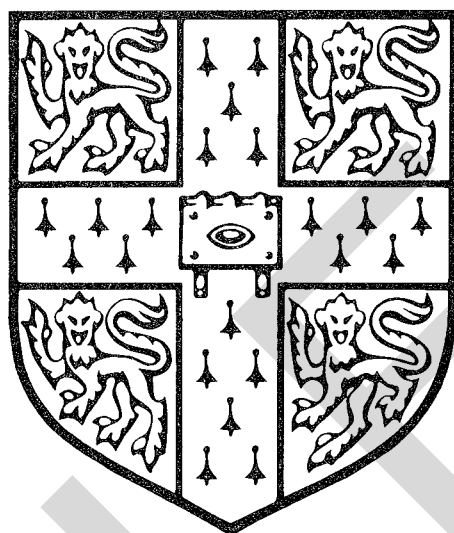


A Level

Chemistry

Session: 1994
Type: Syllabus
Code: 9250

University of Cambridge
Local Examinations Syndicate



CHEMISTRY

Examination Syllabuses for 1994 and 1995
(UK Centres only)

CHEMISTRY

9250

G.C.E. ADVANCED LEVEL

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.

AIMS

These are not listed in order of priority.

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 studies beyond A level in pure sciences, in applied sciences or in science-dependent vocational courses.
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 effective communication.
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 inventiveness.
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.

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 59.)

B Handling, applying and evaluating information

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

1. locate, select, organise and present information from a variety of sources;
2. translate information from one form to another;
3. manipulate numerical and other data;
4. use information to identify patterns, report trends and draw inferences;
5. present reasoned explanations for phenomena, patterns and relationships;
6. make predictions and to put forward hypotheses;
7. apply knowledge, including principles, to novel situations;
8. 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*, *calculate* or *determine*. (See the glossary of terms on page 59.)

C Experimental skills and investigations

Students should be able to:

1. follow a detailed set or sequence of instructions;
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 either 5, 7 or 9 (June), Papers 1, 2, 3, 4 and 6 (November)

Paper	Type of Paper	Duration	Marks
1	Free Response Questions	2½ h	80
2	Option Topics	1 h	40
3	Structured Questions	1 h	40
4	Multiple Choice	1 h	40
5, 6, 7 or 9	Practical Assessment		50

Paper 1 (2½ h) (80 marks)

Eight “free response” questions (ten marks each) to be answered from eleven set. Based on the core syllabus (sections 1–11).

Section A (based mainly on physical chemistry) four questions, three to be answered.

Section B (based mainly on inorganic chemistry) three questions, two to be answered.

Section C (based mainly on organic chemistry) four questions, three to be answered.

Paper 2 (1 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 3 (1 h) (40 marks)

A variable number of structured questions, all compulsory. Based on the core syllabus (sections 1 to 11). Answered on the question paper.

Paper 4 (1 h) (40 marks)

Forty multiple choice questions based on the core syllabus (sections 1 to 11). Thirty items will be of the direct choice type and ten of the multiple completion type.

With effect from 1994 questions will involve 4 response items rather than 5. [For multiple-completion items, i.e. questions 30 to 40, key E (statement 3 only is correct) will be dropped.]

(N.B. Papers 1 to 4 have merely been re-numbered for administrative reasons.)

Paper 5. Paper 6 (Nov) (2 h 30 min) (50 marks)

Practical Examination.

The scope of the practical examination is indicated in the Practical Chemistry syllabus printed on page 38. (The paper will be marked out of 75 and scaled to out of 50.)

Papers 7 and 9 School-based assessment

Paper 7 (Individual Study) This is based on project work. Further information is given on page 39.

Paper 9 This is intended to reflect practical work carried out throughout the course. Further information is given on page 41. (Not available in the November examination, but see note below concerning Paper 85). [It may be noted that the scheme of assessment leads to a mark of 48 not 50. It is **not** necessary for teachers to scale the marks out of 48 to marks out of 50. The difference in maxima is allowed for in the grading process.]

Schools 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 school-based assessment as Paper 87 or 89.

Special Paper (Paper 0)

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 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.

Data Booklet

A *Data Booklet* (dated January 1990) is available for use in Papers 1, 2, 3 and 4 and in the Special Paper. The booklet is reprinted on pages 47 to 54. Copies of the booklet can be ordered from the Syndicate, see page 85.

Nomenclature

The ASE proposals in "*Chemical Nomenclature, Symbols and Terminology for use in school science (1985)*" will generally be adopted. In particular, the names sulphite, nitrite, sulphur trioxide, sulphurous and nitrous acids will be used in question papers.

MARKS ALLOCATED TO ASSESSMENT OBJECTIVES AND SYLLABUS AREAS**Theory Papers (Papers 1, 3 and 4) (160 marks in total)**

Knowledge with understanding, approximately 50 marks allocated to recall and 30 marks allocated to understanding.

Handling, applying and evaluating information, approximately 80 marks.

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

Options Theory Paper (Paper 2) (40 marks)

This paper is designed to test appropriate aspects of objectives A 1 to 5 and B 1 to 6 on pages 3 and 4. Whilst every effort will be made to produce questions of comparable difficulty and reasonable spread of skills, the differing natures of the various options mean that different skills will be required of candidates according to their choice of options and questions.

Practical Assessment (Paper 5, 6, 7 or 9) (50 marks).

Experimental skills and investigations

These papers are designed to test appropriate aspects of objectives C 1 to 6 given on page 4. The practical paper may also involve some calculations based on experimental results.

STRUCTURE OF THE SYLLABUS

The syllabus has been constructed on a “core plus options” basis in which the “core” (Sections 1–11) represents 80% of the whole course. Candidates will be expected to study two options, each representing 10%.

Eight options are currently available:

- (a) Further Transition Metal Chemistry,
- (b) Phase Equilibria,
- (c) Biochemistry, (Candidates should not study both Biochemistry and Food Chemistry.)
- (d) Food Chemistry,
- (e) Soil Chemistry,
- (f) Chemical Engineering,
- (g) Polymers,
- (h) Spectroscopy.

An Environmental Chemistry option is in the process of being submitted to the SEAC. Subject to approval, schools will be informed of the date of its inclusion in the syllabus when it will stand alongside the Soil Chemistry option (c.f. Biochemistry/Food Chemistry).

In order to specify the syllabus more precisely and also to emphasise the importance of skills other than recall, assessment objectives have been used in each section of the syllabus. However, it is appreciated that teachers may wish to compare the content with previous syllabuses and for that reason each section is specified both in the usual “content” form and in assessment objectives. Although this, of necessity, makes the syllabus a much lengthier document, it is hoped that this format will be helpful to teachers. It must be emphasised, however, that this is not intended to be used as a teaching syllabus, nor is it intended to suggest a teaching order.

It is hoped that teachers will incorporate the social, environmental, economic and technological aspects of chemistry wherever possible 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 in the course. Inclusion of further examples in the syllabus has been resisted as this would merely increase the amount of factual recall required of students.

SUBJECT CONTENT

(CORE: Sections 1 to 11 inclusive)

PHYSICAL CHEMISTRY

1. ATOMS, MOLECULES AND STOICHIOMETRY

CONTENT

- 1.1 Relative masses of atoms and molecules. The term ‘relative formula mass’ or M_r will be used for ionic compounds.
- 1.2 The mole, the Avogadro constant.
- 1.3 The determination of relative atomic masses, A_r , and relative molecular masses, M_r , from mass spectra.
Knowledge of the structure of the mass spectrometer is *not* required.
- 1.4 The calculation of empirical and molecular formulae, using composition by mass or combustion data.
- 1.5 Reacting masses and volumes (of solutions and gases).

ASSESSMENT OBJECTIVES

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) describe one method for determining a value for the Avogadro constant (the electrolytic method in Section 6.2 is suitable).
- (d) interpret mass spectra in terms of isotopic abundances and molecular fragmentation.
- (e) calculate the relative atomic mass of an element given the relative abundances of its isotopes, or its mass spectrum.
- (f) define the terms *empirical* and *molecular formulae*.
- (g) calculate empirical and molecular formulae, using combustion data or composition by mass.
- (h) perform calculations (including the mole concept) involving reacting masses, volumes of gases, and volumes and concentrations of solutions, and hence deduce stoichiometric relationships.

2. ATOMIC STRUCTURE

CONTENT

- 2.1 Electrons, protons and neutrons.
- 2.2 The nucleus of the atom, isotopes and proton (atomic) and nucleon (mass) numbers.
- 2.3 Electronic energy levels, ionisation energies, atomic orbitals, extranuclear structure as the basis of periodicity. (See the *Data Booklet*.)

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 neutral and charged species given proton (atomic) and nucleon (mass) numbers.
- (e) describe the contribution of protons and neutrons to atomic nuclei in terms of proton number and nucleon number; 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 orbital; describe the shape of s and of p orbitals.
- (g) predict the electronic configuration of atoms and ions given the proton number (and charge).
- (h) explain the factors influencing the ionisation energies of elements.
- (i) predict the electronic configurations of elements from successive ionisation energy data; interpret these in terms of the position of the element within the Periodic Table.
- (j) explain trends in ionisation energies across a period and down a group of the Periodic Table.

3. CHEMICAL BONDING

CONTENT

An appreciation of the dependence of the properties of solids, liquids and gases on the chemical bonding involved is expected.

- 3.1 Electrovalent bonds between ions.
- 3.2 (a) Covalent bonds: pairing of electrons including dative (co-ordinate) bonds (see also Section 11.1(d)).
 - (b) The qualitative model of repulsion between electron pairs. The shapes of simple molecules, including BF₃ (trigonal), CO₂ (linear), CH₄ (tetrahedral), NH₃ (pyramidal), H₂O (non-linear), SF₆ (octahedral).
 - (c) Consideration of bond energy and bond lengths leading to a qualitative comparison of the reactivity of covalent bonds.
- 3.3 Metallic bonds: a simple treatment of metals as consisting of a lattice of positive ions surrounded by mobile electrons.
- 3.4 Intermolecular forces: a simple treatment based on permanent and induced dipoles (including van der Waals' forces), e.g. as in liquid trichloromethane, liquid bromine and in the liquid noble gases.
- 3.5 Hydrogen bonding and its influence on physical properties.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) describe electrovalent and covalent bonding in terms of 'dot and cross' diagrams.
- (b) describe metallic, intermolecular and hydrogen bonding.
- (c) describe and explain typical properties associated with electrovalent and covalent bonding.
- (d) deduce the type of bonding present in substances from information given.
- (e) explain the differences in the bond angles in the water, ammonia and methane molecules.
- (f) predict and explain the shape of species by using the principle of electron-pair repulsion.
- (g) interpret the electrical conductivities of metals in terms of their bonding.
- (h) deduce the effects of hydrogen bonding on the physical properties of substances (including organic substances).
- (i) deduce the effects of intermolecular forces on the physical properties of substances.
- (j) explain the terms bond energy and bond length and use them qualitatively to compare the reactivities of covalent bonds.

4. GASES, LIQUIDS AND SOLIDS**CONTENT****4.1 Gases**

An awareness of the basic assumptions for ideal gas behaviour and their limitations for very high pressure and very low temperature. (See also Section 8.2.)

- (a) $pV = nRT$ and its use in determining a value for M_r .
- (b) Deviations from ideality: qualitative explanation in terms of intermolecular forces and molecular size only.

No treatment or use of van der Waals' equation is required.

4.2 Liquids

The kinetic concept of the liquid state and a simple kinetic-molecular description of melting, vaporisation and vapour pressure.

4.3 Solids

Lattice structure and spacing.

Generally, only the qualitative idea that the particles are situated at fixed points in a regular pattern is required. It should, however, be appreciated that the individual particles may be atoms, molecules or ions.

Structure in crystalline solids; ionic, molecular, giant molecular, hydrogen-bonded, metallic and layer lattices, illustrated by one simple example in each case.

Reference should be made to the qualitative differences in the forces of attraction between the particles in atomic, molecular and ionic lattices.

The uses of metals and ceramics in terms of their physical properties. Metals as a finite resource. The importance of recycling processes.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) 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.
- (b) state and use the general gas equation $pV = nRT$ in calculations, including the determination of M_r .
- (c) describe, using a kinetic-molecular model, the liquid state, melting, vaporisation and vapour pressure.
- (d) describe qualitatively the nature of the solid state in terms of particles arranged in a regular three-dimensional pattern by repetition of the unit cell.
- (e) explain, qualitatively, differences in the forces of attraction between the particles in atomic, molecular and ionic lattices.
- (f) describe, using one simple example in each case, the structure of a crystalline solid which is
 - (i) metallic,
 - (ii) molecular,

- (iii) giant molecular,
 - (iv) layer,
 - (v) ionic,
 - (vi) hydrogen bonded.
- (g) interpret the physical properties (including electrical conductivity, malleability) of metals in terms of their structure and bonding.
 - (h) interpret the uses of the metals aluminium, iron and chromium in terms of their physical properties.
 - (i) show an awareness that metals are a finite resource and understand the importance of recycling processes.
 - (j) explain the strength, high melting point, electrical and thermal insulation of ceramics in terms of their giant molecular structure.
 - (k) relate the uses of ceramics, based on aluminium oxide and silicon(IV) oxide, to their properties (suitable examples include crockery, electrical insulators and furnace linings).
 - (l) outline the importance of hydrogen bonding to the physical properties of substances, including ice and water.
 - (m) suggest from quoted physical data the type of structure present in a substance.

5. CHEMICAL ENERGETICS

CONTENT

- 5.1 Enthalpy changes, ΔH , of formation, combustion, hydration, solution, neutralisation, atomisation; Hess' Law.
- 5.2 Lattice energies for simple ionic crystals. A qualitative appreciation of the effects of ionic charge and ionic radius on the magnitude of a lattice energy.
- 5.3 Calculations of Born-Haber cycles (including electron affinity) for the formation of simple ionic crystals and their aqueous solutions.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) understand that some chemical reactions are accompanied by energy changes, principally in the form of heat energy; the energy changes can be exothermic or endothermic.
- (b) calculate heat energy changes from experimental measurements using the relationship
$$\text{Energy change} = mc\Delta T$$
- (c) define the terms: enthalpy change of formation, combustion, hydration, solution, neutralisation, atomisation; ionisation energy (see section 2.3).
- (d) understand the terms enthalpy change of reaction, standard conditions.
- (e) calculate enthalpy changes from appropriate experimental results.
- (f) state Hess' Law and use it to find enthalpy changes that cannot be determined directly, e.g. enthalpy changes of formation from enthalpy changes of combustion.
- (g) construct energy level diagrams relating the enthalpy (heat content) to reaction path and also to activation energy.
- (h) define lattice energy for simple ionic crystals in terms of the change from gaseous ions to solid lattice.
- (i) explain in qualitative terms the effects of ionic charge and ionic radius on the numerical magnitude of lattice energy values.
- (j) construct simple energy cycles (which may also include ionisation energy, electron affinity, enthalpy change of hydration of gaseous ions) for the formation of simple ionic crystals and their aqueous solutions.
- (k) calculate enthalpy changes from energy cycles.

6. ELECTROCHEMISTRY

CONTENT

- 6.1 The products and electrode reactions for the electrolysis of brine (see Section 10.4(d)) and of aluminium oxide in molten cryolite. Factors which affect the siting of electrolytic manufacturing plant. The anodising of aluminium and the purification of copper.

- 6.2 Electrolysis: the factors affecting the mass of substance and/or volume of gas liberated during electrolysis. The relationship between the Faraday constant, the Avogadro constant and the charge on the electron $F = Le$.
- 6.3 Electrode potentials. (See the *Data Booklet*.)
- (a) Standard electrode (redox) potentials. A qualitative appreciation of the variation of E with concentration.
 - (b) The electrochemical and redox series.
See also Section 10.5(b)(i).
 - (c) Standard cell potentials as the combination of two standard electrode potentials. Use of E^\ominus values to calculate the e.m.f. of simple redox reactions and to predict the feasibility of a reaction.
 - (d) The development of batteries and fuel cells.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) describe the electrolysis and electrode reactions of
 - (i) brine,
 - (ii) molten aluminium oxide in cryolite.
- (b) describe the methods used to
 - (i) anodise aluminium,
 - (ii) purify copper electrolytically.
- (c) discuss the factors influencing the siting of a chemical production plant (availability of raw materials, services, communication links, workforce, markets, protection of the environment) using data.
- (d) define and explain the relationship between the Faraday constant, the Avogadro constant and the charge on the electron.
- (e) calculate the number of coulombs used, the mass of substance and/or the volume of gas liberated during electrolysis.
- (f) describe the standard hydrogen electrode.
- (g) describe methods used to determine the standard electrode potentials of
 - (i) metals or non-metals in contact with their aqueous ions,
 - (ii) ions of the same element in different oxidation states.
- (h) determine the direction of electron flow from a simple cell given the relevant electrode potentials.
- (i) calculate standard cell potentials using E^\ominus values.
- (j) show an awareness of the importance of the development of improved batteries (e.g. for electric cars) in terms of smaller size, lower mass and higher voltage.
- (k) predict the feasibility of a reaction from E^\ominus values.
- (l) predict qualitatively how the value of the electrode potential will vary with the concentration of the aqueous ion.
- (m) describe the nature of a fuel cell and understand its advantages.
- (n) construct redox equations using the relevant half-equations.

7. EQUILIBRIA

CONTENT

- 7.1 Chemical equilibria: reversible reactions, dynamic equilibrium.
- (a) Factors affecting chemical equilibria: Le Chatelier's principle.
 - (b) Equilibrium constants. The qualitative effect of temperature on equilibrium constants.
 - (c) The Haber process (see also Section 10.3).
- 7.2 Ionic equilibria
- (a) Bronsted-Lowry theory of acids and bases. Qualitative distinctions between strong and weak acids and alkalis.
 - (b) Acid and base dissociation constants, K_a and K_b , and the use of pK_a and pK_b .
 - (c) The ionic product of water, K_w .

- (d) pH, pH indicators; choice of pH indicators; use of pH meter.
- (e) Buffer solutions; their importance in biological systems.
- (f) Solubility product; the common ion effect.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) explain, in terms of the rates of the forward and backward 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 catalysts, or changes in concentration, pressure or temperature, on a system at equilibrium.
- (c) deduce expressions for equilibrium constants in terms of concentrations, K_c , and partial pressures, K_p .
- (d) calculate the values of equilibrium constants in terms of concentrations or partial pressures from appropriate data.
- (e) calculate the quantities present at equilibrium given appropriate data.
- (f) describe and explain the conditions used in the Haber process.
- (g) demonstrate an awareness of the importance of an understanding of chemical equilibrium in the chemical industry.
- (h) understand 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 and use the terms pH, K_a , pK_a , K_b and pK_b .
- (k) explain the significance of the ionic product of water, K_w , and use it in calculations.
- (l) calculate pH values from $[H^+(aq)]$ for strong and weak acids and bases and *vice versa*.
- (m) select suitable indicators for use in acid-base titrations given appropriate data.
- (n) explain the changes in pH during acid-base titrations in terms of the strengths of the acids and bases.
- (o) explain the use of buffer solutions and their importance in biological systems exemplified by the control of pH in blood by HCO_3^- .
- (p) calculate the pH of buffer solutions, given appropriate data.
- (q) explain and use the term solubility product, K_{sp} .
- (r) calculate K_{sp} from concentrations and *vice versa*.
- (s) explain the common ion effect.

Candidates will *not* be asked to recall or explain

the relationship between K_p and K_c ,

the technical details and working of the electrodes of a pH meter.

8. REACTION KINETICS

CONTENT

8.1 Simple rate equations; order of reaction; rate constants.

Rate = $k[A]^m[B]^n$. Treatment should be limited to simple cases of single step reactions and of multi-step processes with a rate-determining step, for which m and n are either 0, 1 or 2.

Integrated forms of rate equations are *not* required.

Problems concerned with the determination of the order of reaction will be based on data where concentrations are known (e.g. initial rates method).

The use of order of reaction in checking that a suggested reaction mechanism is consistent with the observed kinetics.

8.2 The qualitative effect of temperature on rate constants; concept of activation energy as an energy barrier.

Interpreted qualitatively in terms of the variation with temperature of the Boltzmann distribution.

8.3 Catalysis.

Homogeneous and heterogeneous catalysis as exemplified by esterification of organic acids and the Haber process respectively. Enzymes as biological catalysts exemplified by biological washing powders.

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 first-order reaction, rate-determining step, activation energy, catalyst.
- (b) explain qualitatively, in terms of collisions, the effects of concentration and temperature on the rate of a reaction.
- (c) deduce the order of reactions by using the initial rates method; deduce, for zero and for first order reactions, the order of reaction from concentration-time graphs.
- (d) calculate rate constants from initial rates method.
- (e) predict the initial rate from the rate equation and experimental data.
- (f) suggest suitable experimental techniques for studying the rate of a given reaction.
- (g) suggest a reaction mechanism consistent with a given or determined order of reaction, and deduce the kinetics that would result from a suggested reaction mechanism.
- (h) explain that in the presence of a catalyst a reaction follows an alternative path, i.e. one of lower activation energy.
- (i) explain that enzymes are biological catalysts which have specific activity.

INORGANIC CHEMISTRY**9. THE PERIODIC TABLE: PRINCIPLES OF CHEMICAL PERIODICITY****CONTENT**

It is envisaged that the Periodic Table studies outlined below will be closely co-ordinated with other sections of the syllabus, particularly Section 10.

9.1 Periodicity of physical properties of the elements

A qualitative appreciation of the variation in physical properties with proton number across the second and third periods (lithium to neon, sodium to argon).

The variation in atomic radii, ionic radii, melting points, electrical conductivities.

Interpretation and explanation of the above trends and gradations in terms of structure and bonding for the elements sodium to argon.

Ionisation energies as further evidence of periodicity (see the *Data Booklet*).

9.2 Periodic patterns in the properties of compounds

Study in this sub-section should be restricted to the oxides of the elements sodium to sulphur and the chlorides of the elements sodium to phosphorus.

The patterns and gradations in properties should be interpreted in terms of bonding and electronegativities.

Variation in oxidation number exemplified by the oxides and chlorides.

Reaction of oxides and chlorides with water.

Acid/base behaviour of oxides.

No treatment of peroxides or superoxides is required.

9.3 The elements, their oxides, hydroxides, oxoacids, chlorides and hydrides of the period sodium to argon contain several substances of technical, social and environmental consideration.

Awareness that many of these substances are of everyday relevance; their importance in practical fields such as manufacturing (e.g. sulphuric acid, chlorine, bleaches), engineering (e.g. aluminium), agriculture (e.g. lime, phosphates), in food technology (e.g. sulphur dioxide), in environmental concerns (e.g. sulphur dioxide).

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) describe the variations in atomic radii, ionic radii, melting points and electrical conductivities on passing across the second and third periods.
- (b) explain the variations in (a) in terms of structure and bonding of the elements in period 3, sodium to argon.
- (c) interpret appropriate data to demonstrate periodicity of atomic radii, melting points and electrical conductivities on passing across the second and third periods.

- (d) explain the variations in ionisation energies within a period.
- (e) predict the position of an unknown element in the Periodic Table from ionisation energy values.
- (f) state and explain the variation in oxidation number of the oxides and chlorides of the period 3 elements.
- (g) describe the reactions of the oxides of the period 3 elements with water.
- (h) describe the reactions of the chlorides of the period 3 elements with water.
- (i) describe and explain the acid/base behaviour of oxides of the period 3 elements.
- (j) suggest types of chemical bonding present in chlorides and oxides from observations of their chemical and physical properties.
- (k) predict the characteristic properties of an element in a given group by using knowledge of chemical periodicity.
- (l) 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.
- (m) explain from data provided the role in the manufacturing industry and in the environment of elements and compounds.

10. A STUDY OF THE ELEMENTS IN SOME GROUPS OF THE PERIODIC TABLE

CONTENT

It is intended that the study should:

- (a) be concerned primarily with selected aspects of a range of elements and their compounds.
- (b) be firmly based on the Periodic Table.
- (c) include the application of unifying themes to inorganic chemistry, such as structure (Section 2), chemical bonding (Section 3), redox (Section 6), ionic equilibria (Section 7.2), and complexing behaviour (Section 10.5), where appropriate.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) determine electronic configurations from the Periodic Table.
- (b) predict the nature of bonding in compounds from electronic configurations of the constituent elements.
- (c) interpret chemical reactions in terms of the structure and bonding of the species involved.
- (d) interpret redox reactions in terms of changes in oxidation states of the species involved.
- (e) predict the feasibility of reactions from E^\ominus values.
- (f) interpret chemical reactions in terms of ionic equilibria.
- (g) interpret chemical reactions in terms of the formation of complex ions.

10.1 Group II

CONTENT

The elements magnesium to barium as a group of reactive metals which are essentially similar to each other. The changes as the ionic radii increase as exemplified by:

- (a) the thermal decomposition of nitrates, carbonates, and hydroxides;
- (b) the variation in solubility of the sulphates.

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, carbonates and hydroxides.
- (d) interpret and explain qualitatively the thermal decomposition of the nitrates, carbonates and hydroxides in terms of charge density and the polarisability of the large anion.
- (e) interpret and explain qualitatively the variation in solubility of the sulphates of Group II elements in terms of the relative magnitude of the enthalpy changes of hydration for the relevant ions and the corresponding lattice energies.

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

10.2 Group IV

CONTENT

The elements carbon to lead as a group in which the character of the elements changes with increase in proton number from non-metals through metalloids to metals.

- (a) The variation in melting points and electrical conductivities of the elements. Silicon and germanium as semiconductors.
- (b) The bonding, molecular shape, volatility, thermal stability and hydrolysis of the tetrachlorides.
- (c) The bonding, acid/base nature and thermal stability of the oxides of oxidation states II and IV.
- (d) 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) state the use of silicon and germanium for making semiconductors for electronics.
- (c) describe and explain the bonding in, and molecular shape of, the tetrachlorides.
- (d) explain the volatility, thermal stability and hydrolysis of the tetrachlorides in terms of structure and bonding.
- (e) describe and explain the bonding, acid/base nature and thermal stability of the oxides of oxidation states II and IV.
- (f) describe and explain the relative stability of higher and lower oxidation states of the elements in their oxides and aqueous cations.

10.3 Nitrogen

CONTENT

- (a) The element and its lack of reactivity; the production of limited quantities of oxides of nitrogen in the internal combustion engine.
- (b) Ammonia:
- manufacture by the Haber process,
 - formation from ammonium salts,
 - properties as a base,
 - uses, particularly in the manufacture of nitric acid and fertilisers.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) explain the lack of reactivity of nitrogen.
- (b) 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.
- (c) discuss the factors influencing the siting of a chemical production plant (availability of raw materials, services, communication links, workforce, markets, protection of the environment) using supplied data.
- (d) describe the formation of ammonia from ammonium salts and its properties as a base.
- (e) demonstrate an awareness of the industrial importance of ammonia and nitrogen compounds derived from ammonia.
- (f) demonstrate an awareness of the environmental consequences of
- the uncontrolled use of nitrate fertilisers,
 - the production of oxides of nitrogen in car engines.

10.4 Group VII**CONTENT**

The elements chlorine, bromine and iodine as a group of reactive non-metals which are essentially similar to each other with only gradual changes as their proton numbers increase.

- (a) Variations in the volatility and colour of the elements.
- (b) The relative reactivity of the elements as oxidising agents; reactions of the elements with hydrogen and the relative stability of the hydrides.
- (c) Reactions of halide ions with aqueous silver ions followed by aqueous ammonia, and with concentrated sulphuric acid.
- (d) The manufacture of chlorine by the electrolysis of brine by either a mercury cathode cell or a diaphragm cell (diagrams of cells are *not* required).
- (e) The reactions of chlorine with cold and hot aqueous sodium hydroxide.
- (f) The important uses of the halogens and of halogen compounds (see also Section 11.3).

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) recall and describe the characteristic physical and chemical properties 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.
- (d) describe and explain the reactions of the elements with hydrogen and the relative stability of the hydrides; interpret the relative stabilities in terms of bond energies.
- (e) describe and explain the reactions of halide ions with
 - (i) aqueous silver ions followed by aqueous ammonia,
 - (ii) concentrated sulphuric acid.
- (f) outline a method for the manufacture of chlorine from brine.
- (g) describe and interpret in terms of changes of oxidation number the reactions of chlorine with cold and hot aqueous sodium hydroxide.
- (h) demonstrate an awareness of the industrial importance of the halogens and their compounds (e.g. for bleaches, PVC and halogenated hydrocarbons as solvents, refrigerants and in aerosols).

10.5 An introduction to the chemistry of some d-block elements

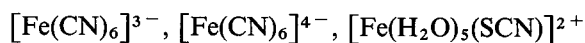
The publication THE FIRST ROW TRANSITION ELEMENTS (see page 85) which is intended for use with the Further Transition Metal Chemistry option may also be found useful in this section.

CONTENT

The first row d-block elements exemplified by chromium and iron. The interpretation of their properties in terms of incomplete d sub-shells, atomic and ionic radii, successive ionisation energies.

- (a) The similarity of the elements to each other exemplified by density and melting point.
- (b) Characteristic chemical properties of chromium and iron.
 - (i) Variable oxidation state and colour: the principal oxidation numbers of these elements in their common cations, oxides and oxoanions, the relative stabilities of these oxidation states: the use of redox potentials in predicting the relative stabilities of aqueous ions (see also Section 6.3).
 - (ii) Formation of complex ions by exchange of ligands. No treatment of stability constants is expected.

It is expected that candidates will be familiar with the common aqueous ions of chromium and iron, together with



Knowledge of the bonding in, or the geometry of, a particular ion is *not* required.

- (iii) Catalytic properties: the use of Fe/Fe₂O₃ in the Haber process (see also Section 10.3(b)); Fe(OH)₃ in the decomposition of H₂O₂.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) use and explain the terms transition element; complex ion; ligand (reference should be made to the co-ordinate bond involved).

- (b) interpret the relative magnitudes of the densities and melting points in terms of the position of Cr and Fe in the Periodic Table.
- (c) explain the variable oxidation states in terms of the energies of the 3d and 4s orbitals.
- (d) describe the formation of complex ions by exchange of ligands, e.g. CO and O₂ with the iron in haemoglobin.
- (e) describe the bonding in complex ions in terms of co-ordinate bond formation between ligand and central metal ion and state the colours of the common complex aqueous ions of chromium and iron.
- (f) explain the catalytic activity of transition elements in terms of variable oxidation states (homogeneous catalysis) or adsorption by co-ordinate bond formation (heterogeneous catalysis).
- (g) predict the effect of adding oxidising or reducing agents to aqueous solutions of compounds of Cr and Fe, and of other transition elements, given relevant E^\ominus data.

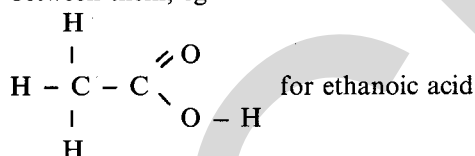
ORGANIC CHEMISTRY

11.1 An Introduction to Organic Chemistry

CONTENT

- (a) Molecular, structural and empirical formulae of organic molecules.
- (b) Functional groups and the naming of organic compounds.
- (c) Characteristics of types of organic reactions.
- (d) The shapes of the ethane, ethene and benzene molecules; the occurrence of π bonds in ethene and benzene.
- (e) Isomerism—structural, *cis-trans* (primarily in relation to alkenes containing one double bond) and optical.

In question papers, an acceptable answer to a request for a structural formula will be to give the minimal detail, using conventional groups, for an unambiguous structure, eg CH₃CH₂CH₂OH for propan-1-ol, not C₃H₇OH. A *displayed formula* should show both the relative placing of atoms and the number of bonds between them, eg



In this context, either of the conventional symbols for the benzene ring,  or , is acceptable.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) use and understand the nomenclature and full structural formulae of the following classes of compounds:
 - (i) alkanes, alkenes and arenes,
 - (ii) halogenoalkanes,
 - (iii) alcohols (including primary, secondary and tertiary) and phenols,
 - (iv) aldehydes and ketones,
 - (v) carboxylic acids and esters,
 - (vi) amines (primary only), amides and amino acids.
- (b) use and understand the following terminology associated with organic reactions:
 - (i) functional groups,
 - (ii) homolytic and heterolytic fission,
 - (iii) free radicals, initiation, propagation, termination,
 - (iv) nucleophile, electrophile,
 - (v) addition, substitution, elimination.
- (c) describe structural isomerism, and the factors which give rise to this phenomenon.
- (d) describe *cis-trans* isomerism in alkenes, and explain its origin in terms of the restricted rotation caused by the π bond.
- (e) explain what is meant by a chiral centre and how this gives rise to optical isomerism.
- (f) determine the possible isomers for an organic molecule of known molecular formula.
- (g) identify chiral centres and/or *cis-trans* isomerism in a molecule of given structural formula.

In each of the following sections, candidates will be expected to be able to predict the reaction products of a given compound with reagents which are chemically similar to those in the specified reactions.

11.2 Hydrocarbons

CONTENT

- (a) Alkanes, exemplified by ethane. Free radical reactions illustrated by e.g. the reaction of chlorine with methyl groups. Crude oil and 'cracking'. Reference should be made to the lack of reactivity of alkanes towards polar reagents.
- (b) Alkenes, exemplified by ethene. Addition of hydrogen and of steam. Simple tests, oxidation and the addition of electrophilic reagents. The industrial importance of ethene. Poly(alkene)s and their disposal.
- (c) Arenes, exemplified by benzene and methylbenzene. Influence of delocalised π electrons on structure and properties. Substitution reactions with electrophiles, e.g. halogenation, nitration; oxidation of side-chain to give carboxylic acid.
- (d) Hydrocarbons as fuels, (e.g. in the internal combustion engine).

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) describe the chemistry of alkanes as exemplified by the following reactions of ethane:
 - (i) combustion,
 - (ii) substitution by halogens.
- (b) describe the mechanism of free radical substitution at methyl groups with particular reference to the initiation, propagation and termination reactions.
- (c) describe the chemistry of alkenes as exemplified by the following reactions of ethene:
 - (i) addition of hydrogen, steam, hydrogen halides and halogens,
 - (ii) oxidation by manganate(VII) ions with further oxidation leading to the rupture of the 1, 2 carbon-to-carbon bond.
 - (iii) polymerisation.
 - (iv) see also Section 11.8.
- (d) demonstrate an awareness of the difficulty of the disposal of poly(alkene)s, i.e. non-biodegradability and harmful combustion products.
- (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; suggest how 'cracking' can be used to obtain more useful alkanes and alkenes of lower M_r from larger hydrocarbon molecules.
- (g) describe the chemistry of arenes as exemplified by the following reactions of benzene and methylbenzene:
 - (i) substitution reactions with halogens,
 - (ii) nitration,
 - (iii) oxidation of side-chain to give carboxylic acid.
- (h) describe the mechanism of electrophilic substitution in arenes using the mononitration of benzene as an example; describe the effect of the delocalisation of electrons in arenes in such reactions.
- (i) predict whether the halogenation will occur in the side-chain or aromatic nucleus in arenes depending on reaction conditions.
- (j) state the positions of substitution in methylbenzene.
- (k) demonstrate an awareness of the environmental consequences of the lead additive in petrol and the carbon monoxide, oxides of nitrogen and unburnt hydrocarbons arising from the internal combustion engine.

11.3 Halogen derivatives

CONTENT

Halogenoalkanes. Nucleophilic substitution; hydrolysis, formation of nitriles, primary amines, elimination. Relative strengths of the C-Hal bond.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) recall the chemistry of halogenoalkanes as exemplified by
 - (i) the following nucleophilic substitution reactions of bromoethane:
 - hydrolysis,
 - formation of nitriles,
 - formation of primary amines by reaction with ammonia,
 - (ii) the elimination of hydrogen bromide from 2-bromopropane.
- (b) describe the mechanism of nucleophilic substitution in halogenoalkanes (reference to S_N1 and S_N2 mechanisms is *not* required).
- (c) interpret the different reactivities of chlorobenzene and halogenoalkanes with particular reference to hydrolysis.
- (d) explain the uses of fluoroalkanes and fluorohalogenoalkanes in terms of their relative chemical inertness.
- (e) demonstrate an awareness of the concern about the effect of chlorofluoroalkanes on the ozone layer.

11.4 Hydroxy compounds**CONTENT**

Hydroxy compounds, exemplified by ethanol and phenol. Production of ethanol by fermentation, treated simply.

Reactions of alcohols: to give halogenoalkanes; with sodium; oxidation; dehydration; esterification; acylation; the tri-iodomethane test.

The acidity of phenol; reaction with sodium; nitration 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 hydroxy compounds, exemplified by ethanol:
 - (i) combustion,
 - (ii) substitution to give halogenoalkanes,
 - (iii) reaction with sodium,
 - (iv) oxidation to carbonyl compound and carboxylic acid,
 - (v) dehydration to alkenes,
 - (vi) esterification,
 - (vii) acylation.
- (c) recall the chemistry of phenol, as exemplified by the following reactions:
 - (i) acidity,
 - (ii) reaction with sodium,
 - (iii) nitration and halogenation of the aromatic ring.
- (d) describe the classification of hydroxy compounds into primary, secondary and tertiary alcohols; suggest characteristic distinguishing reactions, e.g. mild oxidation.
- (f) explain the relative acidities of water, phenol and ethanol.
- (g) describe the reactions of particular hydroxy compounds with iodine to give tri-iodomethane.

11.5 Carbonyl compounds**CONTENT**

(a) Aldehydes, exemplified by ethanal and benzaldehyde. Oxidation to carboxylic acid, reaction with hydrogen cyanide, characteristic tests for aldehydes.

(b) Ketones, exemplified by propanone and phenylethanone. Reaction with hydrogen cyanide, 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 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 (e.g. Fehling's and Tollens' reagents, ease of oxidation).
- (e) describe the reactions of particular carbonyl compounds with aqueous, alkaline iodine to give tri-iodomethane.

11.6 Carboxylic acids and derivatives

CONTENT

- (a) Carboxylic acids, exemplified by ethanoic acid and benzoic acid. Formation from primary alcohols and nitriles. Salt, ester and acyl chloride formation.
- (b) Acyl chlorides, their ease of hydrolysis compared with alkyl and aryl chlorides. Reactions with alcohols, phenols and primary amines.
- (c) Esters, exemplified by ethyl ethanoate and phenyl benzoate, formation from carboxylic acids and from acyl chlorides; hydrolysis (acid and base). Polyesters. Uses of esters exemplified by flavourings and solvents.

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 how structure can influence this acidity in chlorine-substituted ethanoic acids.
- (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) see also Section 11.8.

11.7 Nitrogen compounds

CONTENT

- (a) Primary amines, exemplified by ethylamine and phenylamine; formation by the reduction of nitriles (and phenylamine from nitrobenzene); salt formation. The reactions of phenylamine with aqueous bromine and with nitrous acid, including diazotisation.
- (b) The production of dyes exemplified by the coupling reaction of benzenediazonium chloride with phenol.
- (c) Amides, their formation from acyl chlorides and hydrolysis, polyamides.
- (d) Amino acids, acid and base properties, zwitterion formation. Outline of structure of proteins based on the peptide linkage; the hydrolysis of protein.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) describe the formation of ethylamine (by nitrile reduction) and 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) bromine,
 - (ii) nitrous acid.

- (e) describe the formation of dyestuffs by the coupling of benzenediazonium chloride and phenol.
- (f) describe the formation of amides from $\text{RNH}_2/\text{R}'\text{COCl}$; describe amide hydrolysis on treatment with aqueous alkali or acid.
- (g) describe the acid/base properties of amino acids, and the formation of zwitterions.
- (h) outline the formation of peptide bonds between amino acids, and suggest how this may lead to protein formation.
- (i) describe the hydrolysis of proteins.
- (j) see also Section 11.8.

11.8 Polymerisation

CONTENT

- (a) Addition polymerisation.
- (b) 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 length of a polymer molecule.
- (f) identify the monomer(s) present in a given length of a polymer molecule.

OPTION TOPICS

Candidates are expected to study only two of the following options and they should be advised to attempt only those questions on topics for which they have been prepared, although any answer given will be marked by the examiners: Further Transition Metal Chemistry; Phase Equilibria; Biochemistry; Food Chemistry; Soil Chemistry; Chemical Engineering; Polymers; Spectroscopy.

Candidates should *not* study both the Biochemistry and the Food Chemistry options.

It should be noted that it is intended to introduce a new Environmental Chemistry option which will, in time, replace the Soil Chemistry option.

Options do not now *prescribe* relevant practical work.

FURTHER TRANSITION METAL CHEMISTRY

A detailed treatment of this topic is given in the option booklet 'THE FIRST ROW TRANSITION ELEMENTS' (see page 85).

CONTENT

- Variable oxidation states of transition metals and the use of standard electrode potentials.
- The structures and stabilities of complex ions.
The bonding between ligand and central metal atom/ion.
The stereochemistry of tetrahedral, square planar and octahedral co-ordinated complexes.
The isomerism exhibited in these co-ordinated complexes.
Stoichiometry of complex ion formation.
The colour of transition metal complexes.
- The catalytic properties of transition metals.
Heterogeneous catalysis:
nickel in the hydrogenation of alkenes,
iron/iron oxide in the Haber process.
Homogeneous catalysis:
Fe(III) in the reaction between I^- and $S_2O_8^{2-}$.
- A chemical study of the elements vanadium, chromium, manganese, iron, cobalt, nickel and copper.
 - Vanadium**
The oxidation states +2, +3, +4 and +5.
The use of the metal as an alloying ingredient in hardening steels.
 - Chromium**
The oxidation states +3 and +6.
The stereochemistry and isomerism in octahedral complexes of Cr(III).
The reactions of $Cr_2O_7^{2-}$ as an oxidising agent and with alkali.
The use of the metal in hardening steels and in stainless steel.
 - Manganese**
The oxidation states +2, +4, +6 and +7.
The oxidising properties of MnO_2 and MnO_4^- .
 - Iron**
The oxidation states +2 and +3; the effect of pH and CN^- ligands on their relative stabilities.
The biochemical importance of iron.
The reactions of iron with air, water and acids. The corrosion of iron and its prevention.
 Fe^{3+} as a homogeneous catalyst in the reaction between I^- and $S_2O_8^{2-}$.
The use of Fe/ Fe_2O_3 as a heterogeneous catalyst in the Haber process.
 - Cobalt**
The oxidation states +2 and +3; the stabilisation of the +3 state with NH_3 ligands.
The effect of ligands and/or temperature on the stability and geometry of complex ions.

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

$$\downarrow$$

$$[Co(NH_3)_6]^{2+} \rightarrow [Co(NH_3)_6]^{3+}$$
 The biochemical importance of cobalt.
 - Nickel**
The extraction of pure nickel from nickel(II) oxide by using the volatile neutral complex $Ni(CO)_4$.
The use of nickel in alloys and as a hydrogenation catalyst.

4.7 Copper

The oxidation states +1 and +2. The disproportionation of Cu(I) in aqueous solution.

Complex formation in the presence of H_2O , Cl^- , NH_3 and edta.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- explain the occurrence of variable oxidation states in terms of the energies of 3d and 4s orbitals.
- state the principal oxidation states of the transition metals, and the trends observed across the group.
- predict relative stabilities of aqueous ions by using standard electrode potentials.
- predict the effect of adding oxidising or reducing agents to aqueous solutions of compounds of the seven specified elements, and of other transition elements, given relevant E^\ominus data.
- explain the anomalous E^\ominus values for $\text{Mn}^{3+}/\text{Mn}^{2+}$ and $\text{Fe}^{3+}/\text{Fe}^{2+}$ in terms of the electronic structure of the ions.
- describe the formation of complexes by exchange of ligands in terms of strength of bonding and equilibrium considerations.
- describe the bonding in complexes in terms of co-ordinate bond formation.
- describe the shapes of octahedral, tetrahedral and square planar complexes.
- outline the structural, *cis-trans* and optical isomerism shown by these various complexes.
- suggest possible types of isomerism in complexes of other transition elements, given their formulae.
- describe how the stoichiometry of a complex ion may be determined experimentally.
- calculate the stoichiometry of a complex ion, given relevant data.
- explain the occurrence of coloured complexes, based on simple ideas of d-orbital splitting.
- explain the catalytic activity of transition elements in terms of variable oxidation states (homogeneous catalysis) or adsorption by co-ordinate bond formation (heterogeneous catalysis).
- demonstrate an awareness of the biochemical importance of iron in haemoglobin and of cobalt in vitamin B_{12} .
- describe and explain the corrosion of iron and methods for its prevention.

PHASE EQUILIBRIA

A detailed treatment of this topic is given in the option booklet 'PHASE EQUILIBRIA', see page 85.

1. Phase diagrams

CONTENT

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

ASSESSMENT OBJECTIVES

Candidates should be able to:

- sketch the shape of the phase diagram for water and explain the anomalous behaviour of water.
- understand that phase diagrams are graphical plots of experimentally determined results.
- interpret phase diagrams as curves describing the conditions of equilibrium between phases and as regions representing single phases.
- predict how phases may change with changes in temperature or pressure.
- understand and use the term eutectic.
- sketch the shape of the eutectic diagram for tin and lead.
- interpret eutectic diagrams for two-component systems and predict how composition and phase vary with changes in temperature.

2. Raoult's Law and distillation

CONTENT

- Raoult's Law; its application to liquid-liquid mixtures; positive and negative deviations from it related to intermolecular attractions or bonding.
- Boiling point/composition curves; fractional distillation; azeotropic mixtures.
- 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 how fractionating columns are designed.
- (i) explain the concept of plates in fractionating columns and deduce theoretical plates by graphical means.
- (j) demonstrate a knowledge and understanding of the packing of fractionating columns and other means of establishing equilibrium at different temperatures between liquid and vapour.
- (k) explain qualitatively the advantages and disadvantages of distillation under reduced pressure.
- (l) explain steam distillation of two immiscible liquids.
- (m) demonstrate an awareness of the applications of these methods of distillation to the industrial and laboratory separations of the components of liquid mixtures.

3. Partition**CONTENT**

Partition coefficient; solvent extraction.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) understand and use the term partition coefficient.
- (b) explain, by using ether extraction, how solvent extraction works.
- (c) perform calculations related to partition coefficient for systems in which the solute is in the same molecular state in the two solutions.

4. Chromatography**CONTENT**

Chromatography: theory and practice.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) describe simply and understand qualitatively paper, column, thin layer, and gas/liquid chromatography in terms of adsorption and/or partition.
- (b) demonstrate an awareness of the applications of these methods of chromatography in industry and medicine.

BIOCHEMISTRY

In Paper 4, the Biochemistry and Food Chemistry questions will be grouped together as if in the same option. A maximum of two questions from the "combined option" may be answered.

Preamble

Biochemistry is a 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 this course lays stress on the chemical interpretation of biological processes at a molecular level.

A detailed treatment of this topic is given in the option booklet 'BIOCHEMISTRY' (see page 85).

1. Proteins

CONTENT

- 1.1 Amino acids.
- 1.2 Polypeptides and proteins.
- 1.3 Protein structure: primary, secondary, tertiary and quaternary structures.
- 1.4 Denaturation of proteins.
- 1.5 Fibrous and globular proteins.
- 1.6 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 $\text{RCH}(\text{NH}_2)\text{CO}_2\text{H}$; 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 the formation of the peptide linkage between α -amino acids leading to the idea that polypeptides and proteins are condensation polymers; explain 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 the quaternary structure of proteins: 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) determine the value of the Michaelis constant (K_m) and V_{max} by graphical means: explain the meaning of, and use, K_m and V_{max} .
- (m) explain the significance of K_m by investigation of the different physiological roles of hexokinase and glucokinase.
- (n) explain the concept of the active site in enzyme structure.
- (o) suggest reasons for non-competitive inhibition of enzymes with particular reference to heavy metal ions and feed-back control of metabolism.
- (p) explain the importance of coenzymes with respect to enzyme activity.
- (q) suggest how the structure of lysozyme accounts for its enzymic properties.

2. Carbohydrates

CONTENT

- 2.1 monosaccharides; α - and β -pyranose structure of glucose.
- 2.2 Disaccharides and polysaccharides as condensation polymers. The nature of the glycosidic link; enzymic and acid hydrolysis of the glycosidic linkage.
- 2.3 Structure and function of cellulose as a structural polymer and starch and glycogen as storage polymers.

- 2.4 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 as 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

- 3.1 Biological functions of lipids.
- 3.2 Simple structure and function of triglycerides.
- 3.3 Phosphoglycerides; simplified structure and function; formation of micelles and bilayers.
- 3.4 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 phosphoglycerides and the formation of micelles and bimolecular layers.
- (c) describe the fluid mosaic structure of membranes.
- (d) explain active transport by using the Na^+/K^+ pump as an example.

4. Nucleic acids

CONTENT

- 4.1 Nucleotides and nucleic acids.
- 4.2 DNA and RNA; base pairing.
- 4.3 DNA and genetic information.
- 4.4 m-RNA and the triplet code.
- 4.5 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.

FOOD CHEMISTRY

In Paper 4, the Food Chemistry and Biochemistry questions will be grouped together as if in the same option. A maximum of two questions from the "combined option" may be answered.

Preamble

Students will not be expected to reproduce complex molecular and structural formulae from memory. They will, however, be expected to appreciate the consequences of the presence of certain functional groups within a given molecular structure.

A detailed treatment of this topic is given in the option booklet "FOOD CHEMISTRY" (see page 85).

1. Chemical nature of food

CONTENT

- 1.1 Constituents of food and their main functions in the body.
- 1.2 Proteins: the primary structure of proteins as an unspecified sequence of amino acids; general structure of α -amino acids; essential amino acids; secondary structure formed by hydrogen bonding producing the α -helical and β -pleated sheet structures; tertiary structures; simple, conjugated, globular and fibrous proteins; denaturation of proteins by heating, the addition of polar compounds and mechanical agitation; hydrolysis of proteins and separation of products; the biuret test for proteins.
- 1.3 Carbohydrates; classification of mono-, di- and polysaccharides; open chain and ring structures of glucose/fructose; hydrolysis of sucrose and starch; reducing and non-reducing properties including a distinguishing test; α - and β -linkages with reference to starch and cellulose.
- 1.4 Fats and oils; simple lipids considered as triglyceride esters; their solubility; their hydrolysis; the importance of fatty acids present in determining physical properties of simple lipids; the iodine value; the hardening of oils by hydrogenation; hydrolytic and oxidative rancidity; the concept of calorific value.
- 1.5 Vitamins (A, B (one example only), C, D and K); fat and water solubility as a means of classification; deficiency diseases from lack of listed vitamins where applicable.
- 1.6 Minerals; awareness of importance of certain elements in the diet and the highly toxic nature of certain contaminant metals.
- 1.7 Water; solvent properties; colloidal systems present in butter and milk; emulsifying agents.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) explain the function of the various food components in the body.
- (b) describe the basic structure of an α -amino acid and explain what is meant by essential amino acids.
- (c) describe the primary structure of a protein as an unspecified sequence of amino acids linked by peptide linkages.
- (d) describe the hydrolysis of proteins in the laboratory and the separation of the products and the biuret test for proteins.
- (e) describe the role of hydrogen bonding in the formation of the α -helix and β -pleated sheet secondary structures in proteins, and the formation of the tertiary structure.
- (f) describe the classification of proteins as simple (globular or fibrous), or conjugate (globular), with examples of each where appropriate.
- (g) explain the process of denaturation by heating, addition of polar compounds, and agitation, suggesting which bonds in the protein are affected by such actions.
- (h) explain the classification of glucose, fructose, sucrose, maltose, starch and cellulose as mono-, di- and polysaccharides.
- (i) explain the relationship between the open chain and ring structures of glucose and fructose.
- (j) describe the glycosidic linkage with particular reference to the α - and β -linkage in starch and cellulose, and the use of the two materials in the human diet.
- (k) describe the hydrolysis of the glycosidic linkage in sucrose and starch in the laboratory.
- (l) explain the existence of reducing and non-reducing sugars linked to the functional group present in the molecules and describe a test to distinguish between reducing and non-reducing sugars.
- (m) describe the structure, solubility and physical states of fats and oils (simple lipids).
- (n) describe the hydrolysis of simple lipids and explain how the fatty acid residue affects the properties of the lipid and indicates the source of the lipid.
- (o) describe the iodine value as a measure of the degree of unsaturation of the fatty acid present in the lipid and interpret given iodine values in terms of degree of unsaturation and source of the lipid.
- (p) suggest the need to harden vegetable oils for certain culinary uses and describe the principles of the process, e.g., the manufacture of margarine.
- (q) explain how oxidative and hydrolytic rancidity arises, its effects on foodstuffs and possible methods of prevention.
- (r) understand the concept of calorific values.
- (s) describe the classification of vitamins (A, B (one only), C, D and K) as water soluble (B, C) or fat soluble (A, D, K) and indicate a deficiency disease of vitamins A, B, C and D.

- (t) describe briefly the importance of Ca and P (bones), Na, K, Fe (blood), F, and I; describe the manner in which certain contaminant metals such as Cu, Cd, Hg and Pb enter the food chain.
- (u) describe the importance of water in the body and particularly its solvent properties.
- (v) describe colloidal and emulsion systems as present in milk and butter.
- (w) describe the action of emulsifying agents (agents having functional groups which have an affinity for water and oil).

2. Food preservation and food additives

CONTENT

- 2.1 Deterioration of food.
- 2.2 Principles of food preservation linked, where appropriate, to requirements for microbial growth.
- 2.3 Advantages and disadvantages for the use of colouring agents, antioxidants, texturising and emulsifying agents and flavourings.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) describe food deterioration in terms of bacterial and fungal action and by autolysis and subsequent hydrolysis, oxidation and dehydration.
- (b) describe the requirements for microbial growth and relate these to the various methods of food preservation:
 - (i) removal of moisture; evaporation, drying, freeze drying and smoking osmotic methods; use of salt and sugar
 - (ii) altering temperature:
 - decreasing temperature; refrigeration and freezing
 - increasing temperature; sterilisation and pasteurisation (canning and bottling).
 - (iii) change of pH: pickling
 - (iv) chemical inhibitors: curing and smoking
 - permitted chemical additives: sulphur dioxide and benzoic acid.
- (c) describe the use of food additives to improve colour or flavour; to improve keeping qualities; to make processing easier; as nutrients or artificial sweeteners.
- (d) suggest advantages and disadvantages of food additives from a consumer standpoint.

SOIL CHEMISTRY

Preamble

This option has two main aims: firstly, to provide an area of applied chemistry where the principles met at A level can be shown to be of importance in a more practical context; secondly, to provide some links with both geography and biology. It is hoped that fundamental concepts such as rates, redox potentials, structures and bonding, solubility products and pH will all be further illustrated by a study of the intricate chemistry of soils.

A detailed treatment of this topic is given in the option booklet "SOIL CHEMISTRY" (see page 85).

1. Introduction

CONTENT

- 1. Soil—a general description and an introduction to a soil profile.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) describe the formation of soil in terms of the generation of more stable materials from less stable ones.
- (b) outline a soil profile in terms of the nature of the upper, middle and lower horizons.

2. Silicates

CONTENT

- 2.1 The SiO_4^{4-} tetrahedron as a primary structural unit and the joining of these units to form chains, sheets and framework structures. The increasing resistance to weathering of these structures.
- 2.2 An outline of the structures of kaolinite and montmorillonite to illustrate the formation of 1:1 and 2:1 clays. Gibbsite and brucite sheets.

- 2.3 Isomorphous substitution relating the structures of the feldspars in the three-dimensional silicates. (The recall of the formulae of named minerals is *not* required *nor* is the specific geometry of three-dimensional structures.)

ASSESSMENT OBJECTIVES

Candidates should be able to:

- describe the structure and shape of the SiO_4^{4-} unit.
- explain how SiO_4^{4-} units combine to form chains (pyroxenes and amphiboles); sheets (mica) and framework structures (quartz).
- determine the empirical formulae of the silicate structures in (b).
- predict structures for the silicate materials in (b) given their empirical formulae.
- outline the structures of kaolinite and montmorillonite in terms of lamella of silicate/gibbsite sheets with interlinking hydrogen bonding for kaolinite.
- demonstrate an awareness of the existence of other 1:1 and 2:1 clays which may also involve brucite sheets.
- explain the nature of isomorphous substitution and illustrate this with reference to the feldspars.

3. Soil formation

CONTENT

- The influence of (a) the parent rock, (b) temperature, (c) moisture, (d) oxygen circulation, in the weathering process.
- A general view of weathering in relation to the release from rock material of Group I and Group II metal ions, the breakdown of silicate anions and the formation of aluminium or iron(III) oxides/hydroxides.
- The contribution of organic material to soils in terms of soil structure, C/N ratio and ion exchange.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- outline the influence of surface area and permeability, temperature and moisture on the physical stability of parent rocks.
- outline the influence of oxidation processes in promoting instability in parent rocks.
- explain the release of Group I ions and the precipitation of Group II carbonates in early weathering stages.
- explain the relationship between the structure of silicate clays and their resistance to weathering.
- explain the formation of aluminium and iron(III) oxides/hydroxides as an indication of advanced weathering.
- describe the changes in acidity generally associated with the extent of weathering.
- describe the presence of organic material in soil and its importance to the structure of soil.
- outline the importance of fungi and bacteria in the breakdown of soil materials.
- explain the use of C/N ratio to assess the potential value of organic material.

4. Ion exchange

CONTENT

- An explanation of the cation exchange capacity of soil materials. The difference between the permanent and pH dependent cation exchange properties of the silicate clays.
- A definition of cation exchange capacity. The strength of cation adhesion and selectivity coefficients. The possibility of anion adherence in very acidic conditions.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- explain the permanent and pH dependent cation exchange capacities of soil materials (silicate clays and organic material).
- define cation exchange capacity and perform simple calculations based on the definition.
- explain the effects of size of charge and size of the hydrated ion on cation adherence.
- define selectivity coefficient and explain its relationship with the strength of cation adherence.

- (e) explain anion adherence in very acidic conditions.

5. Soil acidity

CONTENT

- 5.1 The causes of soil acidity and its relationship to weathering; the instability of silicate clays at lower pH values.
- 5.2 The distinction between reserve and active acidity; methods of changing the acidity of soils. The effect of pH on the availability of iron, calcium, nitrogen and phosphorus.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) describe the instability of silicate clays at low pH value and the effect on the ambient acidity of the release of aluminium ions.
- (b) explain the difference between active and reserve acidity.
- (c) explain the use of lime and ammonium sulphate to raise or lower soil pH values.
- (d) explain the effect of pH on the availability of iron and calcium to plants and also on the state and availability of phosphorus and nitrogen.

6. Redox processes

CONTENT

- 6.1 The importance of oxygen in maintaining the ions in soil in higher oxidation states.
- 6.2 The effects of anaerobic conditions on the redox potential of soils with particular reference to the process $\text{NO}_3^- \rightarrow \text{NO}_2^- \rightarrow \text{NH}_4^+$ and $\text{Fe}^{3+} \rightarrow \text{Fe}^{2+}$.
- 6.3 The loss of nutrients from, and the toxicity of, soils under extreme reducing conditions.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) explain, by using quoted redox potentials, the importance of oxygen circulation in soils.
- (b) outline the effects of anaerobic conditions (primarily waterlogging) on the state of nitrogen and iron within the soil.
- (c) outline the effects of extreme reducing conditions in terms of the loss of nutrients from soils (e.g. as CH_4 , H_2S , N_2O or N_2).

7. The supply of ions

CONTENT

- 7.1 The roles and relative importance of organic and inorganic materials in the supply of nitrogen, phosphorus and potassium to plants. The mineralisation and immobilisation of ions within soils.
- 7.2 The mobility of ions containing the elements N, P, K, Ca, S and Fe within plants.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) describe the roles of organic and inorganic material in the supply of nitrogen, potassium and phosphorus to plants.
- (b) explain the meaning of the term mineralisation as applied to soils and the significance of the process for the supply of ions to plants.
- (c) state the mobility of the ions of the elements N, P, K, Ca, S and Fe in plants.
- (d) explain the relationship between the mobility of the ions and the part of the plant showing the effects of a deficiency of that ion.
- (e) relate the various effects of soil acidity and state of oxidation to the possibility of ion deficiencies in a soil.

CHEMICAL ENGINEERING

Preamble

This option has two main aims: firstly, to give an insight into the nature of an area of applied chemistry where the scale of operation is much greater than that encountered in school laboratories; secondly, to show how considerations other than basic chemistry of the process itself affect the work of the chemical engineer. Such consideration involves some topics that are somewhat physical rather than chemical and are questions of cost and efficiency, of safety and other social importance. Where topics of a physical nature are involved, it is *not* intended that these should be treated "from first principles".

Although the use of SI units is not uniform in industry, it is intended that qualitative work in the syllabus should be restricted to SI units, it being assumed that an A level student entering chemical industry should be readily able to convert to other units that may be in use.

A detailed treatment of this topic is given in the option booklet "CHEMICAL ENGINEERING" (see page 85).

1. Introduction

CONTENT

- 1.1 The scope of chemical engineering; range of materials in production, e.g. bulk metals, polymers, heavy chemicals, food dyestuffs and pharmaceuticals.
- 1.2 The role of the chemical engineer: to apply scientific and engineering principles to the study of processes; to the design, construction and operation of the plant in which they take place, i.e. to devise and maintain efficient production (optimum yield at minimum cost), whilst bearing in mind factors such as safety and the environment.
- 1.3 Research and development: recognition of need and demand for product; laboratory studies in finding appropriate chemical route and yields; studies on pilot plant to gather engineering information and to evaluate processes; monitoring full-scale operation.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) describe the role of the chemical engineer in the development of a new process.
- (b) explain the ways a new process might be evaluated for scaling up to production.
- (c) identify problems in a given reaction which would need to be overcome in the scaling-up process.
- (d) suggest methods of overcoming given problems in scaling-up a process, e.g. control of heat, management of waste, by-products.

2. The basic aspects of large-scale production

CONTENT

- 2.1 Raw materials: their sources, locations and purification.
- 2.2 Operating conditions: nature of reaction, gas or liquid phase, homogeneous or heterogeneous; continuous and batch methods; effects of rates of reactions, equilibria; control of heat input and output; separation and purification of product; economics, siting, marketing, packaging and distribution.

This is intended to introduce aspects dealt with more fully in other sections. In view of the wide scope outlined in Section 1, it is intended that attention should be concentrated on particular examples.

Continuous processing, e.g. sulphuric acid, ethanoic acid.

Batch processing, e.g. pharmaceuticals, ethanol by fermentation.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) identify the raw materials and their sources for each of the specified examples (pharmaceuticals in general terms).
- (b) describe the important features of batch and continuous processes, together with the advantages and disadvantages of each.
- (c) suggest the more appropriate form of processing for a reaction from data provided.
- (d) suggest, for a given reaction, how a batch process might be converted into a continuous process.
- (e) explain, in qualitative terms, the effects of rate of reaction and composition of equilibrium mixture on production.

3. Unit operations**CONTENT****3.1 Fluid Flow**

- (a) Streamline and turbulent flow; velocity profiles, critical velocity, Reynolds' number. Characteristic ranges of Reynolds' number for circular duct.
- (b) Measurement of fluid flow. The treatment is intended to be essentially descriptive with no technical details. Measurement by absolute method, i.e. mass/time; displacement; hydrodynamic.
- (c) Fluid transport by pumping. Types of pump, their general characteristics and uses. Considerations involved in selection of pumps.

3.2 Heat Transfer

- (a) Conduction, radiation, convection, condensation, evaporation, heat loss.
- (b) Heat exchangers. Qualitative description of parallel and counter-flow exchangers and their use in preheating reactants and cooling products.
- (c) Temperature measurement of solids, fluids and furnaces. Types of detector: (i) resistance thermometer; (ii) thermocouple; (iii) pyrometer. Qualitative description of their operating principles, typical ranges and uses.

3.3 Mass transfer

- (a) Fractional distillation. Column design and efficiency. Plates real and theoretical. Packing of columns and other means of establishing equilibrium at different temperatures between liquid and vapour.
- (b) Filtration. Qualitative discussion of factors such as filter, medium, size of particles, cake thickness during filtration.
- (c) Other separation techniques. Brief consideration of:
 - (i) gas by liquid; e.g. scrubbing of exhaust gases from power stations,
 - (ii) gas by solid; e.g. gas masks, firemen's breathing apparatus,
 - (iii) liquid by gas; e.g. steam distillation,
 - (iv) liquid by liquid; e.g. solvent extraction,
 - (v) liquid by solid; e.g. coloured material by charcoal,
 - (vi) solid by gas; e.g. drying of solids,
 - (vii) solid by liquid; e.g. leaching.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) explain the origins of streamline and turbulent flow in fluids; calculate the Reynolds' number for a given fluid from data, and hence predict the character of its flow in a given pipe.
- (b) describe how fluid flow may be measured in a pipe by absolute displacement or hydrodynamic methods.
- (c) describe in qualitative terms the characteristics of displacement and centrifugal pumps; outline the advantages and disadvantages of each type.
- (d) suggest appropriate pumps for use in described situations.
- (e) explain how heat may be transferred in chemical production plants.
- (f) describe the differences in operation between a laboratory condenser and an industrial heat exchanger.
- (g) outline the construction of an industrial heat exchanger, including ways in which its efficiency can be improved.
- (h) outline the use of parallel and counter-current heat exchangers.
- (i) describe the methods used to measure the temperatures of solids, fluids and furnaces; outline the principles and typical operating ranges.
- (j) describe the construction of a distillation tower using either sieve plates or bubble caps; outline the advantages and disadvantages of each.
- (k) predict, from data, the number of theoretical plates required to bring about a specified separation.
- (l) outline, in qualitative terms, the advantages and disadvantages of distillation under reduced pressure.
- (m) describe industrial filtration compared with the method used in the laboratory; discuss the factors which affect the efficiency of the process.
- (n) predict which separation technique could be used to separate specified components.

4. Siting of production plants*CONTENT*

Brief discussion of the factors which may influence the choice of a site: access to raw materials; communications; markets; availability of workforce; safety; environmental factors.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) evaluate possible sites from evidence presented in graphical, numerical and written form.
- (b) suggest both advantages and disadvantages of alternative sites.
- (c) suggest necessary modifications to given possible sites to make them viable.
- (d) recognise and explain the conflicting factors which can influence the choice of a site.
- (e) outline the effects of the development of a given site on the environment.

POLYMERS

The option is intended to provide a link between pure and applied chemistry as well as to illustrate the influence of structure on properties of materials.

A detailed treatment of this topic is given in the option booklet "POLYMERS" (see page 85).

1. Raw materials*CONTENT*

- 1.1 Crude oil as a major feedstock; source of crude oil determines its composition; alternative feedstock sources.
- 1.2 Refining; fractional distillation.
- 1.3 Cracking and reforming of products of fractional distillation; thermal cracking; catalytic cracking; reforming.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) describe the sources of feedstock in the polymer industry, possible alternative sources to oil, including the carbide process for ethyne and the fermentation of sugar.
- (b) describe in outline the fractional distillation of crude oil and the processes of thermal and catalytic cracking (ethene from ethane, ethene from decane (in light naphtha), buta-1, 3-diene from butane) and reforming.

2. Polymers and polymerisation*CONTENT*

- 2.1 Polymers; addition and condensation polymers; thermosetting and thermoplastic polymers.
- 2.2 Chemical structure and polymer properties; chemical bonding and properties; structure of simple polymer molecules and their effects on polymer structure.
- 2.3 Polymerisation reactions
 - (i) radical chain (addition) polymerisation,
 - (ii) stepwise (condensation) polymerisation.
- 2.4 Polymerisation processes; bulk, solution, suspension and emulsion methods.
- 2.5 Hydrocarbon plastics; HDPE and LDPE; PVC.
- 2.6 Poly(phenylethene):
 - (i) sources of feedstock,
 - (ii) mechanism of polymerisation,
 - (iii) methods of polymerisation,
 - (iv) control of extent of polymerisation,
 - (v) economics of the process and the development of a continuous process,
 - (vi) fabrication and uses.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) explain the difference between addition and condensation polymers and thermoplastic and thermosetting materials.
- (b) suggest how properties of polymers are related to bonding and to the arrangement of monomers in the polymer.
- (c) describe the mechanism of radical chain (addition) polymerisation for compounds of the type $\text{CH}_2=\text{CHX}$.
- (d) describe an example of stepwise (condensation) polymerisation.
- (e) state the problems of polymerisation processes in terms of polymerisation kinetics.
- (f) explain the principles of the bulk, solution, suspension and emulsion polymerisation processes, with particular reference to their advantages and disadvantages with respect to diffusion of monomers and polymers and heat transfer.
- (g) explain the difference in the structures of LDPE and HDPE and the properties associated with these structures and hence their uses.
- (h) explain the difference in properties and uses of poly(ethene) and PVC in terms of their structures.
- (i) describe the production of poly(phenylethene), including the feedstocks and their sources and the mechanism for the polymerisation reaction.
- (j) state the advantages and disadvantages of the various polymerisation processes as applied to poly(phenylethene) production.
- (k) describe the economic problems inherent in the polymerisation processes for poly(phenylethene) production and indicate how industry is attempting to overcome these problems.
- (l) describe the fabrication and uses of poly(phenylethene).

3. Fibres**CONTENT**

- 3.1 Suitability of molecules as fibres.
- 3.2 Synthetic fibres:
 - (i) polyamides; nylon 66 and nylon 6,
 - (ii) polyesters; *Terylene*.
- 3.3 Correlation of physical properties and uses of synthetic fibres such as nylon, *Terylene* and poly(propene).
- 3.4 Regenerated fibres:
 - (i) rayon,
 - (ii) cellulose ethanoate.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) describe the suitability of polymer molecules for fibre formation and how the structure of a fibre can affect its properties, such as thermal stability and dye uptake, and hence its uses.
- (b) state the monomers and repeat units for nylon 66 and nylon 6 and the conditions necessary to bring about the polymerisation.
- (c) describe the process of cold drawing as applied to fibres such as nylon and explain how the properties of nylon are affected by chain length and chain packing.
- (d) describe the formation of the polyester *Terylene*.
- (e) explain how the physical properties of nylon, *Terylene* and poly(propene) (isotactic) are related to their applications.
- (f) explain the formation of rayon and cellulose ethanoate from regenerated cellulose.
- (g) describe the uses of rayon and cellulose ethanoate and where possible compare them with a natural fibre such as cotton.

4. Elastomers**CONTENT**

- 4.1 Characteristics of elastomers.
- 4.2 Natural rubber; the monomer and *cis* and *trans* forms.

- 4.3 Advantages and disadvantages in the uses of natural rubber; vulcanisation and other additives such as carbon to improve the performance of natural rubber.
- 4.4 Synthetic rubbers; buta-1,3-diene and styrene (phenylethene)—butadiene copolymer.
- 4.5 Heterochain polymers; polysulphide rubber.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) describe the monomer of natural rubber and explain the existence of *cis-trans* isomeric forms of the polymer giving rise to natural rubber and gutta percha.
- (b) explain the reversible stretch of natural rubber and the reason for creep; describe how the reversible stretch can be improved by vulcanisation; explain the reasons for the addition of carbon black to natural rubber.
- (c) describe the structure and uses of synthetic rubbers such as buta-1,3-diene, styrene-butadiene copolymer and a polysulphide polymer (e.g. thiokol A).

5. Silicones

CONTENT

- 5.1 Formation of silicones by hydrolysis of di- and tri-chloroalkyl compounds; the monochloroalkyl compounds as chain stoppers.
- 5.2 Physical and chemical properties of silicones related to their structures and uses.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) describe the formation of silicones by the hydrolysis of di- and tri-chloroalkylsilanes, and the use of the monochloro compounds as chain stoppers.
- (b) describe the extensive domestic and industrial uses of silicones in terms of their properties: water-repellent characteristics, thermal stability, resistance to ozone and u.v. radiation, and high dielectric constants over a wide temperature range.

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.

A detailed treatment of this topic is given in the option booklet "SPECTROSCOPY" (see page 85).

1. Basic principles of spectroscopy

CONTENT

- 1.1 The electromagnetic spectrum; wavelengths, frequencies, energies of radiation used in different types of spectroscopy.
- 1.2 Atomic spectra; absorption; emission; line spectra.
- 1.3 Molecular spectra; molecular energy levels; electronic, vibrational, rotational (quantal formula and selection rules are *not* required).

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.

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

2. Ultra-violet and visible spectroscopy

CONTENT

2.1 The origin of absorptions; transitions between available energy levels.

- (a) Colour in transition metal complexes. The shape and symmetry of the main lobes of d orbitals. Splitting of degenerate d orbitals into two energy levels in octahedral complexes. Colour of complex ions resulting from the absorption of light energy as an electron moves between two non-degenerate d orbitals. Effects of different ligands.

The recall of formulae and structures of particular transition metal complexes and quantitative work on ligand-field splitting is *not* intended.

- (b) Organic molecules: chromophores—groups of atoms (strictly electrons) responsible for absorption; C=C, -NO₂, -N=N-, C=O, benzene: effects of delocalisation. Detailed theory of why chromophores have absorptions of appropriate energy is *not* required.

2.2 Applications of u.v./visible spectroscopy.

- (a) Quantitative analysis limited to the estimation of a single compound obeying Beer's Law; $\lg I_0/I = \epsilon cl$ (where ϵ is taken merely as a constant characteristic of the substance concerned).
- (b) Dyes and indicators: different absorptions of acid/base forms producing colour changes.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) explain the origin of colour in transitional metal complexes; describe the shape and symmetry of the d orbitals.
- (b) describe, in qualitative terms, the effects of different ligands on the absorption, and hence colour, of a given transition metal complex.
- (c) predict the colour of a transition metal complex from its u.v./visible spectrum.
- (d) identify the electronic transitions responsible for absorption in organic molecules; predict whether a given molecule will absorb in the u.v./visible region.
- (e) explain, in qualitative terms, the effects of delocalisation on absorption in the u.v./visible region.
- (f) explain the colour changes in an acid/base indicator, e.g. phenolphthalein, in terms of a change in chromophore delocalisation.
- (g) calculate the concentration of a given species in solution using Beer's Law; use Beer's Law to determine the path length used in a given spectrometer.

3. Infra-red spectroscopy

CONTENT

3.1 I.r. active and inactive modes explained in terms of dipoles, using SO₂ and CO₂ as examples.

3.2 Preparation of samples; liquid films, solutions, mulls and halide discs.

3.3 Applications of i.r. spectroscopy:

- (a) structure elucidation using i.r. spectra of simple organic molecules, containing no more than three functional groups from Section 11 of the "core" syllabus (see the *Data Booklet*),
- (b) analysis, e.g. forensic science, monitoring of air contaminants.

ASSESSMENT OBJECTIVES

Candidates should be able to:

- (a) explain the origin of i.r. absorption of simple molecules.
- (b) predict the number of i.r. absorptions for a given simple molecule and identify the molecular vibrations which give rise to them.
- (c) describe how samples of liquids and solids can be prepared for i.r. analysis; outline the advantages and disadvantages of each of the methods of sample preparation.
- (d) identify characteristic absorptions in the i.r. spectrum of a compound containing up to three functional groups.
- (e) suggest structures for a compound from its i.r. spectrum.

4. Nuclear magnetic resonance spectroscopy

CONTENT

4.1 Magnetic properties of nuclei possessing spin, e.g. ^1H and ^{13}C .

Questions on spectra involving ^{13}C will *not* be set.

(a) Simple, qualitative treatment of nuclear spin.

(b) Resonance considered as the absorption of energy when a nucleus "flips" to the higher energy spin state.

4.2 Effect of chemical environment in a molecule on the position of absorption.

(a) Chemical shifts; use of the δ scale and T.M.S. as a standard. Integration of peak area giving the relative numbers of ^1H present.

(b) Chemical equivalence and spin-spin splitting; use of spin-spin splitting as a diagnostic tool, i.e. to recognise the number of adjacent protons.

No knowledge of the theory of why coupling occurs is required.

4.3 Applications of n.m.r. spectroscopy:

(a) structure elucidation using ^1H n.m.r. spectra of simple organic molecules, containing no more than three functional groups from Section 11 of the "core" syllabus (see the *Data Booklet*): recognition of labile protons by the addition of D_2O ;

(b) quantitative analysis: peak area directly proportional to the number of protons producing the peak.

(c) Non-destructive nature of the technique emphasised by its medical importance, e.g. body scanners.

ASSESSMENT OBJECTIVES

Candidates should be able to:

(a) outline, in simple terms, the principles of nuclear magnetic resonance.

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

(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.

(e) predict, from an n.m.r. spectrum, the number of protons adjacent to a given proton.

(f) suggest, from an n.m.r. spectrum, possible structures for a molecule.

(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

5.1 Determination of relative isotopic masses, isotopic abundance. Distinguishing molecules of similar r.m.m. by high resolution mass spectrometry.

5.2 Mass spectrometry of molecules.

(a) Mass spectra; base peak, molecular ion, and $(M+1)$ and $(M+2)$ peaks where appropriate. Questions involving an $(M+1)$ peak will have ^{13}C as the only contributor.

(b) Fragmentation patterns; simple cleavage.

Students should be aware that rearrangement accompanying cleavage may occur: no details of mechanism of rearrangement are required.

(c) Applications, e.g. determination of position of reaction by isotopic labelling.

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 r.m.m.

(c) explain the use of the $(M+1)$ peak in a mass spectrum for determining the number of carbon atoms in organic molecules.

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

6. Structure elucidation by combined techniques

CONTENT

Information contributing to evidence of an overall structure which each spectrum provides, and its limitations.

All data normally associated with spectra will be given in questions. (See also the *Data Booklet*.)

ASSESSMENT OBJECTIVES

Candidates should be able 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.

PRACTICAL SYLLABUS FOR PAPERS 5 and 6

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

(a) The questions in Papers 5 and 6 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.

Semi-micro methods will be accepted where appropriate.

(b) A knowledge of the following volumetric determinations will be required: 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 sufficient working details will be given.

Candidates should normally record their burette readings to the nearest 0.05 cm³ 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 cm³.

(c) Candidates will be required, having been given full instructions, to carry out an experiment that may involve the measurement 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 simple reactions of the following ions: NH₄⁺, Mg²⁺, Al³⁺, Ca²⁺, Cr³⁺, Mn²⁺, Fe²⁺, Fe³⁺, Cu²⁺, Zn²⁺, Ba²⁺, Pb²⁺, CO₃²⁻, NO₃⁻, NO₂⁻, SO₄²⁻, SO₃²⁻, Cl⁻, Br⁻, I⁻, CrO₄²⁻.

Exercises requiring a knowledge of simple organic reactions as outlined in Section 11, e.g. test-tube reactions indicating the presence of unsaturation, alcoholic, phenolic and carboxylic groups.

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 to draw conclusions of a general nature.

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

APPARATUS LIST

The list given below has been drawn up in order to give guidance to schools concerning the apparatus that is expected to be generally available for examination purposes. The list is not intended to be exhaustive; in particular, items (such as bunsen burners, tripods, glass-tubing) that are commonly regarded as standard equipment in a chemical laboratory are not included. Unless otherwise stated, the rate of allocation is "per candidate".

Two burettes, 50 cm³

Two pipettes, 25 cm³

One pipette, 10 cm³

Dropping pipette

One pipette filler

Conical flasks: 3 within range 150 cm³ to 250 cm³

Volumetric flask, 250 cm³

Measuring cylinders, 50 cm³ and 100 cm³

Wash bottle

Two filter funnels

Porcelain crucible, approximately 15 cm³, with lid

Evaporating basin, at least 30 cm³

Beakers, squat form with lip: 100 cm³, 250 cm³

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

-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).

A LEVEL CHEMISTRY, INDIVIDUAL STUDIES, PAPER 9250/7**Notes**

- (a) It is recognised that only a minority of schools may wish, or be able, to take advantage of using Paper 7 as an alternative form of the assessment of practical skills.
- (b) It should be emphasised that the Syndicate does not envisage that candidates' Individual Studies will show a high degree of originality: it is more important that a candidate demonstrates within a chosen topic a degree of care, awareness and inventiveness appropriate to his or her inevitably limited experience of experimental investigations. Projects at this level rarely lead to definitive results and success may need to be measured in terms of the candidate's ability to respond positively to difficulty.
- (c) It is perfectly acceptable for a candidate to follow in more detail a problem originally generated from a standard class practical or to follow a study suggested by a natural interest.
- (d) In practice, successful projects have been submitted over a wide range of topics: topics that have been linked with the Special Options have been particularly fruitful.
- (e) The following is a representative list of successful Individual Studies:
- (i) An organic operation involving several stages with varied methods of purification.
 - (ii) The analysis of food samples (measurements of iodine number, chromatographic separations and various titrations have been used).
 - (iii) The properties of polymers.
 - (iv) Soil analysis (measurements of nitrogen content and cation exchange capacity have been used).
 - (v) The effects of soil nutrient availability on growth.
 - (vi) The preparation and properties of unusual oxidation states of transition metals.
 - (vii) The measurement of conductivities of ions.
 - (viii) The measurement of orders of reaction (a variety of techniques, e.g. colour changes, acidity changes, have been used).
 - (ix) The construction and efficiency of ion exchange resins.
- (f) It is expected that work on any Individual Study will extend over about three or four terms. It is also recommended that, before starting work on Individual Studies, candidates should have taken part in a straightforward group investigation in order to practise the planning and writing up of an Individual Study.
- (g) Wherever possible, candidates should work individually on their studies, but, if circumstances make it necessary for pairs of candidates to share apparatus and do some of their experimental work together, separate accounts of the work done must be prepared independently by each candidate. These separate accounts should each include statements of their individual contributions.
- (h) It is appreciated that a candidate's original aim may prove too ambitious or otherwise unrealistic such that the work finally submitted may not exactly match the original outline description: for instance, preliminary work on the study may raise points of interest which it seems more profitable to pursue and which may deflect the candidate into channels not directly contributing to the original aim. This should not necessarily count against the candidate, since an intelligent study of the cause of some apparently anomalous findings may prove more worthwhile than the sustained pursuit of the original aim at the expense of leaving a number of experimental results unexplained.

Entry

Each school with candidates wishing to offer Individual Studies must send to the Syndicate for approval, on an **OUTLINE PROPOSAL FORM**, which will be provided on request, as precise a statement as possible of what each candidate proposes to do; broad titles conveying only a vague idea of what is intended should be avoided. The forms should be returned to the Syndicate by 1 November in the year preceding that in which the candidates will sit the Advanced Level examination.

Marking

Candidates' Individual Studies are to be internally assessed by the school concerned and marks should be awarded under the headings explained under (c) below.

- (a) These headings relate, as far as practicable, to the corresponding skills for Internal Assessment of Practical Skills, Paper 9250/9—see below. There are two significant differences:
- (i) the possible variability of topics implies that there should be some degree of flexibility in the weighting of the four skill areas given for Paper 9;
 - (ii) about one-fifth of the marks is specifically allotted to assessing the quality of the final written report.

- (b) Although it is left to the individual teacher to provide an accurate assessment, it should be borne in mind that a mark of 60% represents a satisfactory pass standard while marks in excess of 80% or below 30% will naturally tend to be relatively rare. The Syndicate will moderate the marks submitted only to guarantee compatibility of standards between schools and if a school submits projects from more than one candidate the rank order of the projects will not be changed.
- (c) As far as (a)(i) is concerned, it is suggested that teachers use the same mark scale, i.e. 0 to 6, and the same criteria as set out for Skills A to D under Paper 9, together with a further mark (0 to 6) for the quality of the candidates' final written account.

Then, to accommodate possible differential weightings of Skills A to D, one of the following three strategies may be used.

- I, to apply, for Paper 7, a common weighting factor of $5/3$ for each of the four skills A to D and the quality of the written account; this will then mean that these skills and the quality of the written account all are equally weighted:
- II, to permute the weighting of Skills A to D, with two skills weighted by $3/2$, one skill by $5/3$ and the final skill by 2: the quality of the written account being weighted by $5/3$.
This latter strategy then gives two skills carrying 18%, one skill carrying 20%, the remaining skill of A to D carrying 24%, plus the quality of the written account carrying 20% of the total mark for Paper 7.
- III, to vary the weightings of skills A to D to suit an individual case provided that:
no skill constitutes less than 15% (a weighting of $5/4$) nor more than 30% (a weighting of $5/2$) of the final total;
the sum of the weightings equals 80%.
(The written account should again carry 20% of the total mark.)

The weighting, as used, can then be reported to the Moderator using the Record Card for Paper 7—see below.

Moderator

For moderation purposes, the school will be required to send to the Syndicate by 1 May in the year of the examination the candidates' individual reports on their work, together with the completed Record Cards. For easy reference, candidates must include a table of contents, and the pages must be numbered. Each report should contain a bibliography and appropriate acknowledgements of all external help.

RECORD CARD, A Level Chemistry Individual Studies, Paper 9250/7

Name of Candidate:

Year:

School:

Centre No.:

Title of Project:

Total Mark:

Facilities available to the candidate

Please indicate, by circling one of the numbers below, the facilities available to the candidate.

1. The apparatus was available for use only during normal timetabled lessons.
2. There was some opportunity of work outside normal lesson time.
3. There was regular opportunity of work outside normal lesson time.

Please answer the following.

- (i) What practical work (if any) was done outside the school?
- (ii) Were any special facilities used outside the school?
- (iii) Were there any particular difficulties or delays encountered by the candidate with regard to the provision of apparatus or chemicals?

Please indicate the weighting used as shown below, either by ringing one of the quoted factors or by stating the factor used.

	Mark out of 6	Weighting used	Weighted mark (to 1 dec place)
Skill A (Using and organising techniques, apparatus and materials)		$\frac{3}{2}$ $\frac{5}{3}$ other =	
Skill B (Observing, measuring and recording)		$\frac{3}{2}$ $\frac{5}{3}$ other =	
Skill C (Interpreting experimental observations and data)		$\frac{3}{2}$ $\frac{5}{3}$ other =	
Skill D (Designing and planning the Study)		$\frac{3}{2}$ $\frac{5}{3}$ other =	
Quality of final written account		$\frac{5}{3}$	
Total mark (out of 50) (rounded to nearest integer)			

Name of Teacher _____ Signature _____

Criteria for the quality of the final written account

- 1
- 2— Account is reasonably easy to follow but with evident scope for improvement in clarity of layout or detail or discussion of results.
- 3
- 4— Account is clear and generally well set out with few matters capable of further refinement.
- 5
- 6— An exemplary presentation, possibly with only minor scope for improvement.

INTERNAL ASSESSMENT OF PRACTICAL SKILLS (PAPER 9250/9)

NOTES FOR THE GUIDANCE OF TEACHERS

Introduction

Some of the abilities and skills which should be developed as part of the A level Chemistry course (for example, manipulation of apparatus, observation, interpretation of results and planning) can be taught adequately only through the medium of practical work.

On-going assessment of practical work by the teacher throughout the A level course allows direct observation of all the areas mentioned above. The scheme detailed below is intended to provide guidance for teachers in making the practical assessment but should not exert an undue influence on the methods of teaching or provide a constraint on the practical work undertaken by students. It is not expected that all of the practical work undertaken by a candidate will be assessed.

The scheme given below is intended to follow on from the GCSE assessment scheme for MEG Chemistry.

The experimental skills to be assessed are given below:

- A Using and organising techniques, apparatus and materials.
- B Observing, measuring and recording.
- C Interpreting experimental observations and data.
- D Designing and planning investigations.

The four skills carry equal weighting.

Teachers must give their candidates opportunities to acquire a given skill before they make an assessment.

It is recommended that assessment is not begun until, for example, the second term of a normal two-year course.

Each candidate must be assessed twice for each of the experimental skills. A teacher may carry out a further assessment if a performance on a given occasion is considered to be atypical.

[By using 2 assessments out of 6 marks for each of 4 skills, the assessed mark is out of 48. It is **not** necessary to scale the mark out of 50 (c.f. Papers 5 and 7). The difference in maxima is allowed for during the grading process.]

Criteria for Assessment of Experimental Skills

Each skill is assessed on a 6 point scale, level 6 being the highest level of achievement. A score of 0 is available if there is no evidence of positive achievement for the skill.

Each of the skills is defined in terms of three levels of achievement at scores of 2, 4 and 6.

For candidates who do not meet the criteria for a score of 2, a score of 1 is available if there is some evidence of positive achievement.

A score of 3 is available for candidates who go beyond the level defined for 2 but who do not meet fully the criteria for 4.

Similarly, a score of 5 is available for those who go beyond the level defined for 4 but do not meet fully the criteria for 6.

SKILL A USING AND ORGANISING TECHNIQUES, APPARATUS AND MATERIALS

1

2— With guidance, can perform a simple practical operation using familiar apparatus and materials adequately.

3

4— Adequate ability, generally able to apply an appropriate degree of precision to particular manipulations.

5

6— Full range of skills well displayed. Experiment carried out efficiently and to a suitable degree of accuracy without assistance.

SKILL B OBSERVING, MEASURING AND RECORDING

1

2— Given guidance, makes and records some relevant observations or readings.

3

4— Makes and records relevant observations or measurements.

5

6— Makes and records a full range of relevant observations or measurements to an appropriate degree of accuracy.

SKILL C INTERPRETING EXPERIMENTAL OBSERVATIONS AND DATA

1

2— Draws a simple conclusion from the results of an experiment.

3

4— Draws a conclusion which is consistent with a series of results.

5

6— Expresses conclusions as generalisations or patterns where appropriate. Able to appreciate (i) the limitations of an experiment, (ii) when it is necessary to obtain further results.

SKILL D DESIGNING AND PLANNING INVESTIGATIONS

1

2— Is able to suggest a simple plan to carry out an investigation. Attempts "trial and error" modifications in the light of experience.

3

4— (a) Suggests a sound plan requiring little modification.

(b) Comments critically on their original plan, and implements appropriate changes in the light of the experience. (Note that only one of (a) or (b) needs to be satisfied.)

5

6— Plans efficiently and times the various parts realistically; or is capable of modifying the plan in the light of experience.

These criteria imply that candidates put their plans into operation.

Types of Experiment

Assessment experiments should include both quantitative and qualitative work, and care should be taken that the choice of experiment is not limited to those which can be easily carried out by a large number of students in a limited time.

It is important that, for any skill, *different* types of experiment should be used for the *two* occasions of assessment.

In this context, candidates should have experience of a range of practical work including

- (1) an exercise involving volumetric analysis,
- (2) a kinetic experiment,
- (3) a thermochemical experiment,
- (4) an observational exercise,
- (5) the preparation of a pure compound.

Bearing in mind that the assessment is based on "four skills on two occasions" and that it is possible for one experiment to cover one or two skills, teachers

- (a) may note that it is not essential that all five of the specified types of experiment be included amongst those used for assessment.
- (b) should be aware that difficulties may arise if the assessments of the four skills is based on less than eight experiments (e.g. poor quality observations may prevent adequate interpretation of results).
- (c) should also be aware of the potential for unfairness to candidates if the experiments chosen for assessment are not of appropriate standard to generate valid differentiation.

At centres with large entries which are divided into sets assessed by different teachers, the teachers concerned may find it advantageous in the context of internal moderation, to come to an agreement on which *types* of experiment are to be used for assessment—a degree of conformity in this respect being of potential benefit also for external moderation.

Candidates should be made aware that continuous assessment is being applied, but this should be part of the normal teaching programme.

Further details, including exemplar material, are published separately.

ADMINISTRATION

Entries

Schools must indicate their intention to enter candidates for Paper 9 using the Provisional Entries Estimate Form (PE1) which is received in schools in the September preceding the examination.

Paper 9 will not be available in the November examination but candidates who entered for this paper in the June examination can have their assessment carried forward as Paper 89.

The recording of assessments

The Syndicate will provide two forms to use with this scheme:

- (i) a Student Record Card, i.e. per student
- (ii) a Centre Record Card, i.e. for summarising the assessed marks out of 48 for all students within a Centre.

Copies are available on request from the Syndicate. (In case of difficulty, these Record Cards may be photocopied for use in returning marks to the Syndicate.)

A Student Record Card should be used for each student; the Card is single-sided.

In using the Record Card, the teacher should insert the date and experiment numbers, together with the appropriate marks for each of the abilities being assessed. The two marks for each skill and the total should then be recorded on the Centre Record Card for each student.

The Centre Record Card consists of a double-sided sheet.

One side should be used to enter descriptions of the experiments used in the assessment scheme. Each experiment should be numbered so that the number and the date on which that experiment was carried out by the student can be entered on the Student Record Card. The other side of the sheet should be used to record a summary of the marks for all of the students offering Paper 9, either at a Centre as a whole or within different sets, if assessed by different teachers. It is important that the mark entries, especially candidate totals are arithmetically checked. A duplicate of each Centre Record Card used is to be retained at the Centre.

Pre-printed mark sheets, showing the index numbers and names of candidates—to be used for sending the total marks to the Syndicate—will be forwarded to Centres. These mark sheets should be returned by April 30th, together with

- (i) (a copy of) each of the completed Student Record Cards,

- (ii) a copy of the Centre Record Card (see above).
- (iii) a summary mark distribution,
- (iv) a copy of the mark schemes relevant to the experiments used for assessment.

In using the Centre Record Card, it may be convenient for a separate sheet to be used for each teaching set, if relevant.

Moderation

The primary purpose of moderation is to ensure that the assessments carried out locally across all Centres using Paper 9 are brought into equivalence.

The scheme for Paper 9 deliberately allows for latitude over the choice and detailed marking of experiments for the purpose of assessment. The overall adjustment, if any, made as a result of moderation, i.e. an appraisal of the sample of candidates' notebooks across all centres, is directed towards achievement of parity of standard for all candidates irrespective of the particular experiments used.

Where different teachers at the same Centre are collectively involved in assessing students' practical work, e.g. different teachers being responsible for differing groups of students or for different areas of the syllabus, an essential preliminary to such general moderation is that the assessments by all such staff are brought to a common standard.

There are no specific directives about how this process is achieved—but it may be noted that there is no requirement that students should be assessed on the same series of experiments.

For the purposes of inter-Centre moderation by the Syndicate, Centres will be required to send **all** of the **assessed** practical work for a **sample** of students. See below.

The sample of students' work should be despatched to Cambridge (marked "for the attention of the Chemistry Subject Officer") not later than the day of the last theory paper for A-level Chemistry.

Centres may find it is convenient to send this material earlier, e.g. with the Record Cards etc.

It is essential that

- (i) the work submitted includes the instructions given to the students and the marking scheme or criteria,
- (ii) the work is clearly marked and labelled.

N.B. Since Skill A (Using and organising techniques, apparatus and materials) will not generate written evidence, it is particularly important that it is made clear to Moderators how Skill A marks have been awarded.

The selection of students' work to be included in the sample should be made on the following bases:

- (a) size of entry;
 - (i) where the number of students is 8 or less—all students
 - (ii) where the number of students is greater than 8—a **minimum** of 8 students (see (b), (c) and (d) below)
- (b) number of teachers involved in assessment: —all or 3 students per teacher (whichever the fewer)
- (c) range of marks;
 - (i) two students with marks slightly above, and near, to the middle of the top third of the mark distribution
 - (ii) three students with marks slightly above, near to, slightly below the middle of the middle third of the mark distribution
 - (iii) two students with marks near to, and slightly below, the middle of the bottom third of the mark distribution
- (d) random; if necessary/appropriate (e.g. if (b) and (c) are incompatible)—make up the number by selecting, say, every third or fourth student.

It may be found convenient in applying the above guidelines for a master mark distribution to be drawn up, showing, for example the index numbers and teaching sets of the students.

The process of moderation will not be statistically determined in relation to candidates' performances on other papers but rather on a direct re-appraisal by Syndicate moderators of the sample of candidates' practical work.

In such re-appraisal, the teachers' original rank ordering of their candidates will only be altered in exceptional circumstances.

If necessary, the Moderators will have discretion to call for further samples of candidates' work. This material should therefore be kept available by Centres until the end of the summer term.

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 equations 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 , 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.

SUMMARY OF KEY QUANTITIES AND UNITS

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

Quantity	Used symbols	SI unit
<i>Base quantities</i>		
mass	m	kg, g
length	l	m
time	t	s
electric current	I	A
thermodynamic temperature	T	K
amount of substance	n	mol
<i>Other quantities</i>		
temperature	θ, t	$^{\circ}\text{C}$
volume	V, v	m^3, dm^3
density	ρ	$\text{kg m}^{-3}, \text{g dm}^{-3}, \text{g cm}^{-3}$
pressure	p	Pa
frequency	ν, 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 } potential	$(E^{\ominus}) E$	V
redox }		
electromotive force	E	V
molar gas constant	R	$\text{J K}^{-1} \text{mol}^{-1}$
half-life	$T_{1/2}, t$	s
atomic mass	m_a	kg
relative } atomic } mass	A_r	—
isotopic }		
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
molar enthalpy change of reaction	ΔH^{\ominus}	$\text{J mol}^{-1}, \text{kJ mol}^{-1}$
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 (and base) dissociation constant	$K_a(K_b)$	as appropriate
order of reaction	n, m	—
mole fraction	x	—
concentration	c	mol dm^{-3}
partition coefficient	K	—
degree of dissociation	α	—
ionic product, solubility product	K, K_s	as appropriate
ionic product of water	K_w	$\text{mol}^2 \text{dm}^{-6}$
pH	pH	—

UNIVERSITY OF CAMBRIDGE
LOCAL EXAMINATIONS SYNDICATE
INTERNATIONAL EXAMINATIONS

DATA BOOKLET
for
CHEMISTRY (9250)
PHYSICAL SCIENCE (9270)
PHYSICS (9240)

For use in all papers except
practical examinations

after
January 1990

UCLES

CHEMICAL CONSTANTS

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

	Atomic 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	3550	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 (at 298 K = 25 °C)

Electrode reaction	E^\ominus/V
$\text{Ag}^+ + \text{e}^- = \text{Ag}$	+0.80
$\text{Al}^{3+} + 3\text{e}^- = \text{Al}$	-1.66
$\text{Ba}^{2+} + 2\text{e}^- = \text{Ba}$	-2.90
$\frac{1}{2}\text{Br}_2 + \text{e}^- = \text{Br}^-$	+1.07
$\text{Ca}^{2+} + 2\text{e}^- = \text{Ca}$	-2.87
$\frac{1}{2}\text{Cl}_2 + \text{e}^- = \text{Cl}^-$	+1.36
$\text{HOCl} + \text{H}^+ + \text{e}^- = \frac{1}{2}\text{Cl}_2 + \text{H}_2\text{O}$	+1.64
$\text{Co}^{2+} + 2\text{e}^- = \text{Co}$	-0.28
$\text{Co}^{3+} + \text{e}^- = \text{Co}^{2+}$	+1.82
$[\text{Co}(\text{NH}_3)_6]^{2+} + 2\text{e}^- = \text{Co} + 6\text{NH}_3$	-0.43
$\text{Cr}^{2+} + 2\text{e}^- = \text{Cr}$	-0.91
$\text{Cr}^{3+} + 3\text{e}^- = \text{Cr}$	-0.74
$\text{Cr}^{3+} + \text{e}^- = \text{Cr}^{2+}$	-0.41
$\frac{1}{2}\text{Cr}_2\text{O}_7^{2-} + 7\text{H}^+ + 3\text{e}^- = \text{Cr}^{3+} + \frac{7}{2}\text{H}_2\text{O}$	+1.33
$\text{Cu}^+ + \text{e}^- = \text{Cu}$	+0.52
$\text{Cu}^{2+} + 2\text{e}^- = \text{Cu}$	+0.34
$\text{Cu}^{2+} + \text{e}^- = \text{Cu}^+$	+0.15
$[\text{Cu}(\text{NH}_3)_4]^{2+} + 2\text{e}^- = \text{Cu} + 4\text{NH}_3$	-0.05
$\frac{1}{2}\text{F}_2 + \text{e}^- = \text{F}^-$	+2.87
$\text{Fe}^{2+} + 2\text{e}^- = \text{Fe}$	-0.44
$\text{Fe}^{3+} + 3\text{e}^- = \text{Fe}$	-0.04
$\text{Fe}^{3+} + \text{e}^- = \text{Fe}^{2+}$	+0.77
$[\text{Fe}(\text{CN})_6]^{3-} + \text{e}^- = [\text{Fe}(\text{CN})_6]^{4-}$	+0.36
$\text{Fe}(\text{OH})_3 + \text{e}^- = \text{Fe}(\text{OH})_2 + \text{OH}^-$	-0.56
$\text{H}^+ + \text{e}^- = \frac{1}{2}\text{H}_2$	0.00
$\frac{1}{2}\text{H}_2 + \text{e}^- = \text{H}^-$	-2.25
$\frac{1}{2}\text{I}_2 + \text{e}^- = \text{I}^-$	+0.54
$\text{K}^+ + \text{e}^- = \text{K}$	-2.92
$\text{Li}^+ + \text{e}^- = \text{Li}$	-3.04
$\text{Mg}^{2+} + 2\text{e}^- = \text{Mg}$	-2.38
$\text{Mn}^{2+} + 2\text{e}^- = \text{Mn}$	-1.18
$\text{Mn}^{3+} + \text{e}^- = \text{Mn}^{2+}$	+1.49
$\text{MnO}_2 + 4\text{H}^+ + 2\text{e}^- = \text{Mn}^{2+} + 2\text{H}_2\text{O}$	+1.23
$\text{MnO}_4^- + \text{e}^- = \text{MnO}_4^{2-}$	+0.56
$\text{MnO}_4^- + 4\text{H}^+ + 3\text{e}^- = \text{MnO}_2 + 2\text{H}_2\text{O}$	+1.67
$\text{MnO}_4^- + 8\text{H}^+ + 5\text{e}^- = \text{Mn}^{2+} + 4\text{H}_2\text{O}$	+1.52
$\text{NO}_3^- + 2\text{H}^+ + \text{e}^- = \text{NO}_2 + \text{H}_2\text{O}$	+0.81
$\text{NO}_3^- + 3\text{H}^+ + 2\text{e}^- = \text{HNO}_2 + \text{H}_2\text{O}$	+0.94
$\text{NO}_3^- + 10\text{H}^+ + 8\text{e}^- = \text{NH}_4^+ + 3\text{H}_2\text{O}$	+0.87
$\text{Na}^+ + \text{e}^- = \text{Na}$	-2.71
$\text{Ni}^{2+} + 2\text{e}^- = \text{Ni}$	-0.25
$[\text{Ni}(\text{NH}_3)_6]^{2+} + 2\text{e}^- = \text{Ni} + 6\text{NH}_3$	-0.51
$\frac{1}{2}\text{H}_2\text{O}_2 + \text{H}^+ + \text{e}^- = \text{H}_2\text{O}$	+1.77
$\frac{1}{2}\text{O}_2 + 2\text{H}^+ + 2\text{e}^- = \text{H}_2\text{O}$	+1.23
$\frac{1}{2}\text{O}_2 + \text{H}_2\text{O} + 2\text{e}^- = 2\text{OH}^-$	+0.40
$\text{O}_2 + 2\text{H}^+ + 2\text{e}^- = \text{H}_2\text{O}_2$	+0.68
$2\text{H}_2\text{O} + 2\text{e}^- = \text{H}_2 + 2\text{OH}^-$	-0.83
$\text{Pb}^{2+} + 2\text{e}^- = \text{Pb}$	-0.13

Standard electrode and redox potentials (at 298 K = 25 °C)

Electrode reaction	E^\ominus/V
$\text{Pb}^{4+} + 2\text{e}^- = \text{Pb}^{2+}$	+1.69
$\text{PbO}_2 + 4\text{H}^+ + 2\text{e}^- = \text{Pb}^{2+} + 2\text{H}_2\text{O}$	+1.47
$\text{S} + 2\text{e}^- = \text{S}^{2-}$	-0.51
$\text{S} + 2\text{H}^+ + 2\text{e}^- = \text{H}_2\text{S}$	+0.14
$\text{Sn}^{2+} + 2\text{e}^- = \text{Sn}$	-0.14
$\text{Sn}^{4+} + 2\text{e}^- = \text{Sn}^{2+}$	+0.15
$\text{V}^{2+} + 2\text{e}^- = \text{V}$	-1.20
$\text{V}^{3+} + \text{e}^- = \text{V}^{2+}$	-0.26
$\text{VO}^{2+} + 2\text{H}^+ + \text{e}^- = \text{V}^{3+} + \text{H}_2\text{O}$	+0.34
$\text{VO}_2^+ + 2\text{H}^+ + \text{e}^- = \text{VO}^{2+} + \text{H}_2\text{O}$	+1.00
$\text{VO}_3^- + 4\text{H}^+ + \text{e}^- = \text{VO}^{2+} + 2\text{H}_2\text{O}$	+1.00
$\text{Zn}^{2+} + 2\text{e}^- = \text{Zn}$	-0.76

For simplicity, co-ordinated water molecules have not been included for complex ions.

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, ${}_0^1\text{n}$	m_n	=	$1.67 \times 10^{-27} \text{ kg}$
rest mass of electron, ${}_{-1}^0\text{e}$	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 approximately as 101 kPa and 273 K (0 °C))

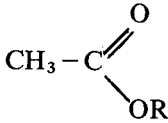
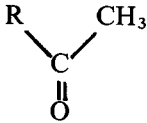
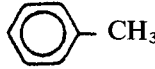
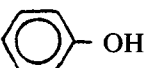
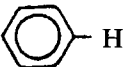
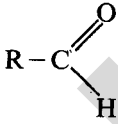
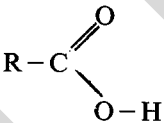
ionic product of water	K_w	=	$1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K (25 °C))
specific heat capacity of water		=	$4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (= $4.18 \text{ J g}^{-1} \text{ K}^{-1}$)

SPECTROSCOPY OPTION

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

Bond		Characteristic ranges
		Wavenumber (reciprocal wavelength) $/\text{cm}^{-1}$
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 \equiv C		2070 to 2250
C \equiv 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_3CH	2.0
	2.0
	2.1
	2.3
$R-C\equiv C-H$	2.6
$R-CH_2-Hal$	3.2-3.7
$R-O-CH_3$	3.8
$R-O-H$	4.5*
$RHC=CH_2$	4.9
$RHC=CH_2$	5.9
	7*
	7.3
	9.7*
	11.5*

* Sensitive to solvent, substituents, concentration.

*Bond energies**(a) Diatomic molecules*

<i>Bond</i>	<i>Energy/kJ mol⁻¹</i>
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

<i>Bond</i>	<i>Energy/kJ mol⁻¹</i>
C – C	350
C = C	610
C ≡ C	840
C ⋯ C (benzene)	520
N – N	160
N = N	410
O – O	150
C – H	410
Si – H	320
N – H	390
O – H	460
C – O	360
C = O	740
C – N	310
C = N	610
C ≡ N	890
C – Cl	340
C – Br	280
C – I	240

The values above are average ones based on a number of different molecules.

CHEMICAL CONSTANTS

CHEMISTRY (9250 papers 0, 1, 2, 3,4)
 PHYSICAL SCIENCE (9272 papers 1, 2, 3, 4)

The Periodic Table

		Group																
I	II	III	IV	V	VI	VII	VIII											
6.9 Li 3	9.0 Be 4	1.0 H 1	12.0 C 6	14.0 N 7	16.0 O 8	19.0 F 9	4.0 He 2											
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	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	88.9 Zr 40	91.2 Nb 41	92.9 Mo 42	101 Ru 44	103 Rh 45	106 Pd 46	108 Ag 47	112 Cd 48	115 In 49	119 Sn 50	122 Sb 51	127 I 53	131 Xe 54			
133 Cs 55	137 Ba 56	La to Lu	178 Hf 72	181 Ta 73	184 W 74	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	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	— Am 95	— Cm 96	— Bk 97	— Cf 98	— Es 99	— Fm 100	— Mv 101	— No 102	— Lr 103

a = relative atomic mass

X = atomic symbol

b = proton (atomic) number

Key

a	X
b	

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 readily 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 the candidate to state in words (using diagrams where appropriate) the main points of this 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 the candidate 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. *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'.
11. *Find* is a general term that may variously be interpreted as *calculate, measure, determine etc.*
12. *Calculate* is used when a numerical answer is required. In general, working should be shown, especially where two or more steps are involved.
13. *Measure* implies that the quantity concerned can be directly obtained from a suitable measuring instrument, e.g. length, using a rule, or mass, using a balance.
14. *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.
15. *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.
16. *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.

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.