A Level

Chemistry

Session: 2000
Type: Syllabus
Code: 9254

OCR

RECOGNISING ACHIEVEMENT

Chemistry (Linear)

9254, 9434

2000

former Cambridge UCLES syllabus

Advanced Level

Syllabus

CHEMISTRY

GCE ADVANCED LEVEL

9254

This syllabus is intended to be "free-standing" and as such it should be equally accessible to students who have studied either Chemistry or any other Science course for GCSE. The syllabus encompasses the "Common Core" syllabus for A Level Chemistry as agreed by the GCE Boards in consultation with (the former) SEAC.

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 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.

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*. (See the glossary of terms on page 80.)

B   Handling, applying and evaluating information

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

1.   locate, select, organise and present information from a variety of sources;

2.   handle information, distinguishing the relevant from the extraneous;

3.   manipulate numerical and other data and translate information from one form to another;

4.   analyse and evaluate information so as to identify patterns, report trends and draw inferences;

5.   construct arguments to support hypotheses or to justify a course of action;

6.   apply knowledge, including principles, to novel situations;

7.   evaluate information and hypotheses.

These assessment objectives cannot be precisely specified in the Subject Content because questions testing such skills may be based on information which is unfamiliar to the candidate. In answering such questions, candidates are required to use principles and concepts that are within the syllabus and apply them in a logical, reasoned or deductive manner to a novel situation. Questions testing these objectives will often begin with one of the following words: *predict, suggest, construct, calculate* or *determine*. (See the glossary of terms on page 80.)

C   Experimental skills and investigations

Students should be able to;

1.   plan experimental work;

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

Candidates are required to enter for: Papers 1, 2, 3, 4 and 5 or 7 or 9 (June), Papers 1, 2, 3, 4 and 6 or 85 or 87 or 89 (November).

Paper	Type of Paper	Duration	Marks
1	Free Response Questions	2 h	72
2	Structured Questions	1¼ h	48
3	Multiple Choice	1 h	40
4	Option Topics	1¼ h	40
5 or 6	Practical Test	2½ h	50
7 or 9	Centre Based Assessment	—	

Paper 1 (2 h)(72 marks)

Section A (based mainly on physical chemistry) three questions;

Section B (based mainly on inorganic chemistry) two questions;

Section C (based mainly on organic chemistry) three questions.

Candidates will be required to answer a total of six questions: two from Section A one from Section B, two from Section C, plus any one other.

Paper 2 (1¼ h)(48 marks)

A variable number of structured questions, all compulsory. Based on the core syllabus (Sections 1 to 10). Answered on the question paper. A maximum of four marks will be allocated to the assessment of Quality of Language.

Paper 3 (1 h)(40 marks)

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

The questions will include 4 responses.

Paper 4 (1¼ h)(40 marks)

Testing the options. Three questions on each option (10 marks each). Candidates to answer a total of four questions, not more than two on any option.

Paper 5 or Paper 6 (2½ h)(50 marks)

The scope of the practical test is indicated in the Practical Chemistry syllabus printed on page 62. (The paper will be marked out of 75 and scaled to a mark out of 50.)

Paper 7 or 9 (Centre-based assessment)

Centre-based assessment is not available in the November examination, but see note below concerning *Papers 87 and 89.*

Paper 7 (Extended Investigation)

A Centre-based assessment of an Extended Investigation, Further details are given on pages 68 to 71.

Paper 9 (Separate Skills Assessment)

A Centre-based assessment of three skills assessed during the course. Further details are given on pages 72 to 77.

Teachers are required to authenticate candidates' practical marks as being derived from the candidates' individual work.

Centres are reminded that candidates re-entering in the November examination have the option of carrying forward their Practical mark from the June examination as *Paper 85*, and their centre-based assessment as *Paper 87 or 89* as appropriate.

Special Paper (9434) (June only)

This Paper is optional and requires an extra fee. It is of 2½ hours' duration and contains harder questions, based only on the core syllabus and arranged in three sections. Section A will contain three questions on Physical Chemistry, Section B will contain three questions on Inorganic Chemistry, and Section C will contain three questions on Organic Chemistry. Candidates will be required to answer five questions, of which not more than two may be selected from any one section.

Candidates may be entered for the Special Paper even if they are not being entered for subject 9254.

Data Booklet

A *Data Booklet* (dated 1994) is available for use in Papers 1, 2, 3 and 4 and in the *Special Paper*. The booklet is reprinted on pages 82 to 92. Copies of the booklet can be ordered from OCR.

Nomenclature

The ASE proposals in *Signs, Symbols and Systematics (The ASE Companion to 5-16 Science, 1995)* will generally be adopted. In particular, the names sulphite, nitrite, sulphur trioxide, sulphurous acid and nitrous acid will be used in question papers.

Grading Conditions

Candidates' results are based on the aggregation of their marks in the various papers, i.e. there are no hurdle conditions under which a prescribed level of performance in an individual paper prevents the award of an A level result.

Disallowed Subject Combinations

Candidates may not simultaneously offer more than one Chemistry syllabus either at the same level, e.g. linear versus modular, or at different levels, e.g. A level, AS, GCSE.

MARKS ALLOCATED TO ASSESSMENT OBJECTIVES AND SYLLABUS AREAS

Theory Papers (Papers 1, 2 and 3)(160 marks in total)

Knowledge with understanding (see page 5), approximately 55 marks allocated to recall and 35 marks allocated to understanding.

Handling, applying and evaluating information (see page 6), approximately 70 marks.

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

Options Theory Paper (Paper 4)(40 marks)

This paper is designed to test appropriate aspects of objectives A1 to A6 and B1 to B7 on pages 5 and 6. 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.

In demonstrating what they know, understand and can do, candidates will be expected, within the theory papers (other than the multiple-choice paper), to use a form of communication appropriate to the context of the question.

Practical Assessment (Papers 5, 6, 7 or 9)

Experimental skills and investigations.

These papers are designed to test appropriate aspects of objectives C1 to C6 given on page 6. These objectives cover the experimental skills as defined in the Chemistry Subject Core for AS/A level (SEAC June 1993). The practical paper may also involve some calculations based on experimental results.

The Subject Core requires some assessment of planning/design skills – a relatively structured example of a possible qualitative analysis format being included with the associated specimen papers. However, the assessment of such skills will not necessarily be confined to this particular area of practical chemistry. It is anticipated that the context and nature of 'planning' exercises within the practical examination will evolve and develop as experience is gained.

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 20% to 30% of the total marks available for the practical examination.

STRUCTURE OF THE SYLLABUS

The syllabus has been constructed on a "core plus options" basis in which the "core" (Sections 1–10) represents 80% of the whole course. Candidates will be expected to study two options, each representing 10%.

The following options are available:

Biochemistry; Environmental Chemistry; Food Chemistry; Phase Equilibria; Spectroscopy; Transition Elements.

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. However, 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 but underlies the comments made on page 9 regarding the objectives of the Options paper.

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.

SUBJECT CONTENT

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).

Assessment Objectives

[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)   interpret mass spectra in terms of isotopic abundances and molecular fragmentation.

         [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.

Assessment Objectives

Candidates should be able to:

(a)   recognise and describe protons, neutrons and electrons in terms of their relative charges and relative masses.

(b)   predict the behaviour of beams of protons, neutrons and electrons in both electric and magnetic 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 the factors influencing the ionisation energies of elements (see the *Data Booklet*);

          (ii)   explain the trends in ionisation energies across a period and down a group of the Periodic Table. (See also Section 9.)

(j)   predict 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.

Assessment Objectives

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 $BF_3.NH_3$.

(c)   explain the shapes of, and bond angles in, molecules by using the qualitative model of electron-pair repulsion (including lone pairs), using as simple examples: BF_3 (trigonal); 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 -NH and -OH groups.

(h)   explain the terms bond energy, bond length and bond polarity and use them to compare the reactivities of covalent bonds.

(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 and spacing.

Assessment Objectives

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 and thermal 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 and 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)   show an awareness that materials are a finite resource and understand 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, atomisation, bond energy, lattice energy, electron affinity.

II   Hess' Law, including Born-Haber cycles.

Assessment Objectives

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) use Hess' Law to construct simple energy cycles, e.g. Born-Haber, and carry out calculations involving such cycles and relevant energy terms (including ionisation energy and electron affinity), 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) the formation of a simple ionic solid and of its aqueous solution;

(iii) average bond energies.

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

6. ELECTROCHEMISTRY

Content

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

II Electrode potentials.

(i) Standard electrode (redox) potentials, $E^{\ominus}$; the redox series.

(ii) Standard cell potentials, $E^{\ominus}_{cell}$, 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.

Assessment Objectives

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) define the terms:

    (i) standard electrode (redox) potential;

    (ii) standard cell potential.

(c) describe the standard hydrogen electrode.

(d) 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.

(e) calculate a standard cell potential by combining two standard electrode potentials.

(f) use standard cell potentials to:

    (i) explain/predict the direction of electron flow from a simple cell;

    (ii) predict the feasibility of a reaction.

(g) construct redox equations using the relevant half-equations. (See also Section 9.5.)

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

(i) show awareness of 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.

(j) state the relationship between the Faraday constant, the Avogadro constant and the charge on the electron, $F = Le$.

(k) show awareness of the factors that affect the identity of the substance liberated during electrolysis, i.e. state of electrolyte (molten or aqueous), position in the redox series (electrode potential) and concentration.

(l) 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 $H_2SO_4(aq)$, $Na_2SO_4(aq)$.

(m) describe the determination of a value of the Avogadro constant by an electrolytic method.

(n) describe, 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;

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(iii) the anodising of aluminium;

(iv) the electrolytic purification of copper.

[Technical details are **not** required.]

7. EQUILIBRIA

Content

I Chemical equilibria: reversible reactions, dynamic equilibrium.

    (i) Factors affecting chemical equilibria.

    (ii) Equilibrium constants.

    (iii) The Haber 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.

Assessment Objectives

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, as an example 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.

(j)   explain the terms pH, K_a, pK_a, and K_w and use them in calculations.

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

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

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

(n)   (i)   explain how buffer solutions control pH,

       (ii)   describe and explain their uses, including the role of HCO_3^- in controlling pH in blood.

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

(p)   show understanding of, and use, the term 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.

Assessment Objectives

Candidates should be able to:

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

(b)   use and construct 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)   checking that a suggested reaction mechanism is consistent with the observed kinetics;

      (iv)   proposing a reaction mechanism consistent with a given, or determined, order of reaction;

      (v)   predicting the order that would result from a given reaction mechanism;

      (vi)   calculating an initial rate using concentration data.

      [Integrated forms of rate equations are **not** required.]

(c)   *(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.

(d)   calculate a rate constant using the initial rates method.

(e)   devise a suitable experimental technique for studying the rate of a reaction, from given information.

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

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

(h)   explain qualitatively, in terms both of the Boltzmann distribution and of collision frequency, the effect of temperature change on a rate constant (and, hence, on the rate) of a reaction.

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

      (ii)   interpret this catalytic effect on a rate constant in terms of the Boltzmann distribution.

(j)   outline the different modes of action of homogeneous and heterogeneous catalysis. (See also Section 9.6*(c)*, *(f)*, *(g)* and *(j)*.)

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

9. INORGANIC CHEMISTRY

Preamble

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 three Groups II, IV and VII;

introduce, with examples, the transition elements 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;

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

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.

Assessment Objectives

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.

(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) make deductions with regard to 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.

Assessment Objectives

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 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.

(e) interpret and explain qualitatively the variation in solubility of the sulphates in terms of the relative magnitudes of the enthalpy change of hydration and the corresponding lattice energy.

(f) interpret, and make predictions from, the trends in physical and chemical properties of the elements and their compounds.

(g) show awareness of the use of magnesium oxide as a refractory lining and of carbonates as building materials.

(h) describe the use of lime in agriculture.

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.

Assessment Objectives

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 – reference to E^0 values.

(f)   show awareness of the properties and uses of ceramics based on silicon(IV) oxide. (See also Section 4.)

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 10.3.)

Assessment Objectives

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 explain the relative reactivity of the elements as oxidising agents, including their reaction with sodium thiosulphate and with reference to $E^{\ominus}$ values.

(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) demonstrate an awareness of the industrial importance and environmental significance of the halogens and their compounds, (e.g. for bleaches, pvc and halogenated hydrocarbons as solvents, refrigerants and in aerosols). (See also Section 10.3.)

9.5 AN INTRODUCTION TO THE CHEMISTRY OF TRANSITION ELEMENTS

[Reference to the more detailed treatment of this topic as given in the Option Booklet *Transition Elements* may be helpful.]

Content

General physical and characteristic chemical properties of the first set of transition elements, titanium to copper.

Assessment Objectives

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 metals 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; the use of sulphur dioxide in food preservation.

　　(ii)　Sulphuric acid.

Assessment Objectives

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 in terms of the applications of the principles of kinetics and equilibria. (See also Sections 7 and 8.)

(d) show awareness of the industrial importance of ammonia and nitrogen compounds derived from ammonia.

(e) show awareness of the environmental consequences of the uncontrolled use of nitrate fertilisers.

(f) describe and explain the occurrence, and catalytic removal, of oxides of nitrogen in the exhaust gases from car engines.

(g) explain simply 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 major environmental consequences of acid-rain.

(j) show knowledge of the Contact process for sulphuric acid production.

[Treatment of the Contact process as an equilibrium reaction is **not** required.]

(k) show awareness of the industrial importance of sulphuric acid.

(l) describe the use of sulphur dioxide in food preservation.

10 ORGANIC CHEMISTRY

Preamble

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.

Concepts that have a connection with physical and inorganic chemistry include:

•   types of bond, including complex formation involving lone pairs of (organic) ligands

•   acid/base behaviour

•   rates of reaction and equilibria

•   stoichiometry

Distinctive features include:

•   the naming of compounds in terms of the functional groups they contain and the concept of aromaticity

- certain types of reaction more commonly, although not exclusively, met in an organic chemistry context, e.g. free-radical, nucleophilic and electrophilic reactions such as addition, substitution, elimination, hydrolysis, condensation, polymerisation, esterification, nitration, halogenation, acylation

- the concept of σ and π bonds

- isomerism (structural, stereochemical – including chirality)

When describing preparative reactions, candidates will be expected to quote the reagents, the essential practical conditions 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.

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.

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

for ethanoic acid.
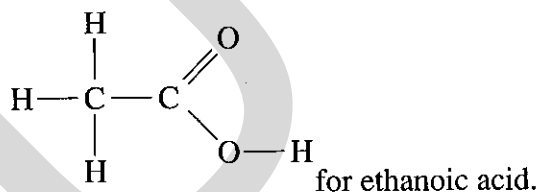
The convention for representing the aromatic ring is preferred.

The symbol for cyclohexane is acceptable.

Assessment Objectives

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, acyl chlorides and esters,

    (vi) amines (primary only), amides, amino acids and nitriles.

(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 and the factors which give rise to this phenomenon.

(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 how such a centre gives rise to optical isomerism.

(h) determine 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.

Assessment Objectives

Candidates should be able to:

(a)   show awareness 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 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.

(i) *(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.

(j) predict whether halogenation will occur in the side-chain or aromatic nucleus in arenes depending on reaction conditions.

(k) state the positions of substitution in methylbenzene.

(l) demonstrate an awareness of the environmental consequences of carbon monoxide, oxides of nitrogen and unburnt hydrocarbons arising from the internal combustion engine and of their catalytic removal. (See also Section 9.6.)

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.

Assessment Objectives

Candidates should be able to:

(a) recall the chemistry of halogenoalkanes as exemplified by

(ii) the following nucleophilic substitution reactions of bromoethane: hydrolysis: formation of nitriles: formation of primary amines by reaction with ammonia.

(iii) the elimination of hydrogen bromide from 2-bromopropane.

(b) describe the mechanism of nucleophilic substitution in halogenoalkanes.

(c) interpret the different reactivities of halogenoalkanes 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) show awareness of the concern about the effect of chlorofluoroalkanes on the ozone layer.

10.4 HYDROXY COMPOUNDS

Content

I   Alcohols (exemplified by ethanol).

(i) Production of ethanol by fermentation.

(ii) Formation of halogenoalkanes.

(iii) Reaction with sodium: oxidation; dehydration; esterification; acylation.

(iv) The tri-iodomethane test.

II   Phenol.

(i) Its acidity; reaction with sodium.

(ii) Nitration of, and halogenation of, the aromatic ring.

Assessment Objectives

Candidates should be able to:

(a) describe and explain the production of ethanol by fermentation.

(b) 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) esterification.

(vii) acylation.

(c) describe the classification of hydroxy compounds into primary, secondary and tertiary alcohols.

(d) suggest characteristic distinguishing reactions, e.g. mild oxidation.

(e) describe the reactions of $CH_3CH(OH)-$ compounds which give tri-iodomethane with alkaline aqueous iodine.

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

    (i) with bases,

    (ii) with sodium,

    (iii) nitration of, and halogenation of, the aromatic ring.

(g) 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.

Assessment Objectives

Candidates should be able to:

(a) describe the formation of aldehydes and ketones from, and their reduction to, primary and secondary alcohols respectively.

(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) determine the nature (aldehyde or ketone) of an unknown carbonyl compound on 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.

Assessment Objectives

Candidates should be able to:

(a) describe the formation of carboxylic acids from alcohols (including vinegar production, treated simply), 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.

10.7 NITROGEN COMPOUNDS

Content

I Primary amines (exemplified by ethylamine and phenylamine).

(i) Their formation.

(ii) Salt formation.

(iii) Other reactions of phenylamine.

II Amides (exemplified by ethanamide).

(i) Their formation from acyl chlorides.

(ii) Their hydrolysis.

III Amino acids (exemplified by aminoethanoic acid).

(i) Their acid and base properties.

(ii) Zwitterion formation.

IV Proteins.

(i) Their structure, based on the peptide linkage.

(ii) The hydrolysis of proteins.

Assessment Objectives

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 reactions 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 dyestuffs.

(f)   describe the formation of amides from RNH_2/R^1COCl.

(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.

Assessment Objectives

Candidates should be able to:

(a)   describe the characteristics of addition polymerisation as exemplified by poly(ethene) and pvc.

(b)   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.

(c)   suggest the type of polymerisation reaction for a given monomer or pair of monomers.

(d)   deduce the repeat unit of a polymer obtained from a given monomer or pair of monomers.

(e)   suggest the type of polymerisation reaction which produces a given section of a polymer molecule.

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

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

BIOCHEMISTRY OPTION

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

Preamble

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 and quaternary structures.

IV   Denaturation of proteins.

V   Fibrous and globular proteins.

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

Assessment Objectives

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) interpret common everyday phenomena in terms of loss of, and formation of, secondary and tertiary structures.

(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) distinguish between 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.

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

Assessment Objectives

Candidates should be able to:

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

(b)   explain the consequences of hydrogen bonding on the solubilities of monosaccharides and polysaccharides.

(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.

Assessment Objectives

Candidates should be able to:

(a)   describe the structure and function of triglyceryl esters.

(b)   describe the structure and function of phosphogylcerides 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.

Assessment Objectives

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 treatment of this topic is given in the publication *Environmental Chemistry* by Alan Winfield, published by Cambridge University Press (ISBN 0521 42156 X).]

Preamble

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, of 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.

Assessment Objectives

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 $HO^\bullet$ 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)   to 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 ultraviolet 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)   show knowledge that carbon monoxide, sulphur dioxide, oxides of nitrogen, 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)   interpret, qualitatively, data relating to sequences of reactions, including those involving free radicals.

(j)   show awareness that the manufacture of lime and cement involves the release of carbon dioxide.

(k)   explain the build-up, and show awareness of 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)   show awareness of possible alternatives to the use of CFCs.

(n) describe qualitatively, in relation to relevant bond and molecular vibrational energies, the role of polyatomic pollutants in the greenhouse effect and outline 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) show awareness of the use of lean-burn engines and catalytic converters in reducing pollutant emissions from petrol-driven cars.

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

    (ii) show awareness of other potential power sources.

(r) show awareness of 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) show an awareness of 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.

Assessment Objectives

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) describe the difference between 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 and its consequence in terms of cation retention on the surface of silicate clays.

(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) explain (including reference to electrode potentials) the effects of reducing conditions in terms of Fe^{2+} formation and the subsequent reduction of nitrate ions.

(k) describe 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) describe 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 the 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.

Assessment Objectives

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)   show an awareness 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.

Assessment Objectives

Candidates should be able to:

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

(b)   show an awareness of 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)   show awareness of problems associated with heavy metals in the environment, typified by lead.

(e)   show an awareness of the problems associated with the disposal of radioactive waste.

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

FOOD CHEMISTRY OPTION

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

Preamble

The aim of this option is to introduce the chemistry that relates to food. The nature of the composition and function of the main nutrients found in food forms the basis of the option, leading to a consideration of factors that affect the quality of food, e.g. the use of additives, the storage and processing of food.

1.   COMPOSITION AND FUNCTIONS OF FOOD

Content

I   Composition: main components.

II   Functions:

  (i)   Growth and repair of tissues.

  (ii)   Production of energy.

  (iii) Regulation of these products.

Assessment Objectives

Candidates should be able to:

(a)   state the nutrients found in foods (proteins, carbohydrates, fats, vitamins, minerals and water).

(b)   state the functions of proteins, carbohydrates and fats in the body.

(c)   describe

  (i)   the structure of an amino acid,

  (ii)   the primary, secondary and tertiary structures of proteins,

  (iii) how the functioning and stability of the protein chain depends on its folding,

  (iv)   the denaturation of proteins.

(d)   describe the classification of proteins as simple (globular or fibrous) or conjugate.

(e)   explain what is meant by total protein and essential amino acids.

(f)   describe enzymes as globular proteins.

(g)   describe in outline protein separation by the use of chromatography.

(h)   explain the classification of glucose, fructose, lactose, sucrose as mono- or di-saccharides and raffinose and stachyose as oligosaccharides.

(i)   describe the effect of human digestion on the di-and oligosaccharides mentioned in *(h)*.

(j)   describe the processes by which jams and sugar confectionery are made from sugar.

(k)   describe and explain how to distinguish between reducing and non-reducing sugars, both qualitatively and quantitatively.

(l)   describe the structural differences between α- and β-glycosidic linkages.

(m)   explain the importance of starch and cellulose in the human diet.

(n)   describe the occurrence of pectin, alginates and cellulose in plants and their importance in the food industry, especially in gels and gums.

(o)   describe the solubility in water and organic solvents, and physical states of fats and oils (simple lipids).

(p)   describe the structure and distribution of fatty acids in simple lipids.

(q)   explain what is meant by essential fatty acids.

(r)   describe the iodine value method as a measure of the degree of unsaturation of the fatty acids in a lipid.

(s)   describe the hydrogenation of unsaturated fatty acids and its importance in the food industry.

(t)   outline the processes which bring about the rancidity of lipids (hydrolytic and oxidative).

(u)   classify vitamins (A, B (one only), C, D and K) as water- or fat-soluble and indicate the consequences of inadequate intake of vitamins A and D.

(v)   describe briefly the importance of an adequate intake of calcium, phosphorus, iron and iodine.

(w)   describe the importance of water in the body and particularly its solvent properties.

(x)   describe the colloidal systems present in jam (a gel), milk and butter (o/w and w/o emulsions) and simply explain the role of emulsifying agents.

(y)   discuss what is meant by the calorific value of a food.

(z)   explain (qualitatively) how age, gender, activity and body mass affect the energy and nutrient requirements of people.

2. FOOD ADDITIVES

Contents

I   Food quality: flavour and colour.

II   Additives: their nature and purposes.

    (i)   Enhancement of; flavour, colour, nutritive value.

    (ii)   Stability.

    (iii) As an aid in food processing.

Assessment Objectives

Candidates should be able to:

(a) explain what are meant by E-numbers and their categorisation.

(b) describe and explain the effects and uses of the following: tartrazine, caramel, benzoic acid, sulphur dioxide, sodium nitrite, ascorbic acid, butylated hydroxyanisole, lecithin, citric acid, monosodium glutamate.

(c) discuss the ethics versus the economics of using additives in processed foods.

(d) recognise that flavours are generally complex mixtures of ingredients, and describe a simple analysis of taste.

3. FOOD STORAGE

Content

I   Storage: purposes of storage; effects of storage on quality.

II   Biochemical changes during storage, effects of micro-organisms and enzymes.

Assessment Objectives

Candidates should be able to:

(a) describe possible sources of food contamination by micro-organisms (moulds, yeast and bacteria).

(b) state that the spoilage organism can make food unpalatable, reduce its nutritive value or cause food poisoning.

(c) discuss microbial spoilage of foodstuffs, using the souring of milk by lactic bacteria and the spoilage of strawberries by *Botrytis cinerea* as examples.

(d) compare and contrast food poisoning by bacterial toxins and bacterial infestations, using *Clostridium botulinum* and *Salmonella* species as examples.

(e) describe the role of beneficial micro-organisms in the production of cheese, vinegar, and in baking.

(f) describe and explain the effects of surface area, pH and temperature on the enzymic browning of fruit.

(g) outline the process of non-enzymic browning (Maillards' reaction).

(h) discuss the importance of *(g)* to the potato crisp industry.

(i) identify ways to prevent non-enzymic browning.

(j) outline the biochemical processes which bring about the formation of oxymyoglobin and metmyoglobin in fresh meat.

(k) identify methods of preventing metmyoglobin formation.

4. FOOD PROCESSING AND ITS EFFECTS ON FOOD

Content

I   Effects of processing: prevention of spoilage; changes in nature.

II   Advantages and disadvantages of processing.

Assessment Objectives

Candidates should be able to:

(a) describe the common methods of food processing: treatment with chemicals, use of low temperature, dehydration, vacuum packing and irradiation.

(b) discuss the advantages (destruction of bacteria and toxins, improvement of texture and denaturation of enzymes) and the disadvantages (effects on the nutritional value, possible deterioration of texture) of cooking foods.

(c) describe the denaturation of proteins brought about by temperature, pH and mechanical agitation.

(d) *(i)* describe the use of sugars in the food industry both as solids and in solution.

  (ii) describe the composition of starch and its reactions with water and the consequence of the reactions in prepared food materials. (See also Composition and Functions of Food.)

(e) describe and explain the effects of cooking on the texture and ascorbic acid content of potatoes.

(f) describe and explain the effects of blanching on fruit and vegetable tissue.

(g) explain the meaning of the terms: anti-oxidant, flavour enhancer, emulsifier, preservative, stabiliser and thickening agent. (See also Food Additives.)

PHASE EQUILIBRIA OPTION

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

Preamble

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.

Assessment Objectives

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.

Assessment Objectives

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   The solubility of gases in liquids; Henry's Law.

II   Partition coefficient; solvent extraction.

Assessment Objectives

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.

Assessment Objectives

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*.]

Preamble

The aim of this option is to introduce students to the principles and methods of modern 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)

Assessment Objectives

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.

Assessment Objectives

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, $\lg(I_0/I) = \varepsilon c l$ (where ε 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.

Assessment Objectives

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 n.m.r. spectroscopy:

  (i)   structure elucidation;

  (ii)   quantitative analysis.

Assessment Objectives

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 n.m.r. 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 n.m.r. 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 n.m.r. 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 n.m.r. 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.

Assessment Objectives

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:

(a)   explain the contribution that each of the spectra normally available for an unknown compound makes to a possible identification.

(b)   use evidence from up to three spectra to suggest a probable structure for a given compound.

(c)   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.*]

Preamble

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: stoichiometry, stereochemistry and isomerism of complexes.

II   Magnetism; colour.

Assessment Objectives

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.

Assessment Objectives

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 its +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 its +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 its +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 its +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

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

$$[Co(NH_3)_6]^{2+} \rightleftharpoons [Co(NH_3)_6]^{3+}$$
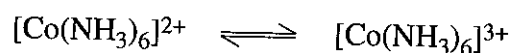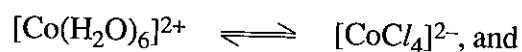
　　(iii) the use of cobalt in alloys, e.g. alnico.

(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 its +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 (PAPER 5 OR 6)

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

(a)   The questions in the practical paper will include:

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

    (ii)   a simple problem: this problem may be combined with *(i)*;

    (iii)   an observational problem in which the candidate will be asked to investigate, by specified experiments, an unknown substance or mixture. Systematic analysis will **not** be required.

    One, or more, of the questions will incorporate some assessment of planning skills.

(b)   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.

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

(d)   Although systematic analysis and a knowledge of traditional methods of separations will **not** be required, it will be assumed that candidates will be familiar with the reactions of the following ions: NH_4^+, Mg^{2+}, Al^{3+}, Ca^{2+}, Cr^{3+}, Mn^{2+}, Fe^{2+}, Fe^{3+}, Cu^{2+}, Zn^{2+}, Ba^{2+}, Pb^{2+}; CO_3^{2-}, NO_3^-, NO_2^-, SO_4^{2-}, SO_3^{2-}, Cl^-, Br^-, I^-, CrO_4^{2-} as given in the qualitative analysis notes on pages 63 and 64.

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.

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 will be allowed to refer to note books and text books in the Practical examination.

The Qualitative Analysis Notes given on pages 63 and 64 will be printed as part of the practical paper.

QUALITATIVE ANALYSIS NOTES (9254)

[Key: ppt. = precipitate; sol. = soluble; insol = insoluble; xs = excess.]

1. Reactions of aqueous cations

cation	reaction with	
	NaOH(aq)	NH$_3$(aq)
aluminium, Al^{3+}(aq)	white ppt. sol. in xs	white ppt. insol. in xs
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. sol. in xs giving dark green solution	grey-green ppt. insol. in xs
copper(II), Cu^{2+}(aq)	pale blue ppt. insol. in xs	blue ppt. sol. in xs giving dark blue solution
iron(II), Fe^{2+}(aq)	green ppt. insol. in xs	green ppt. insol. in xs
iron(III), Fe^{3+}(aq)	red-brown ppt. insol. in xs	red-brown ppt. insol. in xs
lead(II), Pb^{2+}(aq)	white ppt. sol. in xs	white ppt. insol. in xs
magnesium, Mg^{2+}(aq)	white ppt. insol. in xs	white ppt. insol. in xs
manganese(II), Mn^{2+}(aq)	off-white ppt. insol. in xs	off-white ppt. insol. in xs
zinc, Zn^{2+}(aq)	white ppt. sol. in xs	white ppt. sol. in xs

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) (sol. in NH_3(aq)); gives white ppt. with Pb^{2+}(aq)
bromide, Br^-(aq)	gives cream ppt. with Ag^+(aq) (partially sol. in NH_3(aq)); gives white ppt. with Pb^{2+}(aq)
iodide, I^-(aq)	gives yellow ppt. with Ag^+(aq) (insol. in NH_3(aq)); gives yellow ppt. with Pb^{2+}(aq)
nitrate, NO_3^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil
nitrite, NO_2^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil; 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) (insol. in xs dilute strong acid)
sulphite, SO_3^{2-}(aq)	SO_2 liberated with dilute acids; gives white ppt. with Ba^{2+}(aq) (sol. in dilute strong acids)

3. Tests for gases

gas	test
ammonia, NH_3	turns damp red litmus paper blue
carbon dioxide, CO_2	gives a white ppt. with limewater
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

PRACTICAL TECHNIQUES (9254)

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 $0.2 \,°C$, times to the nearest second.

(c)   In qualitative exercises, candidates should use approximately 1 cm depth of a solution (1-2 cm^3) for each test and add reagents gradually, 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: 3 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 $1\,°C$;
$\qquad\qquad\quad -5\,°C$ to $+50\,°C$ at $0.2\,°C$
Plastic beaker or any other suitable alternative
Clocks (or wall-clock) to measure to an accuracy of about 1 s. (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).

CENTRE-BASED ASSESSMENT OF EXPERIMENTAL SKILLS

It is expected that practical activities will underpin the teaching of the whole syllabus.

Centre-based assessment consists of either Paper 7 or Paper 9.

Paper 7 (Extended Investigation) is described on pages 68 to 71 and Paper 9 (Separate Skills Assessment) is described on pages 72 to 77.

Papers 7 and 9 each cover assessment of three skills: Planning, Implementing, and Interpreting and Concluding. These three skills are in the AS/A level Chemistry Subject Core (SEAC 1993).

PAPER 7: EXTENDED INVESTIGATION

1. *General Information*

The Extended Investigation must show evidence of a candidate's ability to identify an issue or problem, conduct practical work, collect and analyse data and present reasoned arguments in drawing conclusions and evaluating the data.

The Investigation can either be **Laboratory/Fieldwork based or Work-related** and must relate to subject content covered by the syllabus.

The Extended Investigation should take up no more than 15 hours work in total. The resulting account should be no more than 2500 words, excluding headings, graphs, tables and appendices.

All Investigations must have approval from OCR before the students begin the work (see notes under *Approval*, below).

2. *The Extended Investigation (Work-related)*

It is intended that this version of the Extended Investigation should be 'applied' in nature and should arise from the stimulus provided by a short work placement or visit.

The work placement should be with industrial/commercial companies whose work is related to chemistry in its broadest sense.

During the work placement/visits the student should take the opportunity to look in detail at one application of chemistry in the particular area of work, as well as gaining a more general knowledge of the work being carried out.

The practical aspect of the work **which must be an integral part of the work-related investigation,** could be work-place based if that can be arranged. If this is not possible, practical work arising from, or leading on from, the work placement may be carried out back in a school laboratory etc, if appropriate.

3. *Approval*

Titles and brief outlines of Extended Investigations must be submitted to OCR on the correct form at least six weeks before the candidates are due to start work on the investigation.

4. *Teacher Assessment of Extended Investigations*

The assessment of the Extended Investigation is based on three skills:

    A   Planning
    B   Implementing
    C   Interpreting and Concluding

There are **six** assessment criteria for each skill. Each assessment criterion is marked on a scale of 0-2. The marks awarded should be as follows:

2: criterion completely met
1: criterion partly met
0: criterion not met at all.

Skill descriptors and assessment criteria are fully detailed on pages 75 to 77. The skills assessed cover Assessment Objectives C1 to C6.

The marks awarded should be based on both the final written work and the teacher's knowledge of the work carried out by the candidate. In assigning a mark, attention should be paid to the extent of guidance needed by / given to the candidate.

For each candidate entered for Paper 7, Centres are required to submit one score out of 12 for each of skills **A**, **B** and **C** assessed in the context of an Extended Investigation.

The total number of raw marks available for the Extended Investigation is 36.

Each Investigation account should be annotated to show how marks have been awarded in relation to the relevant assessment criteria. These annotations should be made at appropriate points in the margins of the text. Appropriate abbreviations or symbols may be used by the teacher to indicate the different marking criteria being assessed.

5. *Internal Moderation*

Where more than one teacher in a Centre is involved in internal assessment, arrangements must be made within the Centre to ensure consistent application of the assessment criteria. A report of these arrangements must be included with the work sent to OCR for external moderation.

Internal moderation is essential to produce a single valid order of merit for the module entry from the Centre.

6. *External Moderation*

(a) If there are 20 or fewer candidates from the Centre, then written work of **all the** candidates should be submitted for moderation;

(b) If there are more than 20 candidates from a Centre, then the written work of 20 **candidates** must be sent to OCR. The 20 candidates should represent the full mark range, as evenly spaced as possible, and should include candidates from each teaching group.

OCR may request the work of additional candidates in order to arrive at a decision regarding the standard of the work.

7. *Authentication*

Teachers must be able to supply evidence of their continuing supervision of the work. Where the nature of the subject requires candidates to undertake assessed coursework activities outside the Centre, a proportion of the work must take place under direct supervision. The proportion must be sufficient to enable the teacher to authenticate each candidate's work with confidence.

8. *Safety in the Laboratory*

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

(a)   the requirements, as published in October 1989, of COSHH (the Committee on Safety of Substances Hazardous to Health).

(b)   *Safe Practices in Chemical Laboratories*, the Royal Society of Chemistry, 1989.

(c)   *Safety in Science Laboratories*, DES Safety Series, **2**, HMSO, 1976.

(d)   *Hazards in the Chemical Laboratory*, ed. L. Bretherick, The Royal Society of Chemistry, 4th ed., 1986.

(e)   *Safeguards in the School Laboratory*, ASE, 9th ed., 1988.

(f)   *Hazcards*, as published by CLEAPSS Development Group, Brunel University, Uxbridge UB8 3PH.

(g)   *Animals and Plants in Schools*: Legal Aspects, DES Administrative Memorandum No. 3/90.

Teachers are reminded that they must comply with school / college / local authority policies and procedures on work placements. OCR will take no responsibility for any injury, etc. which occurs to a student during a work placement.

THE EXTENDED INVESTIGATION

NOTES FOR GUIDANCE OF TEACHERS

The Extended Investigation should be an individual study, and should be either Laboratory/Fieldwork based, or Work-related. Each completed Investigation should be no more than 2500 words in length, excluding headings, tables, graphs and appendices.

Accounts of the Extended Investigation should consist of the following clearly identified sections.

1. A clearly stated title, an abstract and a contents list.

2. An introduction which should briefly put the investigation in context and should include a concise statement of the investigation.

3. An account of the method(s) used in obtaining information. This should include the sequence of experimental or observational work undertaken.

4. The results should be presented clearly and concisely. Tables, line graphs, bar charts, histograms, pie charts etc. are all commonly used and can be helpful, but they must be correctly derived from the observations. Raw data should be given in an appendix.

5. Conclusions or inferences based solely on the results obtained should be clearly stated. The discussion should include implications and relevance of the conclusions if pertinent.

6. Limitations, reliability and sources of error should be evaluated and discussed and their possible effects on the reliability of the data should be noted.

7. Suggestions for any modifications to the original design should be made, based on the evaluation of the results.

8. A list of acknowledgments, indicating the source and extent of any help that has been received.

Pages in the written accounts must be numbered, and the Investigation should be submitted for external moderation in a light paper folder (**not** a heavy ring binder).

PAPER 9: SEPARATE SKILLS ASSESSMENT

1.   *Introduction*

The scheme detailed below is intended to provide guidance for teachers in making the assessment of the Experimental Skills, but should not exert an undue influence on the methods of teaching or provide a constraint on the practical work undertaken by candidates. It is not expected that all of the practical work undertaken by the candidates would be appropriate for assessment.

The assessments may be carried out at any time during the course using suitable practical activities which are related to, or are part of, the teaching of the course. It is expected that students will have had opportunities to acquire experience and develop the relevant skills before assessment takes place.

2.   *Teacher assessment of the experimental skills assessed separately*

The Experimental Skills to be assessed separately are given below:

  A Planning
  B Implementing
  C Interpreting and Concluding

There are **six** assessment criteria for each skill and each assessment criterion is marked on a scale of 0-2.

  2: criterion completely met
  1: criterion partly met
  0: criterion not met at all

The three skills carry equal weighting.

Skill descriptors and assessment criteria are fully detailed on pages 75 to 77.

The skills assessed cover Assessment Objectives C1 to C6.

It is expected that skills **A, B** and **C** will be assessed using different practical exercises. Within each skill area there are a number of assessment criteria. Teachers are advised, therefore, that they may need **to use more than one practical exercise** in order to assess all these assessment criteria.

At whatever stage assessments are carried out, the standards applied must be those of A level, i.e. those expected at the end of the course, as exemplified in the assessment criteria. Students should be informed when an assessment is to take place.

The marks awarded should be based on both the final written work and the teacher's knowledge of the work carried out by the candidate. In assigning a mark, attention should be paid to the extent of guidance needed by / given to the candidate.

For each candidate entered for Paper 9, Centres are required to submit one score out of 12 for each of Skills **A, B** and **C** assessed separately. Hence the maximum raw mark available for Paper 9 is 36.

Students should be assessed on each skill on a **minimum of two occasions** and the **better or best mark** for each skill submitted.

3. *Annotation of Coursework*

Each piece of assessed practical coursework must be annotated to show how the marks have been awarded in relation to the relevant assessment criteria.

The writing of comments on candidates' work can provide a means of dialogue and feedback between teacher and candidate and a means of communication between teachers during internal moderation of coursework. The main purpose of writing comments on candidates' coursework is, however, to provide a means of communication between teacher and coursework moderator, showing where marks have been awarded and why.

For written coursework, annotations should be made at appropriate points in the margins of the text. The annotations should indicate where achievement against a specified assessment criterion for a particular skill has been noted. Appropriate abbreviations or symbols may be used to indicate the marking criterion concerned.

The annotations should also indicate the mark to be awarded for each skill.

The marks for individual assessments should be recorded on the candidate's work as part of the normal feedback from the teacher. The final total score, as submitted to OCR, should not be given to the candidates.

4. *Suitability of Coursework*

It is essential that all teachers assessing candidates' practical work relating to the separate Experimental Skills should be familiar with the requirements of the syllabus.

If teachers in a Centre are not certain that their proposed practical work will satisfy the syllabus requirements, then they should write to the relevant OCR Subject Officer to seek clarification **well before the proposed work is due to be carried out.**

A Handbook for Teachers is available containing exemplar material.

5. *Moderation*

Moderation procedures are as described on page 69.

Each Centre will be required to send the following information about the separate skills assessment to OCR:

(a) a summary which identifies all of the activities used for assessment. This must show how tasks were presented to candidates, including worksheets or other documentation issued to candidates;

(b) an indication of how marks were awarded for assessment criteria for which there is no written evidence in the candidates' work.

6. *Authentication*

Teachers must be able to supply evidence of their continuing supervision of the work. Where the nature of the subject requires candidates to undertake assessed coursework activities outside the Centre, a proportion of the work must take place under direct supervision. The proportion must be sufficient to enable the teacher to authenticate each candidate's work with confidence.

7. *Safety in the Laboratory*

Responsibility for safety matters rests with Centres. Attention is drawn to the publications listed on page 70.

EXPERIMENTAL SKILLS

SKILL A   **PLANNING**

	ASSESSMENT CRITERION	REQUIREMENT	MAXIMUM MARK AVAILABLE
A1	APPLICATION	Scientific information/ideas considered in approaching an identified problem.	2
A2	DEFINITION	Development of a problem, prediction or hypotheses that can be investigated.	2
A3	VARIABLES	Due regard paid to scale of working and, where relevant, control of variables.	2
A4	ORGANISATION	Plan involving a series of well-ordered steps.	2
A5	APPARATUS	Appropriate apparatus and materials selected.	2
A6	PROCEDURES	Developed plan effective in investigating safely the identified problem, prediction or hypothesis.	2

Each assessment criteria is marked on a scale of 0-2.

    2:     criterion fully met
    1:     criterion partly met
    0:     criterion not met at all

The total raw mark available for each skill is 12.

SKILL B   **IMPLEMENTING**

ASSESSMENT CRITERION	REQUIREMENT	MAXIMUM MARK AVAILABLE
B1 CARRYING OUT	Experiment performed in a careful and organised manner.	2
B2 SAFETY	Sensible conduct with concern shown for safety of self and others and/or for equipment.	2
B3 MANIPULATIVE SKILLS	Apparatus used and techniques performed skillfully.	2
B4 MAKING OBSERVATIONS	Accurate and detailed observations made.	2
B5 RECORDING OBSERVATIONS	Observations recorded in a suitable format.	2
B6 PRECISION / ACCURACY	Measurements made are accurate and to the appropriate degree of precision.	2

Each assessment criteria is marked on a scale of 0-2.

    2:    criterion fully met
    1:    criterion partly met
    0:    criterion not met at all

The total raw mark available for each skill is 12.

SKILL C   **INTERPRETING AND CONCLUDING**

ASSESSMENT CRITERION	REQUIREMENT	MAXIMUM MARK AVAILABLE
C1 PROCESSING	Processing of results.	2
C2 RELIABILITY	Reliability and accuracy of own experimental data and/or techniques assessed.	2
C3 MODIFICATION	Modifications suggested to procedures or justification offered for no modifications.	2
C4 INTERPRETING	Processed data interpreted appropriately.	2
C5 CONCLUSION	Conclusion drawn consistent with processed data.	2
C6 COMMUNICATION	Written account well presented with clear logical structure.	2

Each assessment criteria is marked on a scale of 0-2.

2:    criterion fully met
1:    criterion partly met
0:    criterion not met at all

The total raw mark available for each skill is 12.

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 symbol(s)	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	°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	$(E^\ominus)\,E$	V
electromotive force	E	V
molar gas constant	R	$J\,K^{-1}\,mol^{-1}$
half-life	$T_{\frac{1}{2}}, t_{\frac{1}{2}}$	s
atomic mass	m_a	kg
relative { atomic isotopic } mass	A_r	—
molecular mass	m	kg
relative molecular mass	M_r	—
molar mass	M	$kg\,mol^{-1}$
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	$\Delta H^\ominus$	$J\,mol^{-1}$, $kJ\,mol^{-1}$
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_s	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.

Make calculations involving addition, subtraction, multiplication and division of quantities.
Make approximate evaluations of numerical expressions.
Express small fractions as percentages, and vice versa.
Calculate an arithmetic mean.
Transform decimal notation to power of ten notation (standard form).
Use tables or calculators to evaluate logarithms (for pH calculations), squares, square roots, and reciprocals.
Change the subject of an equation. (Most such equations involve only the simpler operations but may include positive and negative indices and square roots.)
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.
Solve simple algebraic equations.
Comprehend and use the symbols/notations $<$, $>$, $\approx$, $/$, Δ, $\equiv$, $\bar{x}$ (or $<x>$).
Test tabulated pairs of values for direct proportionality by a graphical method or by constancy of ratio.
Select appropriate variables and scales for plotting a graph, especially to obtain a linear graph of the form $y = mx + c$.
Determine and interpret the slope and intercept of a linear graph.
Choose by inspection a straight line that will serve as the 'least bad' linear model for a set of data presented graphically.
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.
Comprehend how to handle numerical work so that significant figures are neither lost unnecessarily nor used beyond what is justified.
Estimate orders of magnitude.
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.

GLOSSARY OF TERMS USED IN 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.

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
Local Examinations Syndicate

DATA BOOKLET

for

CHEMISTRY (9254 and 8405)

CHEMISTRY MODULES (4820–4827 and 4846)

TABLES OF CHEMICAL DATA

Important values, constants and standards

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

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

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

QUALITATIVE ANALYSIS NOTES (9254)

[Key: ppt. = precipitate; sol. = soluble; insol = insoluble; xs = excess.]

1.1 Reactions of aqueous cations

cation	*reaction with*	
	NaOH(aq)	NH_3(aq)
aluminium, Al^{3+}(aq)	white ppt. sol. in xs	white ppt. insol. in xs
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. sol in xs giving dark green solution	grey-green ppt. insol. in xs
copper(II), Cu^{2+}(aq)	pale blue ppt. insol. in xs	blue ppt. sol in xs giving dark blue solution
iron(II), Fe^{2+}(aq)	green ppt. insol. in xs	green ppt. insol. in xs
iron(III), Fe^{3+}(aq)	red-brown ppt. insol. in xs	red-brown ppt. insol. in xs
lead(II), Pb^{2+}(aq)	white ppt. sol. in xs	white ppt. insol. in xs
magnesium, Mg^{2+}(aq)	white ppt. insol. in xs	white ppt. insol. in xs
manganese(II), Mn^{2+}(aq)	off-white ppt. insol. in xs	off-white ppt. insol. in xs
zinc, Zn^{2+}(aq)	white ppt. sol. in xs	white ppt. sol. in xs

[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) (sol. in NH_3(aq)); gives white ppt. with Pb^{2+}(aq)
bromide, Br^-(aq)	gives cream ppt. with Ag^+(aq) (partially sol. in NH_3(aq)); gives white ppt. with Pb^{2+}(aq)
iodide, I^-(aq)	gives yellow ppt. with Ag^+(aq) (insol. in NH_3(aq)); gives yellow ppt. with Pb^{2+}(aq)
nitrate, NO_3^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil
nitrite, NO_2^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil; 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) (insol. in xs dilute strong acid)
sulphite, SO_3^{2-}(aq)	SO_2 liberated with dilute acids; gives white ppt. with Ba^{2+}(aq) (sol. 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 xs 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

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

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

Standard electrode 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, ie a redox series.

(a) $E^{\ominus}$ in alphabtical order

Electrode reaction	$E^{\ominus}/V$
$Ag^+ + e^- \rightleftharpoons Ag$	+0.80
$Al^{3+} + 3e^- \rightleftharpoons Al$	−1.66
$Ba^{2+} + 2e^- \rightleftharpoons Ba$	−2.90
$Br_2 + 2e^- \rightleftharpoons 2Br^-$	+1.07
$Ca^{2+} + 2e^- \rightleftharpoons Ca$	−2.87
$Cl_2 + 2e^- \rightleftharpoons 2Cl^-$	+1.36
$2HOCl + 2H^+ + 2e^- \rightleftharpoons Cl_2 + 2H_2O$	+1.64
$Co^{2+} + 2e^- \rightleftharpoons Co$	−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		$E^{\ominus}$/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-}	$+0.56$
$MnO_4^- + 2H_2O + 3e^-$	$\rightleftharpoons$ $MnO_2 + 4OH^-$	$+0.58$
$MnO_4^- + 8H^+ + 5e^-$	$\rightleftharpoons$ $Mn^{2+} + 4H_2O$	$+1.52$
$NO_3^- + 2H^+ + e^-$	$\rightleftharpoons$ $NO_2 + H_2O$	$+0.81$
$NO_3^- + 3H^+ + 2e^-$	$\rightleftharpoons$ $HNO_2 + H_2O$	$+0.94$
$NO_3^- + 10H^+ + 8e^-$	$\rightleftharpoons$ $NH_4^+ + 3H_2O$	$+0.87$
$Na^+ + e^-$	$\rightleftharpoons$ 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	-1.2
$V^{3+} + e^-$	$\rightleftharpoons$ 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 alphabetic list on pages 3 and 4)

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
$Sn^{4+} + 2e^- \rightleftharpoons Sn^{2+}$	+0.15
$SO_4^{2-} + 4H^+ + 2e^- \rightleftharpoons SO_2 + 2H_2O$	+0.17
$S_4O_6^{2-} + 2e^- \rightleftharpoons 2S_2O_3^{2-}$	+0.09
$2H^+ + 2e^- \rightleftharpoons H_2$	0.00
$Pb^{2+} + 2e^- \rightleftharpoons Pb$	−0.13
$Sn^{2+} + 2e^- \rightleftharpoons Sn$	−0.14
$Fe^{2+} + 2e^- \rightleftharpoons Fe$	−0.44
$Zn^{2+} + 2e^- \rightleftharpoons Zn$	−0.76
$Mg^{2+} + 2e^- \rightleftharpoons Mg$	−2.38
$Ca^{2+} + 2e^- \rightleftharpoons Ca$	−2.87
$K^+ + e^- \rightleftharpoons K$	−2.92

Atomic and ionic radii

(a)   Period 3

		atomic / nm		ionic / nm	
metallic		Na	0.186	Na^+	0.095
		Mg	0.160	Mg^{2+}	0.065
		A*l*	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
		C*l*	0.099	Cl^-	0.181
van der Waals		Ar	0.192		

(b)   Group II

	atomic / nm		ionic / nm	
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

	atomic / nm		ionic / nm	
single covalent	C	0.077		
	Si	0.117	Si^{4+}	0.041
	Ge	0.122	Ge^{2+}	0.093
metallic	Sn	0.162	Sn^{2+}	0.112
	Pb	0.175	Pb^{2+}	0.120

(d)   Group VII

	atomic / nm		ionic / nm	
single covalent	F	0.072	F^-	0.136
	C*l*	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

	atomic / nm		ionic / nm	
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

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
Cl—Cl	244
Br—Br	193
I—I	151
H—F	562
H—Cl	431
H—Br	366
H—I	299

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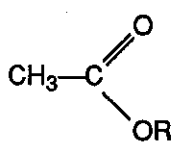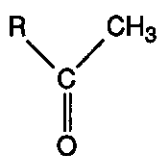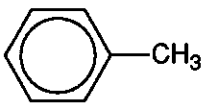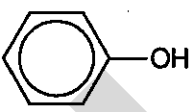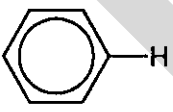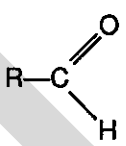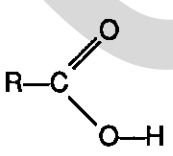
Bond	Energy / kJ mol^{-1}
C—C	350
C=C	610
C≡C	840
C⋯C (benzene)	520
C—H	410
C—Cl	340
C—Br	280
C—I	240
C—N	305
C=N	610
C≡N	890
C—O	360
C=O	740
N—H	390
N—N	160
N=N	410
O—H	460
O—O	150
Si—Cl	359
Si—H	320
Si—O	444
Si—Si	222
S—Cl	250
S—H	347
S—S	264

SPECTROSCOPY OPTION

Characteristic values for infrared absorption (due to stretching vibrations in organic molecules)

Bond		Characteristic ranges Wavenumber (reciprocal wavelength) /cm^{-1}
C—Cl		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 3670

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$_3$CH	2.0
CH$_3$—C($=$O)—OR	2.0
R—C($=$O)—CH$_3$	2.1
C$_6$H$_5$—CH$_3$	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
C$_6$H$_5$—OH	7*
C$_6$H$_5$—H	7.3
R—C($=$O)—H	9.7*
R—C($=$O)—O—H	11.5*

*Sensitive to solvent, substituents, concentration

The Periodic Table

Group																	
I	II												III	IV	V	VI	VII	0

I	II												III	IV	V	VI	VII	0
							1.0 **H** 1											4.0 **He** 2
6.9 **Li** 3	9.0 **Be** 4												10.8 **B** 5	12.0 **C** 6	14.0 **N** 7	16.0 **O** 8	19.0 **F** 9	20.2 **Ne** 10
23.0 **Na** 11	24.3 **Mg** 12												27.0 **Al** 13	28.1 **Si** 14	31.0 **P** 15	32.1 **S** 16	35.5 **Cl** 17	39.9 **Ar** 18
39.1 **K** 19	40.1 **Ca** 20	45.0 **Sc** 21	47.9 **Ti** 22	50.9 **V** 23	52.0 **Cr** 24	54.9 **Mn** 25	55.8 **Fe** 26	58.9 **Co** 27	58.7 **Ni** 28	63.5 **Cu** 29	65.4 **Zn** 30		69.7 **Ga** 31	72.6 **Ge** 32	74.9 **As** 33	79.0 **Se** 34	79.9 **Br** 35	83.8 **Kr** 36
85.5 **Rb** 37	87.6 **Sr** 38	88.9 **Y** 39	91.2 **Zr** 40	92.9 **Nb** 41	95.9 **Mo** 42	– **Tc** 43	101 **Ru** 44	103 **Rh** 45	106 **Pd** 46	108 **Ag** 47	112 **Cd** 48		115 **In** 49	119 **Sn** 50	122 **Sb** 51	128 **Te** 52	127 **I** 53	131 **Xe** 54
133 **Cs** 55	137 **Ba** 56	**La** to **Lu**	178 **Hf** 72	181 **Ta** 73	184 **W** 74	186 **Re** 75	190 **Os** 76	192 **Ir** 77	195 **Pt** 78	197 **Au** 79	201 **Hg** 80		204 **Tl** 81	207 **Pb** 82	209 **Bi** 83	– **Po** 84	– **At** 85	– **Rn** 86
– **Fr** 87	– **Ra** 88	**Ac** to **Lr**																

139 **La** 57	140 **Ce** 58	141 **Pr** 59	144 **Nd** 60	– **Pm** 61	150 **Sm** 62	152 **Eu** 63	157 **Gd** 64	159 **Tb** 65	163 **Dy** 66	165 **Ho** 67	167 **Er** 68	169 **Tm** 69	173 **Yb** 70	175 **Lu** 71
– **Ac** 89	– **Th** 90	– **Pa** 91	– **U** 92	– **Np** 93	– **Pu** 94	– **Am** 95	– **Cm** 96	– **Bk** 97	– **Cf** 98	– **Es** 99	– **Fm** 100	– **Md** 101	– **No** 102	– **Lr** 103

Key

a
X
b

a = relative atomic mass
X = atomic symbol
b = proton (atomic) number