giant molecular, as in graphite; diamond; silicon(IV) oxide
  - (iv) hydrogen-bonded, as in ice
  - (v) metallic, as in copper[the concept of the 'unit cell' is **not** required]
- (f) explain the strength, high melting point and electrical insulating properties of ceramics in terms of their giant molecular structure
- (g) relate the uses of ceramics, based on magnesium oxide, aluminium oxide and silicon(IV) oxide, to their properties (suitable examples include furnace linings; electrical insulators; glass; crockery)
- (h) describe and interpret the uses of the metals aluminium, including its alloys, and copper, including brass, in terms of their physical properties
- (i) understand that materials are a finite resource and the importance of recycling processes
- (j) outline the importance of hydrogen bonding to the physical properties of substances, including ice and water
- (k) suggest from quoted physical data the type of structure and bonding present in a substance

**5. CHEMICAL ENERGETICS****Content**

- I Enthalpy changes:  $\Delta H$  of formation, combustion, hydration, solution, neutralisation and atomisation; bond energy; lattice energy; electron affinity
- II Hess' Law, including Born-Haber cycles

**Learning Outcomes**

Candidates should be able to:

- (a) \* explain that some chemical reactions are accompanied by energy changes, principally in the form of heat energy; the energy changes can be exothermic ( $\Delta H$ , negative) or endothermic
- (b) explain and use the terms:
  - (i) *enthalpy change of reaction* and *standard conditions*, with particular reference to: formation; combustion; hydration; solution; neutralisation; atomisation
  - (ii) *bond energy* ( $\Delta H$  positive, i.e. bond breaking)
  - (iii) *lattice energy* ( $\Delta H$  negative, i.e. gaseous ions to solid lattice)
- (c) calculate enthalpy changes from appropriate experimental results, including the use of the relationship  
enthalpy change =  $mc\Delta T$
- (d) **explain, in qualitative terms, the effect of ionic charge and of ionic radius on the numerical magnitude of a lattice energy**
- (e) apply Hess' Law to construct simple energy cycles, and carry out calculations involving such cycles and relevant energy terms, with particular reference to:
  - (i) determining enthalpy changes that cannot be found by direct experiment, e.g. an enthalpy change of formation from enthalpy changes of combustion
  - (ii) average bond energies
  - (iii) **the formation of a simple ionic solid and of its aqueous solution**
  - (iv) **Born-Haber cycles (including ionisation energy and electron affinity)**
- (f) construct and interpret a reaction pathway diagram, in terms of the enthalpy change of the reaction and of the activation energy (see Section 8)

**6. ELECTROCHEMISTRY****Content**

- I Redox processes: electron transfer and changes in oxidation number (oxidation state)
- II Electrode potentials
  - (i) Standard electrode (redox) potentials,  $E^{\ominus}$ ; the redox series
  - (ii) Standard cell potentials,  $E_{\text{cell}}^{\ominus}$ , and their uses
  - (iii) Batteries and fuel cells
- III Electrolysis
  - (i) Factors affecting the amount of substance liberated during electrolysis
  - (ii) The Faraday constant: the Avogadro constant: their relationship
  - (iii) Industrial uses of electrolysis



**Learning Outcomes**

Candidates should be able to:

- (a) describe and explain redox processes in terms of electron transfer and/or of changes in oxidation number (oxidation state)
- (b) explain, including the electrode reactions, the industrial processes of:
  - (i) the electrolysis of brine, using a diaphragm cell
  - (ii) the extraction of aluminium from molten aluminium oxide/cryolite
  - (iii) the electrolytic purification of copper
- (c) define the terms:
  - (i) **standard electrode (redox) potential**
  - (ii) **standard cell potential**
- (d) describe the standard hydrogen electrode
- (e) describe methods used to measure the standard electrode potentials of:
  - (i) metals or non-metals in contact with their ions in aqueous solution
  - (ii) ions of the same element in different oxidation states
- (f) calculate a standard cell potential by combining two standard electrode potentials
- (g) use standard cell potentials to:
  - (i) explain/deduce the direction of electron flow from a simple cell
  - (ii) \*predict the feasibility of a reaction
- (h) construct redox equations using the relevant half-equations (see also Section 9.5)
- (i) predict qualitatively how the value of an electrode potential varies with the concentration of the aqueous ion
- (j) state the possible advantages of developing other types of cell, e.g. the  $\text{H}_2/\text{O}_2$  fuel cell and improved batteries (as in electric vehicles) in terms of smaller size, lower mass and higher voltage
- (k) state the relationship,  $F = Le$ , between the Faraday constant, the Avogadro constant and the charge on the electron
- (l) predict the identity of the substance liberated during electrolysis from the state of electrolyte (molten or aqueous), position in the redox series (electrode potential) and concentration
- (m) calculate:
  - (i) the quantity of charge passed during electrolysis
  - (ii) the mass and/or volume of substance liberated during electrolysis, including those in the electrolysis of  $\text{H}_2\text{SO}_4(\text{aq})$ ;  $\text{Na}_2\text{SO}_4(\text{aq})$
- (n) describe the determination of a value of the Avogadro constant by an electrolytic method

## 7. EQUILIBRIA

### Content

#### I Chemical equilibria: reversible reactions; dynamic equilibrium

- (i) Factors affecting chemical equilibria
- (ii) Equilibrium constants
- (iii) The Haber process; the Contact process

#### II Ionic equilibria

- (i) Bronsted-Lowry theory of acids and bases
- (ii) Acid dissociation constants,  $K_a$  and the use of  $pK_a$
- (iii) The ionic product of water,  $K_w$
- (iv) pH: choice of pH indicators
- (v) Buffer solutions
- (vi) Solubility product; the common ion effect

### Learning Outcomes

Candidates should be able to:

- (a) \*explain, in terms of rates of the forward and reverse reactions, what is meant by a *reversible reaction* and *dynamic equilibrium*
- (b) \*state Le Chatelier's Principle and apply it to deduce qualitatively (from appropriate information) the effects of changes in temperature, concentration or pressure, on a system at equilibrium
- (c) deduce whether changes in concentration, pressure or temperature or the presence of a catalyst affect the value of the equilibrium constant for a reaction
- (d) deduce expressions for equilibrium constants in terms of concentrations,  $K_c$ , and partial pressures,  $K_p$   
[treatment of the relationship between  $K_p$  and  $K_c$  is **not** required]
- (e) calculate the values of equilibrium constants in terms of concentrations or partial pressures from appropriate data
- (f) calculate the quantities present at equilibrium, given appropriate data (such calculations will not require the solving of quadratic equations)
- (g) describe and explain the conditions used in the Haber process and the Contact process, as examples of the importance of an understanding of chemical equilibrium in the chemical industry (see also Section 9.6)
- (h) show understanding of, and use the Bronsted-Lowry theory of acids and bases
- (i) explain qualitatively the differences in behaviour between strong and weak acids and bases in terms of the extent of dissociation
- (j) explain the terms pH;  $K_a$ ;  $pK_a$ ;  $K_w$  and use them in calculations**
- (k) calculate  $[H^+(aq)]$  and pH values for strong and weak acids and strong bases**
- (l) explain the choice of suitable indicators for acid-base titrations, given appropriate data**
- (m) \*describe the changes in pH during acid-base titrations and explain these changes in terms of the strengths of the acids and bases**

- (n) (i) explain how buffer solutions control pH
- (ii) describe and explain their uses, including the role of  $\text{HCO}_3^-$  in controlling pH in blood
- (o) calculate the pH of buffer solutions, given appropriate data
- (p) show understanding of, and use, the concept of solubility product,  $K_{\text{sp}}$
- (q) calculate  $K_{\text{sp}}$  from concentrations and *vice versa*
- (r) show understanding of the common ion effect

## 8. REACTION KINETICS

### Content

- I Simple rate equations; orders of reaction; rate constants
- II Effect of temperature on rate constants; the concept of activation energy
- III Homogeneous and heterogeneous catalysis

### Learning Outcomes

Candidates should be able to:

- (a) explain and use the terms: *rate of reaction; activation energy; catalysis; rate equation; order of reaction; rate constant; half-life of a reaction; rate-determining step*
- (b) \*explain qualitatively, in terms of collisions, the effect of concentration changes on the rate of a reaction
- (c) \*show understanding, including reference to the Boltzmann distribution, of what is meant by the term activation energy
- (d) \*explain qualitatively, in terms both of the Boltzmann distribution and of collision frequency, the effect of temperature change on the rate of a reaction
- (e) (i) explain that, in the presence of a catalyst, a reaction has a different mechanism, i.e. one of lower activation energy
- (ii) interpret this catalytic effect in terms of the Boltzmann distribution
- (f) describe enzymes as biological catalysts (proteins) which may have specific activity
- (g) **construct and use rate equations of the form  $\text{rate} = k[\text{A}]^m[\text{B}]^n$  (limited to simple cases of single step reactions and of multi-step processes with a rate-determining step, for which  $m$  and  $n$  are 0, 1 or 2), including:**
  - (i) deducing the order of a reaction by the initial rates method
  - (ii) justifying, for zero- and first-order reactions, the order of reaction from concentration-time graphs
  - (iii) *verifying* that a suggested reaction mechanism is consistent with the observed kinetics
  - (iv) *predicting* the order that would result from a given reaction mechanism (and *vice versa*)

- (v) **calculating** an initial rate using concentration data  
[integrated forms of rate equations are not required]
- (h) (i) show understanding that the half-life of a first-order reaction is independent of concentration
- (ii) use the half-life of a first-order reaction in calculations
- (i) calculate a rate constant using the initial rates method
- (j) \*devise a suitable experimental technique for studying the rate of a reaction, from given information
- (k) outline the different modes of action of homogeneous and heterogeneous catalysis, including:
- (i) \*the Haber process
- (ii) the catalytic removal of oxides of nitrogen in the exhaust gases from car engines (see also Section 10.2)
- (iii) the catalytic role of atmospheric oxides of nitrogen in the oxidation of atmospheric sulphur dioxide
- (iv) catalytic role of  $\text{Fe}^{3+}$  in the  $\text{I}^-/\text{S}_2\text{O}_8^{2-}$  reaction

## 9. INORGANIC CHEMISTRY

### Statement of Aims

It is intended that the study should:

be concerned primarily with aspects of selected ranges of elements and their compounds;

be based on a study of the patterns:

- across the third period of the Periodic Table
- in the two Groups II and VII;

introduce, with examples, the transition elements and their compounds;

introduce the more important everyday aspects of nitrogen, sulphur and their compounds

apply unifying themes to inorganic chemistry, such as structure (Section 2), chemical bonding (Section 3), redox (Section 6), the reactions of ions, acid-base behaviour, precipitation (Section 7) and complexing behaviour (Section 9.5), where appropriate;

include:

- the representation of reactions by means of balanced equations (molecular and/or ionic equations, together with state symbols);
- the interpretation of redox reactions in terms of changes in oxidation state of the species involved;
- the prediction of the feasibility of reactions from  $E^\ominus$  values;
- the interpretation of chemical reactions in terms of ionic equilibria;
- the interpretation of chemical reactions in terms of the formation of complex ions.

## 9.1 THE PERIODIC TABLE: CHEMICAL PERIODICITY

### Content

- I Periodicity of physical properties of the elements: variation with proton number across the third period (sodium to argon) of:
  - (i) atomic radius and ionic radius
  - (ii) melting point
  - (iii) electrical conductivity
  - (iv) ionisation energy
- II Periodicity of chemical properties of the elements in the third period
  - (i) Reaction of the elements with oxygen, chlorine and water
  - (ii) Variation in oxidation number of the oxides (sodium to sulphur only) and of the chlorides (sodium to phosphorus only)
  - (iii) Reactions of these oxides and chlorides with water
  - (iv) Acid/base behaviour of these oxides and the corresponding hydroxides

### Learning Outcomes

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

- (a) \*describe qualitatively (and indicate the periodicity in) the variations in atomic radius, ionic radius, melting point and electrical conductivity of the elements (see the *Data Booklet*)
- (b) explain qualitatively the variation in atomic radius and ionic radius
- (c) interpret the variation in melting point and in electrical conductivity in terms of the presence of simple molecular, giant molecular or metallic bonding in the elements
- (d) explain the variation in first ionisation energy
- (e) describe the reactions, if any, of the elements with oxygen (to give  $\text{Na}_2\text{O}$ ;  $\text{MgO}$ ;  $\text{Al}_2\text{O}_3$ ;  $\text{P}_4\text{O}_{10}$ ;  $\text{SO}_2$ ;  $\text{SO}_3$ ), chlorine (to give  $\text{NaCl}$ ;  $\text{MgCl}_2$ ;  $\text{Al}_2\text{Cl}_6$ ;  $\text{SiCl}_4$ ;  $\text{PCl}_5$ ), and water (Na and Mg only)
- (f) state and explain the variation in oxidation number of the oxides and chlorides
- (g) describe the reactions of the oxides with water  
[treatment of peroxides and superoxides is **not** required]
- (h) describe and explain the acid/base behaviour of oxides and hydroxides, including, where relevant, amphoteric behaviour in reaction with sodium hydroxide (only) and acids
- (i) describe and explain the reactions of the chlorides with water
- (j) interpret the variations and trends in (f), (g), (h), and (i) in terms of bonding and electronegativity
- (k) suggest the types of chemical bonding present in chlorides and oxides from observations of their chemical and physical properties

In addition, candidates should be able to:

- (l) predict the characteristic properties of an element in a given group by using knowledge of chemical periodicity
- (m) deduce the nature, possible position in the Periodic Table, and identity of unknown elements from given information of physical and chemical properties

## 9.2 GROUP II

### Content

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

### Learning Outcomes

Candidates should be able to:

- (a) describe the reactions of the elements with oxygen and water
- (b) describe the behaviour of the oxides with water
- (c) describe the thermal decomposition of the nitrates and carbonates
- (d) interpret, and make predictions from, the trends in physical and chemical properties of the elements and their compounds
- (e) explain the use of magnesium oxide as a refractory lining material and calcium carbonate as a building material
- (f) describe the use of lime in agriculture
- (g) **interpret and explain qualitatively the trend in the thermal stability of the nitrates and carbonates in terms of the charge density of the cation and the polarisability of the large anion**
- (h) **interpret and explain qualitatively the variation in solubility of the sulphates in terms of relative magnitudes of the enthalpy change of hydration and the corresponding lattice energy**

## 9.3 GROUP IV

### Content

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

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

### Learning Outcomes

Candidates should be able to:

- (a) **outline the variation in melting point and in electrical conductivity of the elements and interpret them in terms of structure and bonding**
- (b) **describe and explain the bonding in, molecular shape and volatility of the tetrachlorides**



- (c) describe and explain the reactions of the tetrachlorides with water in terms of structure and bonding
- (d) describe and explain the bonding, acid-base nature and thermal stability of the oxides of oxidation states II and IV
- (e) describe and explain the relative stability of higher and lower oxidation states of the elements in their oxides and aqueous cations, including – where relevant -  $E^{\ominus}$  values
- (f) recognize the properties and uses of ceramics based on silicon(IV) oxide

#### 9.4 GROUP VII

##### **Content**

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

- I Characteristic physical properties
- II The relative reactivity of the elements as oxidising agents
- III Some reactions of the halide ions
- IV The manufacture of chlorine
- V The reactions of chlorine with aqueous sodium hydroxide
- VI The important uses of the halogens and of halogen compounds (see also Section 10.4)

##### **Learning Outcomes**

Candidates should be able to:

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

## 9.5 AN INTRODUCTION TO THE CHEMISTRY OF TRANSITION ELEMENTS

### Content

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

### Learning Outcomes

Candidates should be able to:

- (a) explain what is meant by a *transition element*, in terms of d-block elements forming one or more stable ions with incomplete d orbitals
- (b) \*state the electronic configuration of a first row transition element and of its ions
- (c) \*state that the atomic radii, ionic radii and first ionisation energies of the transition elements are relatively invariant
- (d) contrast, qualitatively, the melting point; density; atomic radius; ionic radius; first ionisation energy and conductivity of the transition elements with those of calcium as a typical s-block element
- (e) describe the tendency of transition elements to have variable oxidation states
- (f) predict from a given electronic configuration, the likely oxidation states of a transition element
- (g) describe and explain the use of  $\text{Fe}^{3+}/\text{Fe}^{2+}$ ,  $\text{MnO}_4^-/\text{Mn}^{2+}$  and  $\text{Cr}_2\text{O}_7^{2-}/\text{Cr}^{3+}$  as examples of redox systems (see also Section 6)
- (h) predict, using  $E^\ominus$  values, the likelihood of redox reactions
- (i) \*explain the reactions of transition elements with ligands to form complexes, including the complexes of copper(II) ions with water, hydroxide and ammonia
- (j) explain qualitatively that ligand exchange may occur, including the complexes of copper(II) ions with water, hydroxide and ammonia
- (k) describe the shape and symmetry of the d orbitals, and the splitting of degenerate d orbitals into two energy levels in octahedral complexes using the complexes of copper(II) ions with water and ammonia as examples
- (l) explain the origin of colour in transitional metal complexes resulting from the absorption of light energy as an electron moves between two non-degenerate d orbitals
- (m) describe, in qualitative terms, the effects of different ligands on the absorption, and hence colour, using the complexes of copper(II) ions with water, hydroxide and ammonia as examples
- (n) state examples of catalysis by transition metals and/or their compounds, including iron in the Haber process and vanadium in the Contact process



## 9.6 NITROGEN AND SULPHUR

### Content

#### I Nitrogen

- (i) Its unreactivity
- (ii) Ammonia, the ammonium ion, nitric acid and fertilisers
- (iii) The environmental impact of nitrogen oxides and nitrates

#### II Sulphur

- (i) The formation of atmospheric sulphur dioxide, its role in acid rain formation, the use of sulphur dioxide in food preservation
- (ii) Sulphuric acid

### Learning Outcomes

Candidates should be able to:

- (a) explain the lack of reactivity of nitrogen
- (b) describe:
  - (i) the formation, and structure, of the ammonium ion
  - (ii) the displacement of ammonia from its salts
- (c) describe the Haber process for the manufacture of ammonia from its elements, giving essential operating conditions, and interpret these conditions (qualitatively) in terms of the principles of kinetics and equilibria (see also Sections 7 and 8)
- (d) understand the industrial importance of ammonia and nitrogen compounds derived from ammonia
- (e) understand the environmental consequences of the uncontrolled use of nitrate fertilisers
- (f) understand and explain the occurrence, and catalytic removal, of oxides of nitrogen
- (g) explain why atmospheric oxides of nitrogen are pollutants, including their catalytic role in the oxidation of atmospheric sulphur dioxide
- (h) describe the formation of atmospheric sulphur dioxide from the combustion of sulphur contaminated carbonaceous fuels
- (i) state the role of sulphur dioxide in the formation of acid-rain and describe the main environmental consequences of acid-rain
- (j) state the main details of the Contact process for sulphuric acid production
- (k) understand the industrial importance of sulphuric acid
- (l) describe the use of sulphur dioxide in food preservation

## 10 ORGANIC CHEMISTRY

### Statement of Aims

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

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

## 10.1 INTRODUCTORY TOPICS

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

### Content

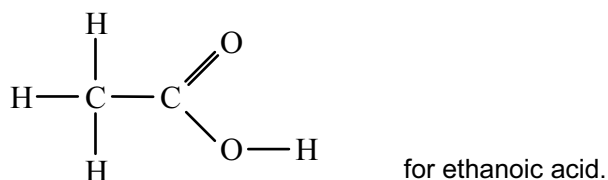
- I Molecular, structural and empirical formulae
- II Functional groups and the naming of organic compounds
- III Characteristic organic reactions
- IV Shapes of organic molecules;  $\sigma$  and  $\pi$  bonds
- V Isomerism: structural; cis-trans; optical

### Structural formulae


In candidates' answers, an acceptable response to a request for a structural formula will be to give the minimal detail, using conventional groups, for an unambiguous structure, e.g.  $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$  for propan-1-ol, **not**  $\text{C}_3\text{H}_7\text{OH}$ .

### Displayed formulae

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

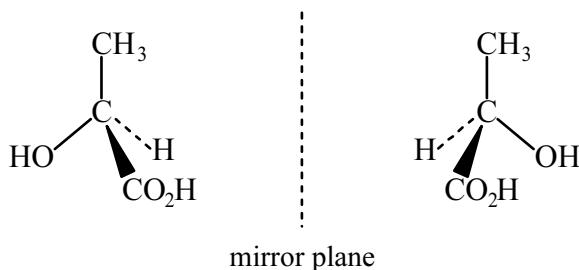


The  convention for representing the aromatic ring is preferred.

The symbol  for cyclohexane is acceptable. Skeletal or partial-skeletal representations of the carbon backbone are also acceptable where they are unambiguous.

### Optical Isomers

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



**Learning Outcomes**

Candidates should be able to:

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

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

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

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

- (c) (i) \*describe the shapes of the ethane, ethene **and benzene** molecules
- (ii) \*predict the shapes of other related molecules
- (d) \*explain the shapes of the ethane, ethene **and benzene** molecules in terms of  $\sigma$  and  $\pi$  carbon-carbon bonds
- (e) describe structural isomerism
- (f) describe *cis-trans* isomerism in alkenes, and explain its origin in terms of restricted rotation due to the presence of  $\pi$  bonds
- (g) \*explain what is meant by a *chiral centre* and that such a centre gives rise to optical isomerism
- (h) deduce the possible isomers for an organic molecule of known molecular formula
- (i) identify chiral centres and/or *cis-trans* isomerism in a molecule of given structural formula

## 10.2 HYDROCARBONS

### Content

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

### Learning Outcomes

Candidates should be able to:

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

- (j) describe the chemistry of arenes as exemplified by the following reactions of benzene and methylbenzene:
- (i) \*substitution reactions with chlorine and with bromine
  - (ii) nitration
  - (iii) oxidation of the side-chain to give a carboxylic acid
- (k) (i) \*describe the mechanism of electrophilic substitution in arenes, using the mono-nitration of benzene as an example
- (ii) describe the effect of the delocalisation of electrons in arenes in such reactions
- (l) predict whether halogenation will occur in the side-chain or aromatic nucleus in arenes depending on reaction conditions
- (m) apply the knowledge of positions of substitution in the electrophilic substitution of arenes

### 10.3 HALOGEN DERIVATIVES

#### Content

- I Halogenoalkanes and halogenoarenes
  - (i) Nucleophilic substitution
  - (ii) Hydrolysis
  - (iii) Formation of nitriles, primary amines
  - (iv) Elimination
- II Relative strength of the C-Hal bond

#### Learning Outcomes

Candidates should be able to:

- (a) recall the chemistry of halogenoalkanes as exemplified by
  - (i) the following nucleophilic substitution reactions of bromoethane: hydrolysis; formation of nitriles; formation of primary amines by reaction with ammonia
  - (ii) the elimination of hydrogen bromide from 2-bromopropane
- (b) \*describe the mechanism of nucleophilic substitution (by both  $S_N1$  and  $S_N2$  mechanisms) in halogenoalkanes
- (c) interpret the different reactivities of halogenoalkanes e.g. CFCs; anaesthetics; flame retardants; plastics **and chlorobenzene** with particular reference to hydrolysis and to the relative strengths of the C-Hal bonds
- (d) explain the uses of fluoroalkanes and fluorohalogenoalkanes in terms of their relative chemical inertness
- (e) recognise the concern about the effect of chlorofluoroalkanes on the ozone layer

## 10.4 HYDROXY COMPOUNDS

### Content

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

### Learning Outcomes

Candidates should be able to:

- (a) recall the chemistry of alcohols, exemplified by ethanol:
  - (i) combustion
  - (ii) substitution to give halogenoalkanes
  - (iii) reaction with sodium
  - (iv) oxidation to carbonyl compounds and carboxylic acids
  - (v) dehydration to alkenes
  - (vi) ester formation
- (b)
  - (i) classify hydroxy compounds into primary, secondary and tertiary alcohols
  - (ii) suggest characteristic distinguishing reactions, e.g. mild oxidation
- (c) **deduce the presence of a  $\text{CH}_3\text{CH}(\text{OH})$ - group in an alcohol from its reaction with alkaline aqueous iodine to form tri-iodomethane**
- (d) **recall the chemistry of phenol, as exemplified by the following reactions:**
  - (i) **with bases**
  - (ii) **with sodium**
  - (iii) **nitration of, and bromination of, the aromatic ring**
- (e) **explain the relative acidities of water, phenol and ethanol**

## 10.5 CARBONYL COMPOUNDS

### Content

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

**Learning Outcomes**

Candidates should be able to:

- (a) describe
  - (i) the formation of aldehydes and ketones from primary and secondary alcohols respectively using  $\text{Cr}_2\text{O}_7^{2-}/\text{H}^+$
  - (ii) the reduction of aldehydes and ketones e.g. using  $\text{NaBH}_4$
- (b) \*describe the mechanism of the nucleophilic addition reactions of hydrogen cyanide with aldehydes and ketones
- (c) describe the use of 2,4-dinitrophenylhydrazine (2,4-DNPH) to detect the presence of carbonyl compounds
- (d) deduce the nature (aldehyde or ketone) of an unknown carbonyl compound from the results of simple tests (i.e. Fehling's and Tollens' reagents; ease of oxidation)
- (e) **describe the reaction of  $\text{CH}_3\text{CO-}$  compounds with alkaline aqueous iodine to give tri-iodomethane**

**10.6 CARBOXYLIC ACIDS AND DERIVATIVES****Content**

- I Carboxylic acids (exemplified by ethanoic acid and benzoic acid)
  - (i) Formation from primary alcohols and nitriles
  - (ii) Salt, ester and acyl chloride formation
- II Acyl chlorides (exemplified by ethanoyl chloride)
  - (i) Ease of hydrolysis compared with alkyl and aryl chlorides
  - (ii) Reaction with alcohols, phenols and primary amines
- III Esters (exemplified by ethyl ethanoate and phenyl benzoate)
  - (i) Formation from carboxylic acids and from acyl chlorides
  - (ii) Hydrolysis (under acidic and under basic conditions)
  - (iii) Uses of esters

**Learning Outcomes**

Candidates should be able to:

- (a) describe the formation of carboxylic acids from alcohols, aldehydes and nitriles
- (b) describe the reactions of carboxylic acids in the formation of
  - (i) salts
  - (ii) esters
  - (iii) **acyl chlorides**
- (c) **explain the acidity of carboxylic acids and of chlorine-substituted ethanoic acids in terms of their structures**
- (d) **describe the hydrolysis of acyl chlorides**
- (e) **describe the reactions of acyl chlorides with alcohols, phenols and primary amines**



- (f) **explain the relative ease of hydrolysis of acyl chlorides, alkyl chlorides and aryl chlorides**
- (g) describe the formation of esters from carboxylic acids **or acyl chlorides**, using ethyl ethanoate and **phenyl benzoate** as examples
- (h) \*describe the acid and base hydrolysis of esters
- (i) **describe the formation of polyesters (see also Section 10.8)**
- (j) state the major commercial uses of esters e.g. solvents; perfumes; flavourings

## 10.7 NITROGEN COMPOUNDS

### Content

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

### Learning Outcomes

Candidates should be able to:

- (a) **describe the formation of ethylamine (by nitrile reduction - see also Section 10.3) and of phenylamine (by the reduction of nitrobenzene)**
- (b) **explain the basicity of amines**
- (c) **explain the relative basicities of ammonia, ethylamine and phenylamine in terms of their structures**
- (d) **describe the reaction of phenylamine with:**
  - (i) **aqueous bromine**
  - (ii) **nitrous acid to give the diazonium salt and phenol**
- (e) **describe the coupling of benzenediazonium chloride and phenol and the use of similar reactions in the formation of dyestuff**
- (f) **describe the formation of amides from the reaction between  $\text{RNH}_2$  and  $\text{R}'\text{COC}/$**
- (g) **describe amide hydrolysis on treatment with aqueous alkali or acid**
- (h) **describe the acid/base properties of amino acids and the formation of zwitterions**



- (i) describe the formation of peptide bonds between amino acids and, hence, explain protein formation
- (j) describe the hydrolysis of proteins
- (k) describe the formation of polyamides (see also Section 10.8)

## 10.8 POLYMERISATION

### Content

- I Addition polymerisation
- II Condensation polymerisation

### Learning Outcomes

Candidates should be able to:

- (a) describe the characteristics of addition polymerisation as exemplified by poly(ethene) and PVC
- (b) \*recognise the difficulty of the disposal of poly(alkene)s, i.e. non-biodegradability and harmful combustion products
- (c) describe the characteristics of condensation polymerisation
  - (i) in polyesters as exemplified by *Terylene*
  - (ii) in polyamides as exemplified by peptides, proteins, nylon 6 and nylon 6,6
- (d) predict the type of polymerisation reaction for a given monomer or pair of monomers
- (e) deduce the repeat unit of a polymer obtained from a given monomer or pair of monomers
- (f) deduce the type of polymerisation reaction which produces a given section of a polymer molecule
- (g) identify the monomer(s) present in a given section of a polymer molecule

## 11 APPLICATIONS OF CHEMISTRY

### Key concepts

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

### 11.1 THE CHEMISTRY OF LIFE

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

**Content**

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

**Learning Outcomes**

Candidates should be able to:

- (a) recall that proteins are condensation polymers formed from amino acid monomers and recognise and describe the generalised structure of amino acids (link to core syllabus, sections 10.7 and 10.8)
- (b) explain the importance of amino acid sequence (primary structure) in determining the properties of proteins
- (c) distinguish between the primary, secondary and tertiary structure of proteins and explain the stabilisation of secondary and tertiary structure using the chemistry learnt in the core syllabus, sections 3 and 10.7
- (d) describe and explain the characteristics of enzyme catalysis, including
  - (i) specificity (using a simple lock and key model) and the idea of competitive inhibition
  - (ii) structural integrity in relation to denaturation and non-competitive inhibition
- (e) given information, use core chemistry to explain how small molecules interact with proteins and how they can modify the structure and function of biological systems (for example, as enzyme inhibitors or cofactors, disrupting protein-protein interactions, blocking ion channels) (link to 11.3 (a))
- (f) describe the double helical structure of DNA in terms of a sugar-phosphate backbone and attached bases (Candidates will be expected to know the general structure in terms of a block diagram but will not be expected to recall the detailed structures of the components involved. Where these are required they will be given in the question paper)
- (g) explain the significance of hydrogen-bonding in the pairing of bases in DNA in relation to the replication of genetic information
- (h) explain in outline how DNA encodes for the amino acid sequence of proteins with reference to mRNA, tRNA and the ribosome in translation and transcription
- (i) explain the chemistry of DNA mutation from provided data
- (j) discuss the genetic basis of disease (for example, sickle cell anaemia) in terms of altered protein structure and function
- (k) explain how modification to protein/enzyme primary structure can result in new structure and/or function
- (l) outline in terms of the hydrolysis of ATP to ADP + P<sub>i</sub>, the provision of energy for the cell

- (m) understand why some metals are essential to life and, given information and with reference to the chemistry of the core syllabus, be able to explain the chemistry involved (for example, iron in haemoglobin (section 9.5 (g) and 11.1(e) and (j)), sodium and potassium in transmission of nerve impulses (section 3, ion solvation and section 5, energetics), zinc as an enzyme cofactor (section 10.1, nucleophilic attack, 11.1(e)))
- (n) recognise that some metals are toxic and discuss, in chemical terms, the problems associated with heavy metals in the environment entering the food chain, for example mercury (development of methods to detect and address these problems will be discussed in 11.2(i) and 11.3(f))

## 11.2 APPLICATIONS OF ANALYTICAL CHEMISTRY

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

### Content

- I Methods of detection and analysis
- II Applications in chemistry and society

### Learning Outcomes

Candidates should be able to:

- (a) describe simply the process of electrophoresis and the effect of pH, using peptides and amino acids as examples (link to 11.1 (a))
- (b) explain, in simple terms, the technique of DNA fingerprinting and its applications in forensic science, archaeology and medicine
- (c) describe the importance to modern medicine, and the challenges, of separating and characterising the proteins in cells (link to 11.1)
- (d) outline in simple terms the principles of nuclear magnetic resonance in  $^1\text{H}$  and be able to interpret simple NMR spectra
- (e) show awareness of the use of NMR and X-ray crystallography in determining the structure of macromolecules and in understanding their function (link to 11.1 (c) and 11.2 (c))
- (f) state what is meant by partition coefficient and calculate a partition coefficient for a system in which the solute is in the same molecular state in the two solvents
- (g) understand qualitatively paper, high performance liquid, thin layer and gas/liquid chromatography in terms of adsorption and/or partition and be able to interpret data from these techniques
- (h) explain the concept of mass spectroscopy, deduce the number of carbon atoms in a compound using the M+1 peak and the presence of bromine and chlorine atoms using the M+2 peak and suggest the identity of molecules formed by simple fragmentation in a given mass spectrum (see also core syllabus, section 1 (c) and (d))
- (i) draw conclusions given appropriate information and data from environmental monitoring (for example, PCBs in the atmosphere, isotopic ratios in ice cores)

### 11.3 DESIGN AND MATERIALS

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

#### **Content**

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

#### **Learning Outcomes**

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

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

# PRACTICAL ASSESSMENT

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## INTRODUCTION

Candidates should be directed towards the practice of experimental skills throughout the whole period of their course of study. As a guide, candidates should expect to spend at least 20% of their time doing practical work individually or in small groups. This 20% does not include the time spent observing teacher demonstrations of experiments. The practical work that candidates do during their course should aim to:

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

Candidates' experimental skills will be assessed in papers 3 and 5. In both papers, the examiners may not be strictly bound by the subject content of the syllabus in finding contexts for the setting of questions. Within unfamiliar contexts, candidates will be told exactly what to do and how to do it. Knowledge of theory and experimental skills will be drawn only from within the syllabus.

## PAPER 3

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

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

The paper will consist of two or three questions, totalling 40 marks. One question will be an observational problem in which the candidate will be asked to investigate by specified experiments, an unknown substance or substances. Candidates will be expected to draw up tables to record their observations, to analyse their results and to draw appropriate conclusions. The substances may be elements, compounds or mixtures. The other question or questions will be quantitative, either volumetric analysis or measurement of some quantity e.g. the enthalpy change of a reaction. Candidates will be expected to draw up tables, graphs and other appropriate means of presenting the data, to analyse it and perform calculations and to draw appropriate conclusions. One or more of the questions will require candidates to identify sources of error and make suggestions for change.

Each examination session, two versions of Paper 3 will be available. Each candidate should take one of these two versions. Some Centres may wish to divide their candidates so that some are entered for one version and the others are entered for the other version; other Centres may wish to enter all of their candidates for the same paper. The two versions of the paper will contain different questions, but will be equivalent in the skills assessed and in the level of demand.

**Mark scheme for Paper 3**

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

| <b>Skill</b>                              |          | <b>Approximate breakdown of marks</b>                                   |         |
|---|----------|---|---------|
| Manipulation, measurement and observation | 16 marks | Successful collection of data and observations                          | 8 marks |
|   |          | Quality of measurements or observations                                 | 4 marks |
|   |          | Decisions relating to measurements or observations                      | 4 marks |
| Presentation of data and observations     | 12 marks | Recording data and observations   | 5 marks |
|   |          | Display of calculation and reasoning                                    | 3 marks |
|   |          | Data layout   | 4 marks |
| Analysis, conclusions and evaluation      | 12 marks | Interpretation of data or observations and identifying sources of error | 6 marks |
|   |          | Drawing conclusions   | 5 marks |
|   |          | Suggesting improvements   | 1 marks |

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

Candidates should be able to:

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

Systematic analysis and a knowledge of traditional methods of separation will not be required. It will be assumed that candidates will be familiar with (i) the reactions of the following cations:  $\text{NH}_4^+$ ;  $\text{Mg}^{2+}$ ;  $\text{Al}^{3+}$ ;  $\text{Ca}^{2+}$ ;  $\text{Cr}^{3+}$ ;  $\text{Mn}^{2+}$ ;  $\text{Fe}^{2+}$ ;  $\text{Fe}^{3+}$ ;  $\text{Cu}^{2+}$ ;  $\text{Zn}^{2+}$ ;  $\text{Ba}^{2+}$ ;  $\text{Pb}^{2+}$ ; (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 which will be included with the question paper and are reproduced at the end of the section.

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

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

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

A knowledge of the following volumetric determinations will be assumed: acids and alkalis using suitable indicators; iron(II), ethanedioic acid (and its salts), by potassium manganate(VII); iodine and sodium thiosulphate. 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  $0.5^\circ\text{C}$  when using a thermometer calibrated in  $1^\circ\text{C}$  intervals and to the nearest  $0.1^\circ\text{C}$  where the interval is  $0.2^\circ\text{C}$ .



**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 making readings;
- identify where repeated readings or observations are appropriate;
- replicate readings or observations as necessary;
- identify where confirmatory tests are appropriate and the nature of such tests.

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  $\pm$  1mm, 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.

Hypotheses that are being tested in AS practical papers will be given, although hypothesis formulation is in skill B, and thus may be tested in the theory components. Conclusions may be expressed in terms of support for, or refutation of, hypotheses, or in terms of the deductions or inductions that can logically be made from the data, observations or calculated values. Simple scientific explanations form a part of such conclusions and therefore form a part of this practical assessment, in which the candidates will be expected to refer to knowledge and understanding gained in their theory part of the course in order to provide explanations of their practical conclusions.

**Suggesting improvements**

Candidates should be able to:

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

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

### Apparatus requirements for Paper 3

The apparatus requirements for Paper 3 will vary from paper to paper. A complete list of apparatus and materials required for each question will be issued in the Confidential Instructions. The Confidential Instructions should be followed very carefully. If there is any doubt at all how the practical examinations should be set up, it is vital that Centres contact CIE as soon as possible.

To provide some variation in the questions set, some novel items of equipment or material may be required. The list of practical apparatus and materials later in the syllabus gives details of the requirements that are frequently required. Candidates should be accustomed to using these.

## PAPER 5

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

- planning;
- analysis and evaluation.

This examination paper will not require laboratory facilities.

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

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

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

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

The paper will consist of two or more questions totalling 30 marks. Candidates will be required to design an experimental investigation of a given problem. Such questions will not be highly structured: candidates will be expected to answer using extended, structured writing, illustrated with appropriate diagrams, flow charts, tables or equations. Candidates may be asked to express a prediction in the form of a written hypothesis linking independent and dependent variables, or in the form of a graph showing the expected outcome. There will be activities in which candidates will be given some experimental data and will be required to analyse, evaluate and draw conclusions from it. These questions also will not be highly structured: candidates will be expected to decide for themselves the means that should be used to analyse, evaluate and conclude.

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

**Mark scheme for Paper 5**

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

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

**Planning****Defining the problem**

Candidates should be able to:

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

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

**Methods**

Candidates should be able to:

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

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

Candidates should be able to carry out a simple risk assessment of their plan, identifying the areas where accident or injury is most likely and areas where it would be most serious. They should be able to use this to propose appropriate safety precautions specifically related to the risks that they have identified – e.g. the experiment gives off NO<sub>2</sub> fumes and should be carried out in a fume hood.

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

### **Analysis, conclusions and evaluation**

#### **Dealing with data**

Candidates should be able to:

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

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

#### **Evaluation**

Candidates should be able to:

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

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

**Conclusions**

Candidates should be able to:

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

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



**APPARATUS AND MATERIALS LIST**

This list given below has been drawn up in order to give guidance to schools concerning the apparatus that is expected to be generally available for examination purposes. 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>, 250 cm<sup>3</sup>

Thermometers: -10 °C to +110 °C at 1 °C;

-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 x 16 mm

Boiling tubes, approximately 150 mm x 25 mm

Clocks (or wall-clock) to measure to an accuracy of about 1s (Where clocks are specified, candidates may use their own wrist watches if they prefer.)

Balance, single-pan, direct reading, minimum accuracy 0.1 g (1 per 8-12 candidates) weighing to 300g

The following list gives the standard reagents and materials for qualitative analysis that are expected to be available for examination purposes. In particular, it is expected that candidates will have access in the examination to all reagents and materials for testing the gases specified in the syllabus. Most examinations will also require reagents not on this list.

Aqueous ammonia (approximately 2.0 mol dm<sup>-3</sup>)

Aqueous sodium hydroxide (approximately 2.0 mol dm<sup>-3</sup>)

Hydrochloric acid (approximately 2.0 mol dm<sup>-3</sup>)

Nitric acid (approximately 2.0 mol dm<sup>-3</sup>)

Sulphuric acid (approximately 1.0 mol dm<sup>-3</sup>)

Aqueous potassium dichromate(VI) (approximately 0.1 mol dm<sup>-3</sup>)

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

Details of the specific requirements for apparatus and materials for a particular examination are given in the Instructions for Supervisors 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 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.

**QUALITATIVE ANALYSIS NOTES***[Key: ppt. = precipitate]***1 Reactions of aqueous cations**

| <i>cation</i>                                  | <i>reaction with</i>   |  |
|--|--|--|
|  | 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) | ammonia produced on<br>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.<br>insoluble in excess                                  | green ppt.<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.<br>insoluble in excess                              | off-white ppt.<br>insoluble in excess                    |
| zinc,<br>Zn <sup>2+</sup> (aq)                 | white ppt.<br>soluble in excess                                    | white ppt.<br>soluble in excess                          |

[Lead(II) 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 pale 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) |
| sulphate,<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)  |
| sulphite,<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,<br>$\text{NH}_3$         | turns damp red litmus paper blue   |
| carbon dioxide,<br>$\text{CO}_2$  | gives a white ppt. with limewater<br>(ppt. dissolves with excess $\text{CO}_2$ ) |
| chlorine,<br>$\text{Cl}_2$        | bleaches damp litmus paper   |
| hydrogen,<br>$\text{H}_2$         | "pops" with a lighted splint   |
| oxygen,<br>$\text{O}_2$           | relights a glowing splint  |
| sulphur dioxide,<br>$\text{SO}_2$ | turns aqueous potassium dichromate(VI) (aq) from orange to green                 |

**SUMMARY OF KEY QUANTITIES AND UNITS**

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

| Quantity                               | Usual symbols      | SI unit  |
|--|--------------------|--|
| <b>Base quantities</b>                 |                    |  |
| mass                                   | $m$                | kg, g  |
| length                                 | $l$                | m  |
| time                                   | $t$                | s  |
| electric current                       | $I$                | A  |
| thermodynamic temperature              | $T$                | K  |
| amount of substance                    | $n$                | mol  |
| <b>Other quantities</b>                |                    |  |
| temperature                            | $\theta, t$        | °C   |
| volume                                 | $V, v$             | $\text{m}^3, \text{dm}^3$                              |
| density                                | $\rho$             | $\text{kg m}^{-3}, \text{g dm}^{-3}, \text{g cm}^{-3}$ |
| pressure                               | $p$                | Pa   |
| frequency                              | $\nu, f$           | Hz   |
| wavelength                             | $\lambda$          | m, mm, nm  |
| speed of electromagnetic waves         | $c$                | $\text{m s}^{-1}$                                      |
| Planck constant                        | $h$                | J s  |
| electric potential difference          | $V$                | V  |
| (standard) electrode redox } potential | $(E^\ominus) E$    | V  |
| electromotive force                    | $E$                | V  |
| molar gas constant                     | $R$                | $\text{J K}^{-1} \text{mol}^{-1}$                      |
| half-life                              | $T_{1/2}, t_{1/2}$ | s  |
| atomic mass                            | $m_a$              | kg   |
| relative { atomic isotopic } mass      | $A_r$              | —  |
| molecular mass                         | $m$                | kg   |
| relative molecular mass                | $M_r$              | —  |
| molar mass                             | $M$                | $\text{kg mol}^{-1}$                                   |
| nucleon number                         | $A$                | —  |
| proton number                          | $Z$                | —  |
| neutron number                         | $N$                | —  |
| number of molecules                    | $N$                | —  |
| number of molecules per unit volume    | $n$                | $\text{m}^{-3}$  |
| Avogadro constant                      | $L$                | $\text{mol}^{-1}$                                      |
| Faraday constant                       | $F$                | $\text{C mol}^{-1}$                                    |
| enthalpy change of reaction            | $\Delta H$         | J, kJ  |
| standard enthalpy change of reaction   | $\Delta H^\ominus$ | $\text{J mol}^{-1}, \text{kJ mol}^{-1}$                |
| ionisation energy                      | $I$                | $\text{kJ mol}^{-1}$                                   |
| lattice energy                         | —                  | $\text{kJ mol}^{-1}$                                   |
| bond energy                            | —                  | $\text{kJ mol}^{-1}$                                   |
| electron affinity                      | —                  | $\text{kJ mol}^{-1}$                                   |
| rate constant                          | $k$                | as appropriate   |
| equilibrium constant                   | $K, K_p, K_c$      | as appropriate   |
| acid dissociation constant             | $K_a$              | as appropriate   |
| order of reaction                      | $n, m$             | —  |
| mole fraction                          | $x$                | —  |
| concentration                          | $c$                | $\text{mol dm}^{-3}$                                   |
| partition coefficient                  | $K$                | —  |
| ionic product, solubility product      | $K, K_{sp},$       | as appropriate   |
| ionic product of water                 | $K_w$              | $\text{mol}^2 \text{dm}^{-6}$                          |
| pH                                     | pH                 | —  |

## **SAFETY IN THE LABORATORY**

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Responsibility for safety matters rests with Centres. Attention is drawn to the following UK publications:

- (a) The requirements, as published in October 1989, of COSHH (the Control of Substances Hazardous to Health) Regulations operative in the UK.
- (b) Safe Practices in Chemical Laboratories, the Royal Society of Chemistry, 1989.
- (c) Safety in Science Laboratories, DES Safety Series, 2, HMSO, 1976.
- (d) Hazards in the Chemical Laboratory, ed. L. Bretherick, The Royal Society of Chemistry, 4th ed., 1986.
- (e) Safeguards in the School Laboratory, ASE, 9th ed., 1988.
- (f) Hazcards, as published by CLEAPSS Development Group, Brunel University, Uxbridge UB8 3PH.

## MATHEMATICAL REQUIREMENTS

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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  $<$ ,  $>$ ,  $\approx$ ,  $/$ ,  $\Delta$ ,  $\equiv$ ,  $\bar{x}$  (or  $\langle x \rangle$ ).
- (k) Test tabulated pairs of values for direct proportionality by a graphical method or by constancy of ratio.
- (l) Select appropriate variables and scales for plotting a graph, especially to obtain a linear graph of the form  $y = mx + c$ .
- (m) Determine and interpret the slope and intercept of a linear graph.
- (n) Choose by inspection a straight line that will serve as the 'least bad' linear model for a set of data presented graphically.
- (o) Understand
  - i. the slope of a tangent to a curve as a measure of rate of change,
  - ii. the 'area' below a curve where the area has physical significance, e.g. Boltzmann distribution curves.
- (p) Comprehend how to handle numerical work so that significant figures are neither lost unnecessarily nor used beyond what is justified.
- (q) Estimate orders of magnitude.
- (r) Formulate simple algebraic equations as mathematical models, e.g. construct a rate equation, and identify failures of such models.

### Calculators

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

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

## INFORMATION TECHNOLOGY (IT) USAGE IN A LEVEL CHEMISTRY

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

### 1 Data Acquisition (Hardware)

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

The following are some examples of the use of sensors and data loggers in standard A level Chemistry experiments:-

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

### 2 Data Analysis (Software)

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

### 3 Teaching Aids and Resources (Software)

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

**ADVANCED LEVEL CHEMISTRY SYLLABUS**

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

**1. ATOMS, MOLECULES AND STOICHIOMETRY**

1(c) offers an opportunity for the use of computer software to simulate the effect on the mass spectra due to the presence of isotopes. 1(g) allows the use of computer software to help students to check whether an equation is balanced.

**2. ATOMIC STRUCTURE**

Computer software can be used to illustrate the nature and simulate the behaviours of the fundamental particles in electric and magnetic fields {2(a) and (b)}.

Computer graphics and models can be used in the visualisation of the shapes and relative energies of orbitals {2(f) and (g)}.

{2(i)(iii) and (k)} allows the use of a spreadsheet to analyse and visualise the trends in ionisation energies.

**3. CHEMICAL BONDING**

Computer software can be used effectively to help students to visualise the bondings, structures, bond angles, orbital overlaps,  $\sigma$  and  $\pi$  bonds and shapes of molecules {3(a), (b), (c), (d) and (e)}.

Computer animation can be used to illustrate intermolecular forces {3(i) and (k)}.

**4. STATES OF MATTER**

3-dimensional computer models can be used to illustrate structure of liquids and crystalline solids {4(d) and (e)}.

**5. CHEMICAL ENERGETICS**

Sensors and data loggers can be used to investigate the heat changes during a chemical reaction {5(a)}. The experimental results can be studied using spreadsheets and graphical displays.

Computer simulation can be used to illustrate the effects of bond enthalpy on the  $\Delta H$  of reaction.

Computer animations can be used to illustrate the process of dissolving.

**6. ELECTROCHEMISTRY**

Computer simulation can be used to model a simple cell and study its feasibility based on  $E^\ominus$  values {6(g)(ii)} and also to illustrate electrolysis.

**7. EQUILIBRIA**

Computer simulation software and spreadsheet programs can be used to model a reversible reaction at equilibrium {7(a)}, and investigate the effects of changing the reaction conditions {7(b)}.

Computer simulations of acid-base titrations and titration curves can be used to illustrate the effects of the strength of the acid/base used {7(m)}.

**8. REACTION KINETICS**

Sensors and data loggers can be used to study the rate of reaction {8(b)}. Spreadsheets and graphical displays can be used effectively to help students in interpreting experimental data concerned with rate of reaction.



Computer software can be used to model the effects of concentration changes on the rate of reaction {8(b)}. The Boltzmann distribution {8(c)} and the effect of temperature {8(d)} can be modelled using simulation software or spreadsheet programs.

Computer animations can be used to illustrate catalysis {8(e)(i)}.

## 9.1 THE PERIODIC TABLE: CHEMICAL PERIODICITY

Spreadsheets and graphical displays can be used to investigate the trends and variations of properties within the groups and across the third period of the Periodic Table {9.1(a)}.

## 9.5 AN INTRODUCTION TO THE CHEMISTRY OF TRANSITION ELEMENTS

Computer software can be used to illustrate the electronic configurations {9.5(b)} and shapes of complexes, d orbital splitting and change in colour of complexes as a result of ligand change.

Spreadsheets and graphical displays can be used to illustrate the trends in the variation of some properties of transition metals {9.5(d)}.

Electronic periodic table can be used to provide physical and chemical data of elements. Digital video can be used to show reactions that are difficult or dangerous to conduct in the school laboratory.

## 10. ORGANIC CHEMISTRY

Molecular visualisation software can be used to help students in visualising the bonding types, molecular shapes and structures of alkanes, alkenes, alcohols, organic acids and their derivatives, carbonyl compounds, amines, and macromolecules. A good collection of three-dimensional simple organic as well as complex biochemical molecular models is available on the Internet in the *PDB* (**P**rotein **D**ata **B**ank) format. The VRML (**V**irtual **R**eality **M**odeling **L**anguage) format allows the visualisation of 3-D molecular models as well as molecular dynamics. These two formats can be easily viewed using standard web browsers with the appropriate plug-ins. Limited user interactions with models in these two formats are possible.

Pre-rendered, non-interactive animation movies on various topics such as organic reaction mechanism are also available on the Internet, mainly in the form of digital movie. Some common formats are *AVI* (**A**udio **V**ideo **I**nterleave), *QT* (**Q**uick**T**ime) and *MPG* (a highly compressed digital video as in Video CD). *Shockwave* movies are also available which can be interactive.

### 10.1 INTRODUCTORY TOPICS

Computer software can be used to help students in learning the nomenclature and general formula of organic compound {10.1(a)}.

Computer programs/graphics can be used to illustrate the shapes of molecules {10.1(c) and (d)}.

Three-dimensional molecular models can be used to illustrate the concept of chirality and optical isomerism {10.1(g)}.

### 10.2 HYDROCARBONS

Computer animations can be used to illustrate the various organic chemistry reaction mechanisms {10.2(c), (d)(i), (d)(ii), (e), (j)(i) and (k)(i)}.

### 10.3 HALOGEN DERIVATIVES

Computer animations can be used to illustrate the mechanism of nucleophilic substitution {10.3(b)}.



**10.5 CARBONYL COMPOUNDS**

Computer animations can be used to illustrate the mechanism of nucleophilic substitution {10.5(b)}.

**10.6 CARBOXYLIC ACIDS AND DERIVATIVES**

Computer animations can be used to illustrate the hydrolysis of esters {10.6(h)}.

**10.8 POLYMERISATION**

Internet resources can be used to provide current information on issues related to disposal of plastics {10.8(b)} and background information and examples on addition and condensation polymers.

## GLOSSARY OF TERMS USED IN SYLLABUS/SCIENCE PAPERS

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

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

In other contexts, *describe and give an account of* should be interpreted more generally, i.e. the candidate has greater discretion about the nature and the organisation of the material to be included in the answer. *Describe and explain* may be coupled in a similar way to *state and explain*.

7. *Discuss requires candidates to give a critical account of the points involved in the topic.*
8. *Outline implies brevity, i.e. restricting the answer to giving essentials.*
9. *Predict or deduce implies that the candidate is not expected to produce the required answer by recall but by making a logical connection between other pieces of information. Such information may be wholly given in the question or may depend on answers extracted in an early part of the question.*
10. *Comment is intended as an open-ended instruction, inviting candidates to recall or infer points of interest relevant to the context of the question, taking account of the number of marks available.*
11. *Suggest is used in two main contexts, i.e. either to imply that there is no unique answer (e.g. in chemistry, two or more substances may satisfy the given conditions describing an 'unknown'), or to imply that candidates are expected to apply their general knowledge to a 'novel' situation, one that may be formally 'not in the syllabus'.*
12. *Find is a general term that may variously be interpreted as calculate, measure, determine etc.*
13. *Calculate is used when a numerical answer is required. In general, working should be shown, especially where two or more steps are involved.*

14. *Measure* implies that the quantity concerned can be directly obtained from a suitable measuring instrument, e.g. length, using a rule, or angle, using a protractor.
15. *Determine* often implies that the quantity concerned cannot be measured directly but is obtained by calculation, substituting measured or known values of other quantities into a standard formula, e.g. relative molecular mass.
16. *Estimate* implies a reasoned order of magnitude statement or calculation of the quantity concerned, making such simplifying assumptions as may be necessary about points of principle and about the values of quantities not otherwise included in the question.
17. *Sketch*, when applied to graph work, implies that the shape and/or position of the curve need only be qualitatively correct, but candidates should be aware that, depending on the context, some quantitative aspects may be looked for, e.g. passing through the origin, having an intercept, asymptote or discontinuity at a particular value.  
  
In diagrams, *sketch* implies that a simple, freehand drawing is acceptable: nevertheless, care should be taken over proportions and the clear exposition of important details.
18. *Construct* is often used in relation to chemical equations where a candidate is expected to write a balanced equation, not by factual recall but by analogy or by using information in the question.
19. *Compare* requires candidates to provide both the similarities and differences between things or concepts.
20. *Classify* requires candidates to group things based on common characteristics.

**Special Note**

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





UNIVERSITY *of* CAMBRIDGE  
International Examinations

# Data Booklet

for

**Chemistry**

(Advanced Subsidiary and Advanced Level)

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

**Tables of Chemical Data****Important values, constants and standards**

|   |       |   |
|---|-------|---|
| molar gas constant  | $R$   | $= 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$  |
| the Faraday constant  | $F$   | $= 9.65 \times 10^4 \text{ C mol}^{-1}$   |
| the Avogadro constant   | $L$   | $= 6.02 \times 10^{23} \text{ mol}^{-1}$  |
| the Planck constant   | $h$   | $= 6.63 \times 10^{-34} \text{ J s}$  |
| speed of light in a vacuum  | $c$   | $= 3.00 \times 10^8 \text{ m s}^{-1}$   |
| rest mass of proton, ${}^1_1\text{H}$                                   | $m_p$ | $= 1.67 \times 10^{-27} \text{ kg}$   |
| rest mass of neutron, ${}^1_0\text{n}$                                  | $m_n$ | $= 1.67 \times 10^{-27} \text{ kg}$   |
| rest mass of electron, ${}^0_{-1}\text{e}$                              | $m_e$ | $= 9.11 \times 10^{-31} \text{ kg}$   |
| electronic charge   | $e$   | $= -1.60 \times 10^{-19} \text{ C}$   |
| molar volume of gas   | $V_m$ | $= 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p<br>$= 24 \text{ dm}^3 \text{ mol}^{-1}$ under room conditions |
| (where s.t.p. is expressed as 101 kPa, approximately, and 273 K (0 °C)) |       |   |
| ionic product of water  | $K_w$ | $= 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$<br>(at 298 K [25 °C])                                  |
| specific heat capacity of water   |       | $= 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$<br>( $= 4.18 \text{ J g}^{-1} \text{ K}^{-1}$ )                    |

**Ionisation energies (1st, 2nd, 3rd and 4th) of selected elements, in kJ mol<sup>-1</sup>**

|    | <b>Proton<br/>Number</b> | <b>First</b> | <b>Second</b> | <b>Third</b> | <b>Fourth</b> |
|----|--------------------------|--------------|---------------|--------------|---------------|
| H  | 1                        | 1310         | -             | -            | -             |
| He | 2                        | 2370         | 5250          | -            | -             |
| Li | 3                        | 519          | 7300          | 11800        | -             |
| Be | 4                        | 900          | 1760          | 14800        | 21000         |
| B  | 5                        | 799          | 2420          | 3660         | 25000         |
| C  | 6                        | 1090         | 2350          | 4610         | 6220          |
| N  | 7                        | 1400         | 2860          | 4590         | 7480          |
| O  | 8                        | 1310         | 3390          | 5320         | 7450          |
| F  | 9                        | 1680         | 3370          | 6040         | 8410          |
| Ne | 10                       | 2080         | 3950          | 6150         | 9290          |
| Na | 11                       | 494          | 4560          | 6940         | 9540          |
| Mg | 12                       | 736          | 1450          | 7740         | 10500         |
| Al | 13                       | 577          | 1820          | 2740         | 11600         |
| Si | 14                       | 786          | 1580          | 3230         | 4360          |
| P  | 15                       | 1060         | 1900          | 2920         | 4960          |
| S  | 16                       | 1000         | 2260          | 3390         | 4540          |
| Cl | 17                       | 1260         | 2300          | 3850         | 5150          |
| Ar | 18                       | 1520         | 2660          | 3950         | 5770          |
| K  | 19                       | 418          | 3070          | 4600         | 5860          |
| Ca | 20                       | 590          | 1150          | 4940         | 6480          |
| Sc | 21                       | 632          | 1240          | 2390         | 7110          |
| Ti | 22                       | 661          | 1310          | 2720         | 4170          |
| V  | 23                       | 648          | 1370          | 2870         | 4600          |
| Cr | 24                       | 653          | 1590          | 2990         | 4770          |
| Mn | 25                       | 716          | 1510          | 3250         | 5190          |
| Fe | 26                       | 762          | 1560          | 2960         | 5400          |
| Co | 27                       | 757          | 1640          | 3230         | 5100          |
| Ni | 28                       | 736          | 1750          | 3390         | 5400          |
| Cu | 29                       | 745          | 1960          | 3350         | 5690          |
| Zn | 30                       | 908          | 1730          | 3828         | 5980          |
| Ga | 31                       | 577          | 1980          | 2960         | 6190          |
| Ge | 32                       | 762          | 1540          | 3300         | 4390          |
| Br | 35                       | 1140         | 2080          | 3460         | 4850          |
| Sr | 38                       | 548          | 1060          | 4120         | 5440          |
| Sn | 50                       | 707          | 1410          | 2940         | 3930          |
| I  | 53                       | 1010         | 1840          | 2040         | 4030          |
| Ba | 56                       | 502          | 966           | 3390         | -             |
| Pb | 82                       | 716          | 1450          | 3080         | 4080          |



**Bond energies****(a) Diatomic molecules**

| <b>Bond</b> | <b>Energy/kJ mol<sup>-1</sup></b> |
|-------------|-----------------------------------|
| H—H         | 436                               |
| D—D         | 442                               |
| N≡N         | 994                               |
| O=O         | 496                               |
| F—F         | 158                               |
| Cl—Cl       | 244                               |
| Br—Br       | 193                               |
| I—I         | 151                               |
| H—F         | 562                               |
| H—Cl        | 431                               |
| H—Br        | 366                               |
| H—I         | 299                               |

**(b) Polyatomic molecules**

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

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

For ease of reference, two tabulations are given:

- (a) an extended list in alphabetical order;  
 (b) a shorter list in decreasing order of magnitude, i.e. a redox series.

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

| Electrode reaction  |   | $E^\ominus/V$ |
|---|---|---------------|
| $\text{Ag}^+ + \text{e}^-$                                | $\rightleftharpoons$ Ag   | +0.80         |
| $\text{Al}^{3+} + 3\text{e}^-$                            | $\rightleftharpoons$ Al   | -1.66         |
| $\text{Ba}^{2+} + 2\text{e}^-$                            | $\rightleftharpoons$ Ba   | -2.90         |
| $\text{Br}_2 + 2\text{e}^-$                               | $\rightleftharpoons$ 2Br <sup>-</sup>                                 | +1.07         |
| $\text{Ca}^{2+} + 2\text{e}^-$                            | $\rightleftharpoons$ Ca   | -2.87         |
| $\text{Cl}_2 + 2\text{e}^-$                               | $\rightleftharpoons$ 2Cl <sup>-</sup>                                 | +1.36         |
| $2\text{HOCl} + 2\text{H}^+ + 2\text{e}^-$                | $\rightleftharpoons$ Cl <sub>2</sub> + 2H <sub>2</sub> O              | +1.64         |
| $\text{Co}^{2+} + 2\text{e}^-$                            | $\rightleftharpoons$ Co   | -0.28         |
| $\text{Co}^{3+} + \text{e}^-$                             | $\rightleftharpoons$ Co <sup>2+</sup>                                 | +1.82         |
| $[\text{Co}(\text{NH}_3)_6]^{2+} + 2\text{e}^-$           | $\rightleftharpoons$ Co + 6NH <sub>3</sub>                            | -0.43         |
| $\text{Cr}^{2+} + 2\text{e}^-$                            | $\rightleftharpoons$ Cr   | -0.91         |
| $\text{Cr}^{3+} + 3\text{e}^-$                            | $\rightleftharpoons$ Cr   | -0.74         |
| $\text{Cr}^{3+} + \text{e}^-$                             | $\rightleftharpoons$ Cr <sup>2+</sup>                                 | -0.41         |
| $\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6\text{e}^-$ | $\rightleftharpoons$ 2Cr <sup>3+</sup> + 7H <sub>2</sub> O            | +1.33         |
| $\text{Cu}^+ + \text{e}^-$                                | $\rightleftharpoons$ Cu   | +0.52         |
| $\text{Cu}^{2+} + 2\text{e}^-$                            | $\rightleftharpoons$ Cu   | +0.34         |
| $\text{Cu}^{2+} + \text{e}^-$                             | $\rightleftharpoons$ Cu <sup>+</sup>                                  | +0.15         |
| $[\text{Cu}(\text{NH}_3)_4]^{2+} + 2\text{e}^-$           | $\rightleftharpoons$ Cu + 4NH <sub>3</sub>                            | -0.05         |
| $\text{F}_2 + 2\text{e}^-$                                | $\rightleftharpoons$ 2F <sup>-</sup>                                  | +2.87         |
| $\text{Fe}^{2+} + 2\text{e}^-$                            | $\rightleftharpoons$ Fe   | -0.44         |
| $\text{Fe}^{3+} + 3\text{e}^-$                            | $\rightleftharpoons$ Fe   | -0.04         |
| $\text{Fe}^{3+} + \text{e}^-$                             | $\rightleftharpoons$ Fe <sup>2+</sup>                                 | +0.77         |
| $[\text{Fe}(\text{CN})_6]^{3-} + \text{e}^-$              | $\rightleftharpoons$ [Fe(CN) <sub>6</sub> ] <sup>4-</sup>             | +0.36         |
| $\text{Fe}(\text{OH})_3 + \text{e}^-$                     | $\rightleftharpoons$ Fe(OH) <sub>2</sub> + OH <sup>-</sup>            | -0.56         |
| $2\text{H}^+ + 2\text{e}^-$                               | $\rightleftharpoons$ H <sub>2</sub>                                   | 0.00          |
| $\text{I}_2 + 2\text{e}^-$                                | $\rightleftharpoons$ 2I <sup>-</sup>                                  | +0.54         |
| $\text{K}^+ + \text{e}^-$                                 | $\rightleftharpoons$ K  | -2.92         |
| $\text{Li}^+ + \text{e}^-$                                | $\rightleftharpoons$ Li   | -3.04         |
| $\text{Mg}^{2+} + 2\text{e}^-$                            | $\rightleftharpoons$ Mg   | -2.38         |
| $\text{Mn}^{2+} + 2\text{e}^-$                            | $\rightleftharpoons$ Mn   | -1.18         |
| $\text{Mn}^{3+} + \text{e}^-$                             | $\rightleftharpoons$ Mn <sup>2+</sup>                                 | +1.49         |
| $\text{MnO}_2 + 4\text{H}^+ + 2\text{e}^-$                | $\rightleftharpoons$ Mn <sup>2+</sup> + 2H <sub>2</sub> O             | +1.23         |
| $\text{MnO}_4^- + \text{e}^-$                             | $\rightleftharpoons$ MnO <sub>4</sub> <sup>2-</sup>                   | +0.56         |
| $\text{MnO}_4^- + 4\text{H}^+ + 3\text{e}^-$              | $\rightleftharpoons$ MnO <sub>2</sub> + 2H <sub>2</sub> O             | +1.67         |
| $\text{MnO}_4^- + 8\text{H}^+ + 5\text{e}^-$              | $\rightleftharpoons$ Mn <sup>2+</sup> + 4H <sub>2</sub> O             | +1.52         |
| $\text{NO}_3^- + 2\text{H}^+ + \text{e}^-$                | $\rightleftharpoons$ NO <sub>2</sub> + H <sub>2</sub> O               | +0.81         |
| $\text{NO}_3^- + 3\text{H}^+ + 2\text{e}^-$               | $\rightleftharpoons$ HNO <sub>2</sub> + H <sub>2</sub> O              | +0.94         |
| $\text{NO}_3^- + 10\text{H}^+ + 8\text{e}^-$              | $\rightleftharpoons$ NH <sub>4</sub> <sup>+</sup> + 3H <sub>2</sub> O | +0.87         |
| $\text{Na}^+ + \text{e}^-$                                | $\rightleftharpoons$ Na   | -2.71         |

| Electrode reaction            |                      |  | $E^{\ominus}/V$ |
|-------------------------------|----------------------|--|-----------------|
| $Ni^{2+} + 2e^{-}$            | $\rightleftharpoons$ | Ni   | -0.25           |
| $[Ni(NH_3)_6]^{2+} + 2e^{-}$  | $\rightleftharpoons$ | Ni + 6NH <sub>3</sub>                        | -0.51           |
| $H_2O_2 + 2H^{+} + 2e^{-}$    | $\rightleftharpoons$ | 2H <sub>2</sub> O                            | +1.77           |
| $O_2 + 4H^{+} + 4e^{-}$       | $\rightleftharpoons$ | 2H <sub>2</sub> O                            | +1.23           |
| $O_2 + 2H_2O + 4e^{-}$        | $\rightleftharpoons$ | 4OH <sup>-</sup>                             | +0.40           |
| $O_2 + 2H^{+} + 2e^{-}$       | $\rightleftharpoons$ | H <sub>2</sub> O <sub>2</sub>                | +0.68           |
| $2H_2O + 2e^{-}$              | $\rightleftharpoons$ | H <sub>2</sub> + 2OH <sup>-</sup>            | -0.83           |
| $Pb^{2+} + 2e^{-}$            | $\rightleftharpoons$ | Pb   | -0.13           |
| $Pb^{4+} + 2e^{-}$            | $\rightleftharpoons$ | Pb <sup>2+</sup>                             | +1.69           |
| $PbO_2 + 4H^{+} + 2e^{-}$     | $\rightleftharpoons$ | Pb <sup>2+</sup> + 2H <sub>2</sub> O         | +1.47           |
| $SO_4^{2-} + 4H^{+} + 2e^{-}$ | $\rightleftharpoons$ | SO <sub>2</sub> + 2H <sub>2</sub> O          | +0.17           |
| $S_2O_8^{2-} + 2e^{-}$        | $\rightleftharpoons$ | 2SO <sub>4</sub> <sup>2-</sup>               | +2.01           |
| $S_4O_6^{2-} + 2e^{-}$        | $\rightleftharpoons$ | 2S <sub>2</sub> O <sub>3</sub> <sup>2-</sup> | +0.09           |
| $Sn^{2+} + 2e^{-}$            | $\rightleftharpoons$ | Sn   | -0.14           |
| $Sn^{4+} + 2e^{-}$            | $\rightleftharpoons$ | Sn <sup>2+</sup>                             | +0.15           |
| $V^{2+} + 2e^{-}$             | $\rightleftharpoons$ | V  | -1.20           |
| $V^{3+} + e^{-}$              | $\rightleftharpoons$ | V <sup>2+</sup>                              | -0.26           |
| $VO^{2+} + 2H^{+} + e^{-}$    | $\rightleftharpoons$ | V <sup>3+</sup> + H <sub>2</sub> O           | +0.34           |
| $VO_2^{+} + 2H^{+} + e^{-}$   | $\rightleftharpoons$ | VO <sup>2+</sup> + H <sub>2</sub> O          | +1.00           |
| $VO_3^{-} + 4H^{+} + e^{-}$   | $\rightleftharpoons$ | VO <sup>2+</sup> + 2H <sub>2</sub> O         | +1.00           |
| $Zn^{2+} + 2e^{-}$            | $\rightleftharpoons$ | Zn   | -0.76           |

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

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

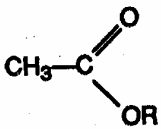
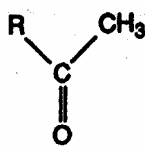
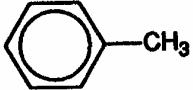
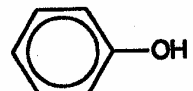
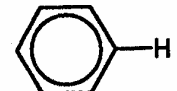
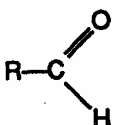
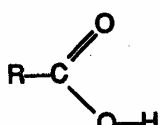
(see also the extended alphabetical list on the previous pages)

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

**Atomic and ionic radii**

| (a) <b>Period 3</b>                      | <b>atomic/nm</b> |       | <b>ionic/nm</b>  |       |
|--|------------------|-------|------------------|-------|
|  |                  |       |                  |       |
| metallic                                 | Na               | 0.186 | Na <sup>+</sup>  | 0.095 |
|  | Mg               | 0.160 | Mg <sup>2+</sup> | 0.065 |
|  | Al               | 0.143 | Al <sup>3+</sup> | 0.050 |
| single covalent                          | Si               | 0.117 | Si <sup>4+</sup> | 0.041 |
|  | P                | 0.110 | P <sup>3-</sup>  | 0.212 |
|  | S                | 0.104 | S <sup>2-</sup>  | 0.184 |
|  | Cl               | 0.099 | Cl <sup>-</sup>  | 0.181 |
| van der Waals                            | Ar               | 0.192 |                  |       |
| (b) <b>Group II</b>                      |                  |       |                  |       |
|  |                  |       |                  |       |
| metallic                                 | Be               | 0.112 | Be <sup>2+</sup> | 0.031 |
|  | Mg               | 0.160 | Mg <sup>2+</sup> | 0.065 |
|  | Ca               | 0.197 | Ca <sup>2+</sup> | 0.099 |
|  | Sr               | 0.215 | Sr <sup>2+</sup> | 0.113 |
|  | Ba               | 0.217 | Ba <sup>2+</sup> | 0.135 |
|  | Ra               | 0.220 | Ra <sup>2+</sup> | 0.140 |
| (c) <b>Group IV</b>                      |                  |       |                  |       |
|  |                  |       |                  |       |
| single covalent                          | C                | 0.077 |                  |       |
|  | Si               | 0.117 | Si <sup>4+</sup> | 0.041 |
|  | Ge               | 0.122 | Ge <sup>2+</sup> | 0.093 |
| metallic                                 | Sn               | 0.162 | Sn <sup>2+</sup> | 0.112 |
|  | Pb               | 0.175 | Pb <sup>2+</sup> | 0.120 |
| (d) <b>Group VII</b>                     |                  |       |                  |       |
|  |                  |       |                  |       |
| single covalent                          | F                | 0.072 | F <sup>-</sup>   | 0.136 |
|  | Cl               | 0.099 | Cl <sup>-</sup>  | 0.181 |
|  | Br               | 0.114 | Br <sup>-</sup>  | 0.195 |
|  | I                | 0.133 | I <sup>-</sup>   | 0.216 |
|  | At               | 0.140 |                  |       |
| (e) <b>First row transition elements</b> |                  |       |                  |       |
|  |                  |       |                  |       |
| single covalent                          | Sc               | 0.144 | Sc <sup>3+</sup> | 0.081 |
|  | Ti               | 0.132 | Ti <sup>2+</sup> | 0.090 |
|  | V                | 0.122 | V <sup>3+</sup>  | 0.074 |
|  | Cr               | 0.117 | Cr <sup>3+</sup> | 0.069 |
|  | Mn               | 0.117 | Mn <sup>2+</sup> | 0.080 |
|  | Fe               | 0.116 | Fe <sup>2+</sup> | 0.076 |
|  |                  |       | Fe <sup>3+</sup> | 0.064 |
|  | Co               | 0.116 | Co <sup>2+</sup> | 0.078 |
|  | Ni               | 0.115 | Ni <sup>2+</sup> | 0.078 |
|  | Cu               | 0.117 | Cu <sup>2+</sup> | 0.069 |
|  | Zn               | 0.125 | Zn <sup>2+</sup> | 0.074 |
|  |                  |       |                  |       |
|  |                  |       |                  |       |
|  |                  |       |                  |       |

**Typical proton chemical shift values ( $\delta$ ) relative to T.M.S.=0**

| Type of proton  | Chemical shift (ppm) |
|---|----------------------|
| $R-CH_3$  | 0.9                  |
| $R-CH_2-R$  | 1.3                  |
| $R_3CH$   | 2.0                  |
|    | 2.0                  |
|    | 2.1                  |
|    | 2.3                  |
| $R-C\equiv C-H$   | 2.6                  |
| $R-CH_2-Hal$  | 3.2–3.7              |
| $R-O-CH_3$  | 3.8                  |
| $R-O-H$   | 4.5*                 |
| $RHC=CH_2$  | 4.9                  |
| $RHC=CH_2$  | 5.9                  |
|  | 7*                   |
|  | 7.3                  |
|  | 9.7*                 |
|  | 11.5*                |

\*Sensitive to solvent, substituents, concentration

The Periodic Table of the Elements

| Group  |                              |                              |                               |                             |                                |                                |                              |                            |                              |                            |                            |                             |                               |                             |                              |                             |                             |
|--|------------------------------|------------------------------|-------------------------------|-----------------------------|--------------------------------|--------------------------------|------------------------------|----------------------------|------------------------------|----------------------------|----------------------------|-----------------------------|-------------------------------|-----------------------------|------------------------------|-----------------------------|-----------------------------|
| I  | II                           | 1.0<br>H<br>hydrogen<br>1    |                               |                             |                                |                                |                              |                            |                              |                            |                            | III                         | IV                            | V                           | VI                           | VII                         | 0                           |
| <div>Key</div> <div>relative atomic mass</div> <div>atomic symbol</div> <div>name</div> <div>atomic number</div> |                              |                              |                               |                             |                                |                                |                              |                            |                              |                            |                            |                             |                               |                             |                              |                             |                             |
| 6.9<br>Li<br>lithium<br>3  | 9.0<br>Be<br>beryllium<br>4  |                              |                               |                             |                                |                                |                              |                            |                              |                            |                            | 10.8<br>B<br>boron<br>5     | 12.0<br>C<br>carbon<br>6      | 14.0<br>N<br>nitrogen<br>7  | 16.0<br>O<br>oxygen<br>8     | 19.0<br>F<br>fluorine<br>9  | 20.2<br>Ne<br>neon<br>10    |
| 24.3<br>Mg<br>magnesium<br>12  | 40.1<br>Ca<br>calcium<br>20  | 45.0<br>Sc<br>scandium<br>21 | 47.9<br>Ti<br>titanium<br>22  | 50.9<br>V<br>vanadium<br>23 | 52.0<br>Cr<br>chromium<br>24   | 54.9<br>Mn<br>manganese<br>25  | 55.8<br>Fe<br>iron<br>26     | 58.9<br>Co<br>cobalt<br>27 | 58.7<br>Ni<br>nickel<br>28   | 63.5<br>Cu<br>copper<br>29 | 65.4<br>Zn<br>zinc<br>30   | 69.7<br>Ga<br>gallium<br>31 | 72.6<br>Ge<br>germanium<br>32 | 74.9<br>As<br>arsenic<br>33 | 79.0<br>Se<br>selenium<br>34 | 79.9<br>Br<br>bromine<br>35 | 83.8<br>Kr<br>krypton<br>36 |
| 87.6<br>Sr<br>strontium<br>38  | 88.9<br>Y<br>yttrium<br>39   | 88.9<br>Y<br>yttrium<br>39   | 91.2<br>Zr<br>zirconium<br>40 | 92.9<br>Nb<br>niobium<br>41 | 95.9<br>Mo<br>molybdenum<br>42 | 98.9<br>Tc<br>technetium<br>43 | 101<br>Ru<br>ruthenium<br>44 | 103<br>Rh<br>rhodium<br>45 | 106<br>Pd<br>palladium<br>46 | 108<br>Ag<br>silver<br>47  | 112<br>Cd<br>cadmium<br>48 | 115<br>In<br>indium<br>49   | 119<br>Sn<br>tin<br>50        | 122<br>Sb<br>antimony<br>51 | 128<br>Te<br>tellurium<br>52 | 127<br>I<br>iodine<br>53    | 131<br>Xe<br>xenon<br>54    |
| 137<br>Ba<br>barium<br>56  | 139<br>La<br>lanthanum<br>57 | 139<br>La<br>lanthanum<br>57 | 178<br>Hf<br>hafnium<br>72    | 181<br>Ta<br>tantalum<br>73 | 184<br>W<br>tungsten<br>74     | 186<br>Re<br>rhenium<br>75     | 190<br>Os<br>osmium<br>76    | 192<br>Ir<br>iridium<br>77 | 195<br>Pt<br>platinum<br>78  | 197<br>Au<br>gold<br>79    | 201<br>Hg<br>mercury<br>80 | 204<br>Tl<br>thallium<br>81 | 207<br>Pb<br>lead<br>82       | 209<br>Bi<br>bismuth<br>83  | 210<br>Po<br>polonium<br>84  | 210<br>At<br>astatine<br>85 | 222<br>Rn<br>radon<br>86    |
| 88<br>Ra<br>radium   | 89<br>Ac<br>actinium         | 89<br>Ac<br>actinium         | 104<br>Rf<br>rutherfordium    | 105<br>Db<br>dubnium        | 106<br>Sg<br>seaborgium        | 107<br>Bh<br>bohrium           | 108<br>Hs<br>hassium         | 109<br>Mt<br>meitnerium    | 110<br>Unn<br>ununium        | 111<br>Uuu<br>ununium      | 112<br>Uub<br>ununbium     | 114<br>Uuq<br>ununquadium   | 116<br>Uuh<br>ununhexium      | 118<br>Uuo<br>ununoctium    | 118<br>Uuo<br>ununoctium     | 118<br>Uuo<br>ununoctium    | 118<br>Uuo<br>ununoctium    |

|               |                           |                                 |                              |                               |                             |                             |                               |                            |                               |                            |                           |                            |                              |                             |
|---------------|---------------------------|---------------------------------|------------------------------|-------------------------------|-----------------------------|-----------------------------|-------------------------------|----------------------------|-------------------------------|----------------------------|---------------------------|----------------------------|------------------------------|-----------------------------|
| lanthanides * | 140<br>Ce<br>cerium<br>58 | 141<br>Pr<br>praseodymium<br>59 | 144<br>Nd<br>neodymium<br>60 | 145<br>Pm<br>promethium<br>61 | 150<br>Sm<br>samarium<br>62 | 152<br>Eu<br>europium<br>63 | 157<br>Gd<br>gadolinium<br>64 | 159<br>Tb<br>terbium<br>65 | 163<br>Dy<br>dysprosium<br>66 | 165<br>Ho<br>holmium<br>67 | 167<br>Er<br>erbium<br>68 | 169<br>Tm<br>thulium<br>69 | 173<br>Yb<br>ytterbium<br>70 | 175<br>Lu<br>lutetium<br>71 |
| actinides *   | 90<br>Th<br>thorium       | 91<br>Pa<br>protactinium        | 92<br>U<br>uranium           | 93<br>Np<br>neptunium         | 94<br>Pu<br>plutonium       | 95<br>Am<br>americium       | 96<br>Cm<br>curium            | 97<br>Bk<br>berkelium      | 98<br>Cf<br>californium       | 99<br>Es<br>einsteinium    | 100<br>Fm<br>fermium      | 101<br>Md<br>mendelevium   | 102<br>No<br>nobelium        | 103<br>Lr<br>lawrencium     |



## TEXTBOOKS AND IT RESOURCES

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The following books have been endorsed by CIE for use with this syllabus. They have been through an independent quality assurance process and match the syllabus content closely.

Chemistry for Advanced Level by P. Cann & P. Hughes, (Edition 2002), published by John Murray [www.johnmurray.co.uk](http://www.johnmurray.co.uk) (ISBN 071958602X)

AS Level and A Level Chemistry (Edition 2004) by B. Ratcliff, H. Eccles, J. Raffan, J. Nicholson, D. Johnson, & J. Newman, published by Cambridge University Press [www.cambridge.org](http://www.cambridge.org) (ISBN 0521544718)

The booklet *Applications of Chemistry* has been written to cover the subject material of section 11 of this syllabus and is strongly recommended. It is available from the CIE Publications Office using the appropriate order form.

Teachers may also find reference to the following books helpful.

\*Advanced Chemistry by P. Matthews, published by Cambridge University Press, (ISBN 0-521-42333-3 & 0421-42323-5)

Understanding Chemistry for Advanced Level (2nd Edition) by T. Lister & J. Renshaw, published by Stanley Thornes (ISBN 0-7487-1978-4)

Calculations on AS/A Level Chemistry by J. Clark (Edition 2000) published by Pearson Education Ltd (ISBN 0582411270)

Chemistry in Context (4th Edition) by Hill & Holman, published by Nelson (ISBN 0-17-448191-8)

Chemistry in Context Laboratory Manual and Study Guide (3rd Edition) by Hill & Holman, published by Nelson (ISBN 0-17-448231-0)

Experiments and Exercises in Basic Chemistry (3rd Edition) by S. Murov, published by John Wiley (ISBN 0-471-27232-9)

Chemical Ideas (Salters' Advanced Chemistry) by G. Burton, published by Heinemann (ISBN 0-435-63105-5)

ILPAC Advanced Practical Chemistry (second edition) edited by A. Lainchbury, J. Stephens, A. Thompson, published by John Murray (ISBN 0-7195-7507-9)

A-Level Chemistry (3rd Edition) by E. N. Ramsden, published by Stanley Thornes (ISBN 0-7487-1688-2)

Advanced Chemistry through Diagrams by M. Lewis, published by Oxford University Press, [www4.oup.co.uk](http://www4.oup.co.uk) (ISBN 0199141983)

Chemistry 1 by B. Ratcliff, D. Johnson, H. Eccles, J. Nicholson & J. Raffan, published by Cambridge University Press (ISBN 0521787785)

Chemistry 2 by B. Ratcliff & H. Eccles, published by Cambridge University Press (ISBN: 0521798825)

Classic Chemistry Experiments by Kevin Hutchings, (Edition 2000), published by The Royal Society of Chemistry [www.rsc.org](http://www.rsc.org) (ISBN: 0854049193)

Classic Chemistry Demonstrations by Ted Lister, (Edition 1995), published by The Royal Society of Chemistry (ISBN 1870343387)

Microscale Chemistry by John Skinner, (Edition 1997), published by The Royal Society of Chemistry (ISBN 1870343492)

These titles represent some of the texts available in the UK at the time of printing this booklet. Teachers are encouraged to choose texts for class use which they feel will be of interest to their students and will support their own teaching style.

\*The book marked with an asterisk is also available from Cambridge University Press in a low Priced Edition (ISBN 0-421-56698-3) from their local distributors in Africa, the Caribbean, Bangladesh, India, Nepal, Pakistan and Sri Lanka. For a full list of distributors in your local area please contact Mark Ellwood at CUP:mellwood@cambridge.org, phone +44 1223 312393, fax +44 1223 315052.

Many publishers are also producing videos and software appropriate for A-level Chemistry students.

### **Teacher's Resources on the Internet**

Chemistry and Science Sites:

<http://www.chemsoc.org>

<http://www.rsc.org>

<http://www.ase.org.uk>

CIE run a free discussion group for teachers that can be joined by visiting the CIE website [www.cie.org.uk](http://www.cie.org.uk)