IMPORTANT NOTICE

University of Cambridge International Examinations (CIE) in the UK and USA

With effect from the June 2003 examination University of Cambridge International Examinations will only accept entries in the UK and USA from students registered on courses at CIE registered Centres.

UK and USA private candidates will not be eligible to enter CIE examinations unless they are repatriating from outside the UK/USA and are part way through a course leading to a CIE examination. In that case a letter of support from the Principal of the school which they had attended is required. Other UK and USA private candidates should not embark on courses leading to a CIE examination after June 2003.

This regulation applies only to entry by private candidates in the UK and USA. Entry by private candidates through Centres in other countries is not affected.

Further details are available from Customer Services at University of Cambridge International Examinations.

You can find syllabuses and information about CIE teacher training events on the CIE Website (www.cie.org.uk).

CHEMISTRY

GCE Advanced Subsidiary Level and GCE Advanced Level 9701

CONTENTS

NOTE

Copies of syllabuses, past papers and Examiners' reports are available on CD-ROM and can be ordered using the Publications Catalogue, which is available on CIE Online at http://www.cie.org.uk/CIE/WebSite/qualificationsandawardshub/orderpublications/orderpublications.jsp.

INTRODUCTION

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

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

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.*

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.*

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

AS candidates are required to enter for Papers 1, 2 and 3

A2 candidates are required to enter for Papers 4, 5 and 6

A Level candidates are required to enter for Papers 1, 2, 3, 4, 5 and 6.

Paper	Type of Paper	Duration	Marks	Weighting (%)	
				AS	A
1	Multiple Choice	1 h	40	32	16
2	Structured Questions on AS Core	1 h 15 min	60	48	24
3	Practical Test	1 h 15 min	25	20	10
4	Structured Questions on A2 Core	1 h 15 min	60	-	23
5	Practical Test	1 h 30 min	30	-	11
6	Options	1 h	40	-	16

Paper 1 (1 h)(40 marks)

Forty multiple choice questions based on the AS core syllabus (Sections 1 to 10). Thirty items will be of the direct choice type and ten of the multiple completion type. All questions will include 4 responses.

Paper 2 (1¼ h)(60 marks)

A variable number of structured questions all compulsory, based on the AS core syllabus (Sections 1 to 10). Answered on the question paper.

Paper 3 (1¼ h)(25marks)

This will feature experiments and investigations, the Examiners will not be restricted by the subject content. The scope of the practical test is indicated in the Practical Chemistry syllabus section. The techniques required will be less demanding than those required for Paper 5 and will consist of a simple titration and a qualitative analysis.

Paper 4 (1¼ h)(60 marks)

Combining a variable number of structured and free response style questions, all compulsory, based on the A2 core syllabus. Answered on the question paper.

Paper 5 (1½ h)(30 marks)

This will feature experiments and investigations of a more demanding nature, the Examiners will not be restricted by subject content. Approximately 30% of the marks will be for assessment of planning skills. The scope of the practical test is indicated in the Practical Chemistry syllabus section and may test a wider variety of skills and more complicated titrations, investigations and analysis.

Paper 6 (1 h)(40 marks)

Candidates will be required to choose only **two** out of the five option topics and answer **all** the questions for those two options. This section will be set on the Option syllabuses (but knowledge of core material may be required) and count for a total of 40 marks.

MARKS ALLOCATED TO ASSESSMENT OBJECTIVES AND SYLLABUS AREAS

Whilst the overall allocation of marks to A and B in the theory papers is given below, the balance on each paper may vary slightly.

Theory Papers (Papers 1, 2, 4 and 6)

Knowledge with understanding (see Assessment Objectives), approximately 60% of marks, not more than 35% to recall and 25% allocated to understanding.

Handling, applying and evaluating information (see Assessment Objectives), approximately 40%.

The overall proportion of marks allocated to Physical, Inorganic and Organic chemistry in Papers 1, 2 and 4 taken together will be in the approximate ratio 3:2:3.

Options Theory Section (Paper 6)

This section is designed to test appropriate aspects of objectives A and B. Whilst every effort will be made to produce questions of comparable difficulty and reasonable spread of skills, the differing natures of the various options mean that different skills will be required of candidates according to their choice of options and questions.

Practical Test (Papers 3 & 5)

Experimental skills and investigations.

This paper is designed to test appropriate aspects of objective C. The practical paper may also involve some calculations based on experimental results.

Depending on the context in which the ‘planning/design’ element is set, the number of marks associated with this element will be in the range of 15% to 30% of the total marks available for the practical test.

Data Booklet

A *Data Booklet* is available for use in Papers 1, 2, 4 and 6. 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

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 a choice of **two** out of five Options. The Options represent about 16% of the whole course (or 30% of the A2 course).

The following options are available:

Biochemistry	**Environmental Chemistry**	**Transition Elements**
Phase Equilibria	**Spectroscopy**	

Option booklets covering these topics are available from CIE Publications.

It will be noted that some of the options are specifically directed to applied chemistry. The chosen options are also intended to illustrate the variety of contexts in which understanding of the underlying chemistry is relevant.

The options are also intended to cater for differing interests of students, for differing expertise and resources within schools and to take account of differences in locale in which schools are teaching chemistry, e.g. schools in rural or industrial communities/the local employment opportunities.

Some of the options are more obviously quantitative/mathematical in nature, whereas others have a greater descriptive content. Similarly, choice of option may also be influenced by other subjects being studied alongside chemistry. This deliberate variety is seen as a virtue of the complete syllabus.

Notwithstanding the different balances within the options to descriptive/quantitative aspects, it is intended that teachers will take appropriate opportunity to incorporate practical work relevant to the content of the options chosen.

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

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 syllabus 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

- 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}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 σ and π bonds

(e) *explain the shape of, and bond angles in, the ethane, ethene **and benzene** molecules in terms of σ and π bonds (see also Section 10.1)

(f) predict the shapes of, and bond angles in, molecules analogous to those specified in *(c)* and *(e)*

(g) describe hydrogen bonding, using ammonia and water as simple examples of molecules containing N-H and O-H groups

(h) 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, 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: ΔH of formation, combustion, hydration, solution, neutralisation and atomisation; bond energy; lattice energy; electron affinity

II Hess' Law, including Born-Haber cycles

Learning Outcomes

Candidates should be able to:

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

(b) explain and use the terms:

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

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

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^θ; the redox series
  - (ii) Standard cell potentials, E^θ_{cell}, and their uses
  - (iii) Batteries and fuel cells
- III Electrolysis
  - (i) Factors affecting the amount of substance liberated during electrolysis
  - (ii) The Faraday constant: the Avogadro constant: their relationship
  - (iii) Industrial uses of electrolysis

Learning Outcomes

Candidates should be able to:

(a) 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 9.4)**

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

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

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

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

(m) **calculate:**

  (i) ***the quantity of charge passed during electrolysis***

  (ii) ***the mass and/or volume of substance liberated during electrolysis, including those in the electrolysis of $H_2SO_4(aq)$; $Na_2SO_4(aq)$***

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

7. EQUILIBRIA

Content

I Chemical equilibria: reversible reactions; dynamic equilibrium
  (i) Factors affecting chemical equilibria
  (ii) Equilibrium constants
  (iii) The Haber process; the Contact process
II Ionic equilibria
  (i) 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 apply use in calculations**

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

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

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

(n)

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

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

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

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

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

8. REACTION KINETICS

Content

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

Learning Outcomes

Candidates should be able to:

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

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

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

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

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

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

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

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

which *m* and *n* are 0, 1 or 2), including:

- ***(i)*** **deducing the order of a reaction 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 Fe^{3+} in the $I^-/S_2O_8^{2-}$ reaction**

9. INORGANIC CHEMISTRY

Statement of Aims

It is intended that the study should:

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

be based on a study of the patterns:

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

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

introduce the more important everyday aspects of nitrogen, 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 Na_2O; MgO; Al_2O_3; P_4O_{10}; SO_2; SO_3), chlorine (to give $NaCl$; $MgCl_2$; Al_2Cl_6; $SiCl_4$; PCl_5), and water (Na and Mg only)

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

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

(ii) **describe the formation, and state the colour of, these complexes**

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

(j) **explain qualitatively that ligand exchange may occur, including CO/O_2 in haemoglobin**

(k) state examples of catalysis by transition metals and/or their compounds

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; σ and π bonds

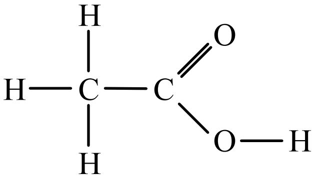
V Isomerism: structural; cis-trans; optical

Structural formulae

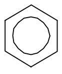
In candidates' answers, an acceptable response to a request for a structural formula will be to give the minimal detail, using conventional groups, for an unambiguous structure, e.g. $CH_3CH_2CH_2OH$ for propan-1-ol, **not** C_3H_7OH.

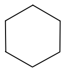
Displayed formulae

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



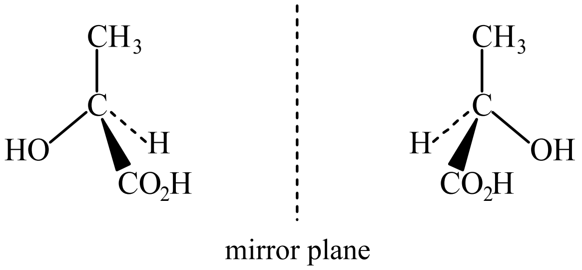
for ethanoic acid.

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 σ and π 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 π 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 π electrons on structure and properties
  - (ii) Substitution reactions with electrophiles
  - (iii) Oxidation of side-chain
- IV Hydrocarbons as fuels

Learning Outcomes

Candidates should be able to:

(a) 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 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 $CH_3CH(OH)$- group in an alcohol from its reaction with alkaline aqueous iodine to form tri-iodomethane**

(d) **recall the chemistry of phenol, as exemplified by the following reactions:**

- ***(i)*** **with bases**
- ***(ii)*** **with sodium**
- ***(iii)*** **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 $Cr_2O_7^{2+}/H^+$

(ii) the reduction of aldehydes and ketones e.g. using $NaBH_4$

(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 CH_3CO- compounds with alkaline aqueous iodine to give tri-iodomethane**

10.6 CARBOXYLIC ACIDS AND DERIVATIVES

Content

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

Learning Outcomes

Candidates should be able to:

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

(b) describe the reactions of carboxylic acids in the formation of

  (i) salts

  (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 RNH_2 and $R'COCl$**

(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 66**

(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**

INTRODUCTION TO OPTIONS

The Options are designed to be part of the A2 course and are supported by the Option Booklets available from CIE Publications.

BIOCHEMISTRY OPTION

[A detailed treatment of this topic is given in the Option Booklet *Biochemistry.*]

Statement of Aims

Biochemistry is the study of chemical processes in living organisms. Students should be aware of the characteristics of living organisms and recognise that these characteristics are maintained by complex chemical reactions. The basic structure of animal cells with reference to the structure and function of sub-cellular organelles (nucleus, mitochondria, ribosomes, endoplasmic reticulum and the cell membrane) is useful background but will **not** be examined in this option. Students will **not** be expected to memorise the formulae or structures of complex substances, such as proteins, polysaccharides and nucleic acids. Students studying Biology will inevitably have met some of the ideas in this option, but it is important to emphasise that the course lays stress on the chemical interpretation of biological processes at the molecular level.

1. PROTEINS

Content

I Amino acids

II Polypeptides and proteins

III Protein structure: primary; secondary; tertiary; quaternary structures

IV Denaturation of proteins

V Fibrous and globular proteins

VI Enzymes: relationship between enzymes and substrates; active sites; reversible inhibition; coenzymes; lysozyme

Learning Outcomes

Candidates should be able to:

(a) state the general formula for α-amino acids as $RCH(NH_2)CO_2H$; describe the nature of the functional groups contained in R and be able to interpret the properties of α-amino acids in terms of their structure

(b) *explain

  (i) the formation of the peptide linkage between α-amino acids leading to the idea that polypeptides and proteins are condensation polymers

  (ii) the term primary structure of proteins

(c) describe the hydrolysis of proteins and peptides and the separation of the products by electrophoresis and ion-exchange chromatography

(d) interpret information obtained by the techniques as outlined in *(c)*

(e) *describe the secondary structure of proteins: α-helix and β-pleated sheet and the stabilisation of these structures by hydrogen bonding

(f) state the importance of the tertiary protein structure and explain the stabilisation of the tertiary structure with regard to the R groups in the amino acid residues (ionic linkages, disulphide bridges, hydrogen bonds and van der Waals' forces)

(g) describe

  (i) *the quaternary structure of proteins

(ii) the protein components of haemoglobin

(h) explain denaturation of proteins by heavy metal ions, extremes of temperature and pH changes

(i) apply the knowledge of the loss and formation of secondary and tertiary structures to interpret common everyday phenomena

(j) describe the behaviour of enzymes as catalysts of high activity and specificity

(k) explain the relationship between enzyme and substrate concentrations in biochemical systems

(l)

(i) determine the value of V_{max} and K_m, the Michaelis constant, by graphical means

(ii) explain the meaning of, and use, V_{max} and K_m

(m) explain the significance of K_m in the different physiological roles of hexokinase and glucokinase

(n) *explain the concept of the active site in enzyme structure

(o) compare competitive and non-competitive inhibition of enzymes in terms of their effects on V_{max} and K_m

(p) *explain competitive inhibition, including feed-back control of metabolism

(q) *explain non-competitive inhibition, including by heavy metal ions

(r) explain the importance of coenzymes and cofactors with respect to enzyme activity

2. CARBOHYDRATES

Content

I Monosaccharides: α- and β-pyranose structure of glucose

II Disaccharides and polysaccharides as condensation polymers. The nature of the glycosidic link; enzymic and acid hydrolysis of the glycosidic linkage

III Structure and function of cellulose as a structural polymer and starch and glycogen as storage polymers

IV Consequences of hydrogen bonding on the relative solubilities of monosaccharides and polysaccharides in water

Learning Outcomes

Candidates should be able to:

(a) *describe the α- and β-pyranose ring structures of glucose polysaccharides and condensation polymers

(b) predict the relative solubilities of monosaccharides and polysaccharides on the basis of hydrogen bonding

(c) suggest how the structures and properties of cellulose, starch and glycogen make them suitable for their roles as structural or storage polymers in plants and animals

3. LIPIDS AND MEMBRANE STRUCTURE

Content

I Biological functions of lipids

II Simple structure and function of triglycerides

III Phosphoglycerides; simplified structure and function; formation of micelles and bilayers

IV Membranes; fluid mosaic model; active transport

Learning Outcomes

Candidates should be able to:

(a) describe the structure and function of triglyceryl esters

(b) describe the structure and function of phosphoglycerides and the formation of micelles and bimolecular layers

(c) describe the fluid mosaic structure of membranes

(d) *explain active transport by using the Na^+/K^+ pump as an example

4. NUCLEIC ACIDS

Content

I Nucleotides and nucleic acids

II DNA and RNA; base pairing

III DNA and genetic information

IV m-RNA and the triplet code

V ATP as an important example of a nucleotide; its importance in metabolic activity

Learning Outcomes

Candidates should be able to:

(a) *describe, in simple terms, the structure of nucleotides and their condensation polymers, nucleic acids

(b) describe the chemical and physical differences between DNA and RNA molecules including the concept of base pairing and the part played by hydrogen bonding

(c) explain the role of DNA as the repository of genetic information, including the triplet code

(d) describe the role of m-RNA in the transcription and translation phases in protein synthesis

(e) describe the importance of the nucleotide ATP, with regard to the part it plays in metabolic activity

ENVIRONMENTAL CHEMISTRY OPTION

[A detailed treatment of this topic is given in the Option Booklet *Environmental Chemistry*.]

Statement of Aims

Throughout this option, the emphasis is on the application of chemical facts and principles to the explanation of the processes occurring in the environment, and to the solution of problems of environmental chemical instability and pollution. In the context of this option, it is thought important that students should appreciate this aspect, bearing in mind the currently increasing concern, both national and international, for safeguarding the environment.

As standard practice, where relevant, the questions on this option will be accompanied in the question paper with data on the nitrogen, carbon, oxygen and water cycles. Questions will be based on this syllabus, not necessarily on the content of the publication described above.

Throughout this option, the teaching of the topics should be put into an environmental context.

1. THE ATMOSPHERE

Content

I The atmosphere and some of the processes that maintain its chemical composition

II The carbon cycle: photosynthesis, respiration, the exchange of carbon dioxide and oxygen between air and water

III The nitrogen cycle

IV Naturally occurring free-radical reactions

V The effects on the atmosphere of the combustion of carbon-containing fuels and of the release of pollutant gases

VI Polyatomic gases and the greenhouse effect: the control of the release of pollutants

VII Generation of power

Learning Outcomes

Candidates should be able to:

(a)

(i) apply to the carbon cycle the concepts of chemical equilibrium to describe and explain how [CO_2(atm)] depends on: photosynthesis; plant and animal respiration; equilibrium with carbon dioxide dissolved in surface water, including reference to other solution processes

(ii) calculate [CO_2(aq)] given appropriate information

(b) apply to the nitrogen cycle the concepts of chemical equilibrium to describe how [NO(atm)] and [NO_2(atm)] depends on: their production as a result of lightning discharges; the removal of NO_2 by solution in water, forming acid rain

(c) apply the concepts of dynamic chemical equilibrium to describe and explain how the stratospheric concentration of ozone is maintained by: the photodissociation of NO_2, O_2 and O_3 to give reactive oxygen atoms; the formation of O_3 and $OH^•$ by reaction of oxygen atoms with O_2 and H_2O; the reaction between O_3 and NO

(d) *(i)* apply the principles of chemical kinetics to the above reactions between free radicals and molecules

(ii) explain why free-radical reactions are important under the conditions obtaining in the upper atmosphere

(e) outline the role of ozone in the stratosphere in reducing the intensity of harmful ultra-violet radiation at the Earth's surface

(f) show understanding that the relative rates at which a substance is supplied to and removed from the atmosphere by various sinks leads to the concept of 'residence time'

(g) recognise that carbon monoxide, sulphur dioxide, oxides of nitrogen and lead compounds may be released as a result of the combustion of hydrocarbon-based fuels

(h) outline problems associated with the release of the pollutants specified in (g), including acid rain and the formation by free-radical reactions of hazardous inorganic, and organic, compounds (e.g. peroxyacetyl nitrate, pan)

(i) analyse, qualitatively, data relating to sequences of reactions, including those involving free-radicals

(j) recognise that the manufacture of lime and cement involves the release of carbon dioxide

(k) explain the build-up, and recognise the adverse effects, of ozone in the lower atmosphere

(l) describe, in terms of relevant physical properties and chemistry,

(i) the use of CFCs

(ii) the role of CFCs in destroying ozone in the stratosphere (photodissociation and free-radical chain reactions)

(m) recognise possible alternatives to the use of CFCs

(n) describe qualitatively, in terms of their ir spectra, the role of polyatomic pollutants in the greenhouse effect and predict possible consequences of this effect

(o) outline the main industrial methods of controlling sulphur dioxide emission (flue desulphurisation, removal of sulphur-containing compounds, alkaline scrubbing, use of limestone-based fluidised beds)

(p) recognise the use of lean-burn engines and catalytic converters in reducing pollutant emissions from petrol-driven cars

(q) *(i)* deduce environmental considerations related to the usage and generation of power (with particular reference to fossil fuels and nuclear energy*)*

(ii) identify other potential power sources

(r) recognise the hazards associated with radon emission from uranium-bearing rocks and with nuclear accidents

(s) outline the implications of absorption of carbon dioxide by the oceans - the greenhouse effect and rock formation

(t) recognise other functions of the oceans in regulating climate

2. THE CHEMICAL STRUCTURE OF SOIL; PROCESSES INVOLVING SOILS AND WATER

Content

I A general description of soil

II Ion exchange in soils

III Redox processes in soil and water

IV The generation of acidity within soils, its effects and control

Learning Outcomes

Candidates should be able to:

(a) describe soil as a mixture of decomposing organic material and inorganic compounds (with particular reference to N, P and K)

(b) explain the prevalence of oxides, carbonates and silicates as common insoluble components in weathered soils

(c) *outline the structure of layer silicates in terms of the combination of sheets of silicon/oxygen and aluminium/oxygen

(d) *compare 1:1 and 2:1 layer silicates, noting the importance of hydrogen bonding in the former

(e) describe ion substitution (Al^{3+} for Si^{4+} in Si/O layers and Mg^{2+} for Al^{3+}) within layer silicates

(f) explain the formation of cracks in soils as a result of drying

(g) explain how ion retention occurs on the surface of silicate clays and the importance of this for plant growth

(h) explain how adsorbed hydrogen ions maintain soil acidity (see also *(o)*, *(p)* and *(q)* below)

(i) explain the role of oxygen in maintaining nitrogen in an oxidised form to facilitate plant growth

(j) deduce from the electrode potentials the effects of reducing conditions in terms of Fe^{2+} formation and the subsequent reduction of nitrate ions

(k) explain the formation of methane and hydrogen sulphide under extreme reducing conditions, (e.g. from buried organic waste material)

(l) explain the importance of dissolved oxygen in rivers

(m) explain the role of oxides of carbon, sulphur and nitrogen in decreasing the pH of water

(n) describe soil acidification as a result of respiration and growth

(o) explain the enhancement of nitrate reduction by increased acidity and its effect on nitrogen availability

(p) describe the replacement of cations at exchange sites by hydrogen ions as the ambient acidity increases

(q) explain the lack of stability of silicate clays in acid solution and the consequent release of aluminium ions

(r) explain how the hydrated aluminium ion enhances acidity

(s) describe the increased solubility of heavy metal ions in acid solution

(t) explain how bedrocks containing carbonates limit the effects of acidity

(u) explain, in terms of the relevant equilibria, the buffering actions of the HCO_3^- ion and humus (regarded as an organic acid, RCO_2H)

(v) explain the role and limitations of liming, (e.g. as acid ice melts) in acidity control

3. THE WATER CYCLE

Content

I The primary, secondary and tertiary treatment of sewage; BOD values; nitrates and phosphates in water

II (i) The disposal of solid waste

(ii) The removal of metallic ions from industrial waste

Learning Outcomes

Candidates should be able to:

(a) explain the preparation of potable water by the separation of solid material, precipitation by using $Al^{3+}(aq)$ and purification by chlorine

(b) *outline the treatment of sewage as a removal of solids, organic matter, measured by BOD, and the use of activated charcoal and selective precipitations

(c) recognise that chlorination can cause the formation of chlorinated organic matter in domestic water

(d) explain the need for nitrogen- and phosphate-containing fertilisers

(e) describe the leaching of nitrate and the conditions leading to the release of nitrogen oxides and ammonia from fertilised land

(f) explain the function of phosphate additives in detergents and the disadvantage of its presence (along with nitrates) in river water, e.g. eutrophication

4. WASTE MANAGEMENT

Content

Disposal, treatment of waste and recycling

Learning Outcomes

Candidates should be able to:

(a) outline the use of ion exchange in the treatment of industrial waste

(b) *recognise the potential consequence of the use of land-filling and incineration (including the importance of temperature control and the possible release of dioxins) for the disposal of solid waste

(c) *outline the advantages and disadvantages of dumping waste at sea and in rivers (including sewage as a source of nutrients and the problems associated with oil spillages)

(d) *recognise the problems associated with heavy metals in the environment, typified by lead

(e) *recognise the problems associated with the disposal of radioactive waste

(f) outline the advantages and difficulties of recycling waste materials

PHASE EQUILIBRIA OPTION

[A detailed treatment of this topic is given in the Option Booklet *Phase Equilibria.*]

Statement of Aims

This option applies equilibrium concepts within the main body of the syllabus to the interactions between the different phases that occur in single component systems and those that apply to multi-component systems, i.e. mixtures/solutions involving solids and liquids.

The application of these ideas to certain analytical techniques is also included.

1. PHASE DIAGRAMS

Content

I Phase diagrams of: pure compounds; solutions of solids in solids and in liquids; solutions of liquids in liquids.

II Eutectics.

III Alloys.

Learning Outcomes

Candidates should be able to:

(a) understand that phase diagrams are graphical plots of experimentally determined results

(b) interpret phase diagrams as curves describing the conditions of equilibrium between phases and as regions representing single phases

(c) predict how phases may change with changes in temperature or pressure

(d) sketch the shape of the phase diagram for water and explain the anomalous behaviour of water

(e) understand and use the term eutectic

(f) interpret phase diagrams for two-component systems and predict how composition and phase vary with changes in temperature

(g) sketch the shape of the phase diagram for mixtures of tin and lead

(h) state, and explain in simple terms, how the properties of common alloys differ from those of pure metals in hardness, resistance to tarnishing, melting

(i) sketch the shape of the phase diagram for a two-component system, such as sodium chloride, or potassium nitrate, and water

(j) sketch the shape of the solubility curve of one of these salts in water.

2. RAOULT'S LAW AND DISTILLATION

Content

I Raoult's Law; its application to liquid-liquid mixtures; positive and negative deviations from it related to intermolecular attractions or bonding.

II Boiling point/composition curves; fractional distillation; azeotropic mixtures.

III Steam distillation.

Learning Outcomes

Candidates should be able to:

(a) state and apply Raoult's Law

(b) explain qualitatively the effect of a non-volatile solute on the vapour pressure of a solvent and, hence, on its freezing point and boiling point

(c) outline in qualitative terms the relationships between boiling point, enthalpy change of vaporisation and intermolecular forces

(d) interpret the boiling point/composition curves for mixtures of two miscible liquids in terms of 'ideal' behaviour, or positive or negative deviations from Raoult's Law

(e) understand and use the term azeotropic mixture

(f) explain the limitations on separating two components which form an azeotropic mixture

(g) describe the principles of fractional distillation of ideal liquid mixtures

(h) describe a typical laboratory fractionating column

(i) demonstrate a knowledge and understanding of the packing of fractionating columns and other means of establishing equilibrium at different temperatures between liquid and vapour

(j) (i) explain the concept of theoretical plates in fractionating columns

(ii) deduce the number of theoretical plates by graphical means, using given data

(k) explain steam distillation of two immiscible liquids

(l) demonstrate an awareness of the applications of these methods of distillation to the laboratory separation of the components of liquid mixtures

3. DISTRIBUTION BETWEEN PHASES

Content

I Solubility of gases in liquids; Henry's Law

II Partition coefficient; solvent extraction

Learning Outcomes

Candidates should be able to:

(a) describe and explain how the solubility of a gas in a liquid is affected by pressure, temperature and change of chemical state

(b) state Henry's Law and apply it in simple calculations

(c) (i) state what is meant by a partition coefficient

(ii) calculate a partition coefficient for a system in which the solute is in the same molecular state in the two solutions

(d) explain solvent extraction. e.g. by using ether

4. SEPARATION TECHNIQUES FOR ANALYSIS: CHROMATOGRAPHY AND ELECTROPHORESIS

Content

I Chromatography: theory and practice

II Electrophoresis: theory and practice in relation to peptide analysis and detection of metal ions

Learning Outcomes

Candidates should be able to:

(a) describe simply and explain qualitatively, paper, high performance liquid, thin layer and gas/liquid chromatography in terms of adsorption and/or partition, based on appropriate practical experience

(b) demonstrate an awareness of the applications of these methods of chromatography in industry and medicine

(c) describe simply the process of electrophoresis, and the effect of pH

(d) describe the hydrolysis of proteins and the separation and detection of the products by electrophoresis

(e) outline simply the process of analysis of genes and genetic fingerprinting

SPECTROSCOPY OPTION

[A detailed treatment of this option is given in the Option Booklet *Spectroscopy*.]

Statement of Aims

The aim of this option is to introduce students to the principles and methods of modem structural and quantitative analysis. The syllabus is designed to develop and complement those areas of the "core" syllabus previously encountered and to show how the various analytical techniques may be used in combination to provide evidence of structural features in molecules. In addition, the syllabus attempts to highlight the analytical methods which students will encounter both in further study and in many areas of employment in the broadly scientific field.

In questions all data normally associated with the appropriate spectra will be given. (See also the *Data Booklet*.)

1. BASIC PRINCIPLES OF SPECTROSCOPY

Content

I The electromagnetic spectrum: wavelength, frequency and energy.

II Atomic spectra: absorption and emission line spectra.

III Molecular spectra: molecular energy levels (electronic, vibration, rotational)

Learning Outcomes

Candidates should be able to:

(a) state the regions of the electromagnetic spectrum in which absorptions observed in each of the branches of spectroscopy studied occur

(b) explain the processes which bring about absorption and emission atomic spectra, using hydrogen as an example

(c) describe the molecular processes which bring about absorptions of energy; describe the relative magnitudes of such changes [Quantal formulae and selection rules are not required.]

(d) outline the use of atomic spectroscopy in an analytical context, e.g. the quantitative determination of sodium in blood serum

2. ULTRAVIOLET AND VISIBLE SPECTROSCOPY

Content

I The origin of absorptions:

- (i) colour in transition metal complexes
- (ii) organic chromophores; effects of delocalisation

II Applications of uv/visible spectroscopy:

- (i) quantitative analysis
- (ii) dyes and indicators

Learning Outcomes

Candidates should be able to:

(a) describe the shape and symmetry of the d orbitals, and the splitting of degenerate d orbitals into two energy levels in octahedral complexes

(b) (i) 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

(ii) explain the lack of colour of the complexes of Zn^{2+} and Cu^{+}

(c) describe, in qualitative terms, the effects of different ligands on the absorption, and hence colour, of a given transition metal complex

(d) predict the colour of a transition metal complex from its uv/visible spectrum

(e) predict whether a given organic molecule will absorb in the uv/visible region

(f) identify the electronic transitions responsible for absorption in organic molecules containing C=C, $-NO_2$, -N=N-, C=O benzene ring [Detailed theory of why chromophores have absorptions of appropriate energy is not required.]

(g) explain, in qualitative terms, the effects of delocalisation on absorption in the uv/visible region

(h) explain the colour changes in an acid/base indicator, e.g. phenolphthalein, in terms of a change in delocalisation

(i) use Beer's Law, $\lg(I_o/I)=\varepsilon cl$ (where c is taken merely as a constant characteristic of the substance concerned) e.g. to calculate the concentration of a given species in solution

3. INFRA-RED SPECTROSCOPY

Content

I Infra-red active and inactive modes of vibration.

II Experimental techniques.

III Applications of ir spectroscopy:

- (i) structure elucidation;
- (ii) analysis.

Learning Outcomes

Candidates should be able to:

(a) explain the origin of ir absorption of simple molecules

(b) predict the number of ir absorptions for a given simple molecule (such as CO_2 or SO_2), and identify the molecular vibrations which give rise to them

(c) describe how samples of liquids and solids can be prepared for ir analysis (liquid films, solutions, mulls and halide discs), and outline the advantages and disadvantages of each

(d) identify characteristic absorptions in the ir spectrum of a compound containing up to three functional groups (taken from Section 10 of the 'core syllabus', see also the *Data Booklet)*

(e) suggest structures for a compound from its ir spectrum

(f) outline the use of ir spectroscopy in analysis, e.g. forensic science, the monitoring of air pollution

4. NUCLEAR MAGNETIC RESONANCE SPECTROSCOPY

Content

- I Magnetic properties of nuclei possessing spin; resonance
- II Effect on absorption of chemical environment in a molecule
  - (i) Chemical shifts
  - (ii) Chemical equivalence and spin-spin splitting
- III Applications of nmr spectroscopy
  - (i) Structure elucidation
  - (ii) Quantitative analysis

Learning Outcomes

Candidates should be able to:

(a) outline, in simple terms, the principles of nuclear magnetic resonance in ^1H and ^{13}C

(b) explain

(i) how the chemical environment of a proton affects the magnetic field it experiences, and hence the absorption of energy at resonance

(ii) use of the δ scale, and TMS as a standard

(c) describe the effects of adjacent protons on the magnetic field experienced by a given proton

(d) predict, from an nmr spectrum, the number of protons in each group present in a given molecule (integration of peak area giving the relative numbers of 1H present)

(e) predict from an nmr spectrum, the number of protons adjacent to a given proton (use of spin-spin splitting as a diagnostic tool [Knowledge of the theory of why coupling occurs is not required.]

(f) suggest, from an nmr spectrum, possible structures for a molecule containing up to three functional groups (taken from Section 10 of the 'core syllabus', see also the *Data Booklet)*

(g) describe how the addition of D_2O may be used to identify labile protons

(h) outline the use of nmr spectroscopy as an important diagnostic tool in medicine in body scanners

5. MASS SPECTROMETRY

Content

I Mass spectrometry of atomic ions: determination of relative isotopic masses, isotopic abundance; high resolution mass spectrometry.

II Mass spectrometry of molecular ions: fragmentation patterns; simple cleavage; applications.

Learning Outcomes

Candidates should be able to:

(a) outline the use of mass spectrometry in the determination of relative isotopic masses and isotopic abundance

(b) explain the use of high resolution mass spectrometry in distinguishing between molecules of similar M_r

(c) explain the use of the (M+1) peak in a mass spectrum for determining the number of carbon atoms in organic molecules (questions involving an (M+ 1) peak will have ^{13}C as the only contributor)

(d) explain the use of the (M+2) and (M+4) peak(s) in the identification of halogen compounds (chlorine and bromine)

(e) suggest the identity of the major fragment ions in a given mass spectrum

(f) suggest the identity of molecules formed by fragmentation in a given mass spectrum [Students should be aware that re-arrangement accompanying cleavage may occur; details of mechanism of re-arrangement are not required.]

(g) explain the use of mass spectrometry in isotopic labelling to determine the position of reaction in a molecule

NOTE

Questions may also be set which require students to interpret several spectra. All data normally associated with the appropriate spectra will be given in questions (see also the *Data Booklet).*

In such questions, candidates may be expected to:

- explain the contribution that each of the spectra normally available for an unknown compound makes to a possible identification,
- use evidence from up to three spectra to suggest a probable structure for a given compound,
- suggest what further evidence might be required to confirm a structure suggested by study of spectra.

TRANSITION ELEMENTS OPTION

[A detailed treatment of this topic is given in the Option Booklet *Transition Elements.*]

Statement of Aims

The material in this option is intended to build on (but be essentially independent of) the transition element material incorporated in the 'core syllabus'.

1. COMPLEXES

Content

I Bonding in complexes: stoichiornetry, stereochemistry and isomerism of complexes.

II Magnetism; colour.

Learning Outcomes

Candidates should be able to:

(a) explain the terms complex, ligand, co-ordinate (dative covalent) bond

(b) explain the formation of complexes in terms of co-ordinate bonds and the splitting of d electron energy levels

(c) state that ligands may be neutral or anionic

(d) state that complexes typically exhibit four-fold or six-fold co-ordination

(e) describe the shape of four-fold complexes as either planar or tetrahedral

(f) describe the shape of six-fold complexes as octahedral

(g) explain the types of isomerism that complexes (of the listed metals) may exhibit, including those associated with polydentate ligands

(h) describe and explain ligand exchanges in terms of competing equilibria, including the dissolving of insoluble compounds

(i) explain ligand exchange in terms of stability constants

(j) explain redox reactions of complexes in terms of $E^\ominus$ values

(k) interpret the effect of ligand exchange on $E^\ominus$ values

(l) explain, in terms of d orbital splitting, why transition element complexes are usually coloured

(m) explain changes in colour of complexes as a result of ligand exchange

(n) explain the magnetic properties of transition metals and their complexes in terms of paired and unpaired d electrons

2. CHEMISTRY OF TRANSITION ELEMENTS

Contents

I Characteristic transition element chemistry as illustrated by vanadium, chromium, manganese, iron, cobalt, nickel and copper.

II Some other chemistry of these metals.

Learning Outcomes

Candidates should be able to describe and explain the chemistry of:

(a) vanadium, in respect of:

- (i) its use in hardening steel,
- (ii) the occurrence, relative stability and colour of its aqueous ions and compounds containing the metal in the +2, +3, +4, +5 oxidation states.

(b) chromium, in respect of:

- (i) its use in stainless steel and in hardening steel
- (ii) the occurrence, relative stability and colour of its aqueous ions and compounds containing the metal in the +3 and +6 oxidation states
- (iii) the use of dichromate(VI) as an oxidising agent
- (iv) the chromate(VI) to dichromate(VI) interconversion

(c) manganese, in respect of:

- (i) the occurrence and relative stability and colour of its aqueous ions and compounds containing the metal in the +2, +4, +6 and +7 oxidation states
- (ii) redox reactions involving MnO_2, MnO_4^{2-} and MnO_4^-

(d) iron, in respect of:

- (i) the biochemical importance of iron in haemoglobin and in cytochrome
- (ii) the rusting of iron and its prevention
- (iii) the use of iron, its ions or compounds in homogeneous and heterogeneous catalysis, i.e. the Fe^{3+} in the $I^-/S_2O_8^{2-}$ reaction; Fe/Fe_2O_3 in the Haber process
- (iv) the occurrence, relative stability and colour of its aqueous ions and compounds containing the metal in the +2 and +3 oxidation states, including (in particular) the effect of pH and the cyanide ligand on stability
- (v) tests to distinguish between $Fe^{2+}(aq)$ and $Fe^{3+}(aq)$, namely $Fe(CN)_6^{3-}(aq)$ and $SCN^-(aq)$, respectively

(e) cobalt, in respect of

- (i) the biochemical importance of cobalt
- (ii) the occurrence, relative stability and colour of ions and compounds containing the metal in its +2 and +3 oxidation states, including the use of anhydrous cobalt(II) ions as a test for water and the effect of ligands and/or temperature on the stability and geometry of cobalt complexes, using as examples

$$[Co(H_2O)_6]^{2+} \rightleftharpoons [CoCl_4]^{2-}, \text{ and}$$
$$[Co(NH_3)_6]^{2+} \rightleftharpoons [Co(NH_3)_6]^{3+}$$

- (iii) the use of cobalt in alloys, e.g. alnico

(f) nickel, in respect of:

- (i) the production of pure nickel by using carbon monoxide
- (ii) the use of nickel in alloys, e.g. alnico
- (iii) the use of nickel as a hydrogenation catalyst

(g) copper, in respect of:

- (i) its electrolytic purification, including reference to what happens to the metallic impurities
- (ii) its use in brass, bronze and other alloys
- (iii) the occurrence and relative stability of ions and compounds containing the metal in the +1 and +2 oxidation states, including the disproportionation (and stabilisation) of $Cu^+(aq)$
- (iv) the use of alkaline aqueous Cu^{2+} complexes as a test for aldehydes
- (v) the $Cu^{2+}(aq)/I^-(aq)$ reaction

PRACTICAL SYLLABUS (PAPERS 3 AND 5)

Questions requiring recall of the techniques involved in the practical syllabus will **not** be set in the theory papers.

The questions in the practical paper may include the following:

(i) A volumetric analysis problem, based on one set of titrations;

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.

(ii) Candidates may be required to carry out an experiment that involves the determination of some quantity, e.g. the enthalpy change of a reaction or, the rate of a reaction. Such experiments will depend on the simple manipulation of usual laboratory apparatus.

(iii) An observational problem in which the candidate will be asked to investigate, by specified experiments, an unknown substance. The substance may be an element, a compound or a mixture.

Systematic analysis and a knowledge of traditional methods of separation will **not** be required. It will be assumed that candidates will be familiar with (i) the reactions of the following cations: NH_4^+; Mg^{2+}; Al^{3+}; Ca^{2+}; Cr^{3+}; Mn^{2+}; Fe^{2+}; Fe^{3+}; Cu^{2+}; Zn^{2+}; Ba^{2+}; Pb^{2+}; (ii) the reactions of the following anions: CO_3^{2-}; NO_3^-; NO_2^-; SO_4^{2-}; SO_3^{2-}; Cl^-; Br^-; I^-; CrO_4^{2-}; (iii) tests for the following gases: NH_3; CO_2; Cl_2; H_2; O_2; SO_2, as detailed in the qualitative analysis notes which will be included with the question paper and are reproduced at the end of this 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 as outlined in Section 10, e.g. test-tube reactions indicating the presence of unsaturated, alcoholic, phenolic and carboxylic groups, may also be set, but this would be for the testing of observation skills and drawing general conclusions only.

Candidates are NOT allowed to refer to note books, text books or any other information in the Practical examination.

One, or more, of the questions may incorporate some assessment of planning skills or evaluating evidence and procedures.

Candidates may also be required to carry out calculations as detailed in the theory syllabus.

Practical Techniques

The following notes are intended to give schools and candidates an indication of the accuracy that is expected in quantitative exercises and general instructions for qualitative exercises.

(a) Candidates should normally record burette readings to the nearest 0.05 cm^3 and they should ensure that they have carried out a sufficient number of titrations, e.g. in an experiment with a good end-point, two titres within 0.10 cm^3.

(b) Candidates should normally record: weighings to the nearest 0.01 g,
temperature readings to the nearest 0.5 °C when using a thermometer calibrated in 1 °C intervals and to the nearest 0.1 °C where the interval is 0.2 °C.

(c) In qualitative analysis exercises, candidates should use approximately 1 cm depth of a solution (1-2 cm^3) for each test and add reagents slowly, ensuring good mixing, until no further change is seen. Candidates should indicate at what stage a change occurs, writing any deductions alongside the observation on which they are based. Answers should include details of colour changes and precipitates formed and the names and chemical tests for any gases evolved (equations are **not** required).

Marks for deductions or conclusions can only be gained if the appropriate observations are recorded.

APPARATUS 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^3
Two pipettes, 25 cm^3
One pipette, 10 cm^3
Dropping pipette
One pipette filler
Conical flasks: three within range 150 cm^3 to 250 cm^3
Volumetric flask, 250 cm^3
Measuring cylinders, 25 cm^3 and 50 cm^3
Wash bottle
Two filter funnels
Porcelain crucible, approximately 15 cm^3, with lid
Evaporating basin, at least 30 cm^3
Beakers, squat form with lip: 100 cm^3, 250 cm^3
Thermometers: -10 °C to +110 °C at 1 °C;
-5 °C to +50 °C at 0.2 °C
Plastic beaker, e.g. polystyrene, of approximate capacity 150 cm^3
Test-tubes (some of which should be Pyrex or hard glass) approximately 125 mm 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, 0.01 g or better (1 per 8-12 candidates).

Details of the requirements 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

cation	*reaction with*	
	NaOH(aq)	NH_3(aq)
aluminium, Al^{3+}(aq)	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, NH_4^+(aq)	ammonia produced on heating	
barium, Ba^{2+}(aq)	no ppt. (if reagents are pure)	no ppt.
calcium, Ca^{2+}(aq)	white ppt. with high [Ca^{2+}(aq)]	no ppt.
chromium (III), Cr^{3+}(aq)	grey-green ppt. soluble in excess giving dark green solution	grey-green ppt. insoluble in excess
copper(II), Cu^{2+}(aq),	pale blue ppt. insoluble in excess	blue ppt. soluble in excess giving dark blue solution
iron(II), Fe^{2+}(aq)	green ppt. insoluble in excess	green ppt. insoluble in excess
iron(III), Fe^{3+}(aq)	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
lead(II), Pb^{2+}(aq)	white ppt. soluble in excess	white ppt. insoluble in excess
magnesium, Mg^{2+}(aq)	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), Mn^{2+}(aq)	off-white ppt. insoluble in excess	off-white ppt. insoluble in excess
zinc, Zn^{2+}(aq)	white ppt. soluble in excess	white ppt. soluble in excess

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

2 Reactions of anions

ion	*Reaction*
carbonate, CO_3^{2-}	CO_2 liberated by dilute acids
chromate(VI), $CrO_4^{2-}(aq)$	yellow soln turns orange with $H^+(aq)$; gives yellow ppt. with $Ba^{2+}(aq)$; gives bright yellow ppt. with $Pb^{2+}(aq)$
chloride, $Cl^-(aq)$	gives white ppt. with $Ag^+(aq)$ (soluble in $NH_3(aq)$); gives white ppt. with $Pb^{2+}(aq)$
bromide, $Br^-(aq)$	gives pale cream ppt. with $Ag^+(aq)$ (partially soluble in NH_3 (aq)); gives white ppt. with $Pb^{2+}(aq)$
iodide, $I^-(aq)$	gives yellow ppt. with $Ag^+(aq)$ (insoluble in $NH_3(aq)$); gives yellow ppt. with $Pb^{2+}(aq)$
nitrate, $NO_3^-(aq)$	NH_3 liberated on heating with $OH^-(aq)$ and A*l* foil
nitrite, $NO_2^-(aq)$	NH_3 liberated on heating with $OH^-(aq)$ and A*l* foil; NO liberated by dilute acids (colourless NO - (pale) brown NO_2 in air)
sulphate, $SO_4^{2-}(aq)$	gives white ppt. with $Ba^{2+}(aq)$ or with $Pb^{2+}(aq)$ (insoluble in excess dilute strong acids)
sulphite, $SO_3^{2-}(aq)$	SO_2 liberated with dilute acids; gives white ppt. with $Ba^{2+}(aq)$ (soluble in dilute strong acids)

3 Tests for gases

gas	*test and test result*
ammonia, NH_3	turns damp red litmus paper blue;
carbon dioxide, CO_2	gives a white ppt. with limewater (ppt. dissolves with excess CO_2)
chlorine, Cl_2	bleaches damp litmus paper
hydrogen, H_2	“pops” with a lighted splint
oxygen, O_2	relights a glowing splint
sulphur dioxide, SO_2	turns aqueous potassium dichromate(VI) 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
Base quantities		
mass	m	kg, g
length	l	m
time	t	s
electric current	I	A
thermodynamic temperature	T	K
amount of substance	n	mol
Other quantities		
temperature	θ, t	$^{\circ}$C
volume	V, v	m^3, dm^3
density	ρ	kg m^{-3}, g dm^{-3}, g cm^{-3}
pressure	p	Pa
frequency	v, f	Hz
wavelength	λ	m, mm, nm
speed of electromagnetic waves	c	m s^{-1}
Planck constant	h	J s
electric potential difference	V	V
(standard) electrode redox potential	$(E^{\theta})\ E$	V
electromotive force	E	V
molar gas constant	R	J K^{-1} mol^{-1}
half-life	$T_{½}$, $t_{½}$	s
atomic mass	m_a	kg
relative atomic isotopic mass	A_r	–
molecular mass	m	kg
relative molecular mass	M_r	–
molar mass	M	kg mol^{-1}
nucleon number	A	–
proton number	Z	–
neutron number	N	–
number of molecules	N	–
number of molecules per unit volume	n	m^{-3}
Avogadro constant	L	mol^{-1}
Faraday constant	F	C mol^{-1}
enthalpy change of reaction	ΔH	J, kJ
standard enthalpy change of reaction	ΔH^{θ}	J mol^{-1}, kJ mol^{-1}
ionisation energy	I	kJ mol^{-1}
lattice energy	–	kJ mol^{-1}
bond energy	–	kJ mol^{-1}
electron affinity	–	kJ mol^{-1}
rate constant	k	as appropriate
equilibrium constant	K, K_p, K_c	as appropriate
acid dissociation constant	K_a	as appropriate
order of reaction	n, m	–
mole fraction	x	–
concentration	c	mol dm^{-3}
partition coefficient	K	–
ionic product, solubility product	K, K_{sp},	as appropriate
ionic product of water	K_w	mol^2 dm^{-6}
pH	pH	–

MATHEMATICAL REQUIREMENTS

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

(a) Make calculations involving addition, subtraction, multiplication and division of quantities.
(b) Make approximate evaluations of numerical expressions.
(c) Express small fractions as percentages, and vice versa.
(d) Calculate an arithmetic mean.
(e) Transform decimal notation to power of ten notation (standard form).
(f) Use tables or calculators to evaluate logarithms (for pH calculations), squares, square roots, and reciprocals.
(g) Change the subject of an equation. (Most such equations involve only the simpler operations but may include positive and negative indices and square roots.)
(h) Substitute physical quantities into an equation using consistent units so as to calculate one quantity. Check the dimensional consistency of such calculations, e.g. the units of a rate constant k.
(i) Solve simple algebraic equations.
(j) Comprehend and use the symbols/notations $<$, $>$, $\approx$, $/$, Δ, $\equiv$, $\bar{x}$ (or $<x>$).
(k) Test tabulated pairs of values for direct proportionality by a graphical method or by constancy of ratio.
(l) Select appropriate variables and scales for plotting a graph, especially to obtain a linear graph of the form $y = mx + c$.
(m) Determine and interpret the slope and intercept of a linear graph.
(n) Choose by inspection a straight line that will serve as the ‘least bad’ linear model for a set of data presented graphically.
(o) Understand
    i. the slope of a tangent to a curve as a measure of rate of change,
    ii. the ‘area’ below a curve where the area has physical significance, e.g. Boltzmann distribution curves.
(p) Comprehend how to handle numerical work so that significant figures are neither lost unnecessarily nor used beyond what is justified.
(q) Estimate orders of magnitude.
(r) Formulate simple algebraic equations as mathematical models, e.g. construct a rate equation, and identify failures of such models.

Calculators

If calculators are to be used, it is suggested that they should have the following functions:
$+, -, \times, \div, \sqrt{x}, x^2, x^y, \lg x$. A *memory* function may be useful but is not essential.

INFORMATION TECHNOLOGY (IT) USAGE IN A LEVEL CHEMISTRY

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 spent more time on the analysis and evaluation of the data. In the case of chemistry, data loggers and sensors could be used for experiments such as those involving measurement of temperature, pH, pressure or transmittance of light through solutions.

The following are some examples of the use of sensors and data loggers in standard 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

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, σ and π bonds and shapes of molecules {3*(a)*, *(b)*, *(c)*, *(d)* and *(e)*}.

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

4. STATES OF MATTER

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

5. CHEMICAL ENERGETICS

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

Computer simulation can be used to illustrate the effects of bond enthalpy on the ΔH of reaction.

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

6. ELECTROCHEMISTRY

Computer simulation can be used to model a simple cell and study its feasibility based on E^{θ} 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

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	$= 8.31$ J K^{-1} mol^{-1}
the Faraday constant	F	$= 9.65 \times 10^{4}$ C mol^{-1}
the Avogadro constant	L	$= 6.02 \times 10^{23}$ mol^{-1}
the Planck constant	h	$= 6.63 \times 10^{-34}$ J s
speed of light in a vacuum	c	$= 3.00 \times 10^{8}$ m s^{-1}
rest mass of proton, $^{1}_{1}\mathrm{H}$	m_{p}	$= 1.67 \times 10^{-27}$ kg
rest mass of neutron, $^{1}_{0}\mathrm{n}$	m_{n}	$= 1.67 \times 10^{-27}$ kg
rest mass of electron, $^{0}_{-1}\mathrm{e}$	m_{e}	$= 9.11 \times 10^{-31}$ kg
electronic charge	e	$= -1.60 \times 10^{-19}$ C
molar volume of gas	V_{m} V_{m}	$= 22.4$ dm^{3} mol^{-1} at s.t.p $= 24$ dm^{3} mol^{-1} under room conditions

(where s.t.p. is expressed as 101 kPa, approximately, and 273 K (0 ºC))

ionic product of water	K_{w}	$= 1.00 \times 10^{-14}$ mol^{2} dm^{-6} (at 298 K [25 ºC])
specific heat capacity of water		$= 4.18$ kJ kg^{-1} K^{-1} ($= 4.18$ J g^{-1} K^{-1})

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

	Proton Number	**First**	**Second**	**Third**	**Fourth**
H	1	1310	-	-	-
He	2	2370	5250	-	-
Li	3	519	7300	11800	-
Be	4	900	1760	14800	21000
B	5	799	2420	3660	25000
C	6	1090	2350	4610	6220
N	7	1400	2860	4590	7480
O	8	1310	3390	5320	7450
F	9	1680	3370	6040	8410
Ne	10	2080	3950	6150	9290
Na	11	494	4560	6940	9540
Mg	12	736	1450	7740	10500
A*l*	13	577	1820	2740	11600
Si	14	786	1580	3230	4360
P	15	1060	1900	2920	4960
S	16	1000	2260	3390	4540
C*l*	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

Bond	**Energy/kJ mol^{-1}**
H—H	436
D—D	442
N≡N	994
O=O	496
F—F	158
C*l*—C*l*	244
Br—Br	193
I—I	151
H—F	562
H—C*l*	431
H—Br	366
H—I	299

(b) Polyatomic molecules

Bond	**Energy/kJ mol^{-1}**
C—C	350
C=C	610
C≡C	840
C┄C (benzene)	520
C—H	410
C—C*l*	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—C*l*	359
Si—H	320
Si—O	444
Si—Si	222
S— C*l*	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
$Ag^+ + e^-$	$\rightleftharpoons$	Ag	+0.80
$\mathrm{A}l^{3+} + 3e^-$	$\rightleftharpoons$	$\mathrm{A}l$	-1.66
$Ba^{2+} + 2e^-$	$\rightleftharpoons$	Ba	-2.90
$Br_2 + 2e^-$	$\rightleftharpoons$	$2Br^-$	+1.07
$Ca^{2+} + 2e^-$	$\rightleftharpoons$	Ca	-2.87
$\mathrm{C}l_2 + 2e^-$	$\rightleftharpoons$	$2\mathrm{C}l^-$	+1.36
$2HO\mathrm{C}l + 2H^+ + 2e^-$	$\rightleftharpoons$	$\mathrm{C}l_2 + 2H_2O$	+1.64
$Co^{2+} + 2e^-$	$\rightleftharpoons$	Co	-0.28
$Co^{3+} + e^-$	$\rightleftharpoons$	Co^{2+}	+1.82
$[Co(NH_3)_6]^{2+} + 2e^-$	$\rightleftharpoons$	$Co + 6NH_3$	-0.43
$Cr^{2+} + 2e^-$	$\rightleftharpoons$	Cr	-0.91
$Cr^{3+} + 3e^-$	$\rightleftharpoons$	Cr	-0.74
$Cr^{3+} + e^-$	$\rightleftharpoons$	Cr^{2+}	-0.41
$Cr_2O_7^{2-} + 14H^+ + 6e^-$	$\rightleftharpoons$	$2Cr^{3+} + 7H_2O$	+1.33
$Cu^+ + e^-$	$\rightleftharpoons$	Cu	+0.52
$Cu^{2+} + 2e^-$	$\rightleftharpoons$	Cu	+0.34
$Cu^{2+} + e^-$	$\rightleftharpoons$	Cu^+	+0.15
$[Cu(NH_3)_4]^{2+} + 2e^-$	$\rightleftharpoons$	$Cu + 4NH_3$	-0.05
$F_2 + 2e^-$	$\rightleftharpoons$	$2F^-$	+2.87
$Fe^{2+} + 2e^-$	$\rightleftharpoons$	Fe	-0.44
$Fe^{3+} + 3e^-$	$\rightleftharpoons$	Fe	-0.04
$Fe^{3+} + e^-$	$\rightleftharpoons$	Fe^{2+}	+0.77
$[Fe(CN)_6]^{3-} + e^-$	$\rightleftharpoons$	$[Fe(CN)_6]^{4-}$	+0.36
$Fe(OH)_3 + e^-$	$\rightleftharpoons$	$Fe(OH)_2 + OH^-$	-0.56
$2H^+ + 2e^-$	$\rightleftharpoons$	H_2	0.00
$I_2 + 2e^-$	$\rightleftharpoons$	$2I^-$	+0.54
$K^+ + e^-$	$\rightleftharpoons$	K	-2.92
$Li^+ + e^-$	$\rightleftharpoons$	Li	-3.04

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

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

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

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

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

Atomic and ionic radii

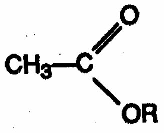
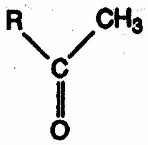
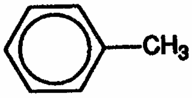
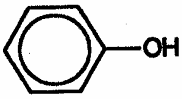
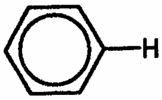
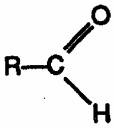
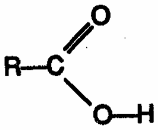
		atomic/nm		ionic/nm	
(a)	**Period 3**				
	metallic	Na	0.186	Na^{+}	0.095
		Mg	0.160	Mg^{2+}	0.065
		Al	0.143	Al^{3+}	0.050
	single covalent	Si	0.117	Si^{4+}	0.041
		P	0.110	P^{3-}	0.212
		S	0.104	S^{2-}	0.184
		Cl	0.099	Cl^{-}	0.181
	van der Waals	Ar	0.192		
(b)	**Group II**				
	metallic	Be	0.112	Be^{2+}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

Spectroscopy Option

Characteristic values for infra-red absorption (due to stretching vibrations in organic molecules).

Bond		Characteristic ranges Wavenumber (reciprocal wavelength) /cm^{-1}
C—C*l*		700 to 800
C—O	alcohols, ethers, esters	1000 to 1300
C=C		1610 to 1680
C=O	aldehydes, ketones, acids, esters	1680 to 1750
C≡C		2070 to 2250
C≡N		2200 to 2280
O—H	'hydrogen-bonded' in acids	2500 to 3300
C—H	alkanes, alkenes, arenes	2840 to 3095
O—H	'hydrogen-bonded' in alcohols, phenols	3230 to 3550
N—H	primary amines	3350 to 3500
O—H	'free'	3580 to 3650

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

Type of proton	*Chemical shift (ppm)*
$R—CH_3$	0.9
$R—CH_2—R$	1.3
R_3CH	2.0
	2.0
	2.1
	2.3
$R—C≡C—H$	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

Key

relative atomic mass
atomic symbol
name
atomic number

Group

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

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

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