

CHEMISTRY

HIGHER 1

(Syllabus 8872)

INTRODUCTION

Candidates will be assumed to have knowledge and understanding of Chemistry at O Level, as a single subject or as part of a balanced science course.

This syllabus is designed to place less emphasis on factual material and greater emphasis on the understanding and application of scientific concepts and principles. This approach has been adopted in recognition of the need for students to develop skills that will be of long term value in an increasingly technological world rather than focusing on large quantities of factual material which may have only short term relevance.

Experimental work is an important component and should underpin the teaching and learning of Chemistry.

AIMS

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

The aims are to

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

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

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

B Handling, applying and evaluating information

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

1. locate, select, organise and present information from a variety of sources;
2. handle information, distinguishing the relevant from the extraneous;
3. manipulate numerical and other data and translate information from one form to another;
4. analyse and evaluate information so as to identify patterns, report trends and conclusions, and draw inferences;
5. present reasoned explanations for phenomena, patterns and relationships;
6. construct arguments to support hypotheses or to justify a course of action;
7. apply knowledge, including principles, to novel situations;
8. evaluate information and hypotheses;
9. demonstrate an awareness of the limitations of chemistry theories and models;
10. bring together knowledge, principles and concepts from different areas of chemistry, and apply them in a particular context;
11. use chemical skills in contexts which bring together different areas of the subject.

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

SCHEME OF ASSESSMENT

All candidates are required to enter for Papers 1 and 2.

Paper	Type of Paper	Duration	Marks	Weighting (%)
1	Multiple Choice	50 min	30	33
2	Structured and Free Response Questions	2 h	80	67

Paper 1 (50 min, 30 marks)

30 multiple choice questions, all compulsory. 25 items will be of the direct choice type and 5 of the multiple completion type. All questions will include 4 responses.

Paper 2 (2h, 80 marks)

Section A (40 marks)

A variable number of structured questions plus one or two data-based questions, all compulsory. Answered on the question paper. The data-based question(s) constitute(s) 10-15 marks for this paper.

The data-based question(s) provide(s) good opportunity to test higher order thinking skills such as handling, applying, and evaluating information.

Section B (40 marks)

Candidates will be required to answer a total of two out of three questions. Each question will carry 20 marks. All the questions will require candidates to integrate knowledge and understanding from different areas and topics of the chemistry syllabus.

MARKS ALLOCATED TO ASSESSMENT OBJECTIVES

Relationship between the assessment objectives and assessment components in the Theory Papers.

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

Assessment Objectives		Weighting (%)	Assessment Components
A	Knowledge with understanding	40	Papers 1, 2
B	Handling, applying and evaluating information	60	Papers 1, 2

The proportion of marks allocated to Physical, Inorganic and Organic Chemistry in Papers 1 and 2 will be in the approximate ratio 5:1:3.

Data Booklet

A *Data Booklet* is available for use in the Theory Papers. The booklet is reprinted at the end of this syllabus document.

Nomenclature

Students will be expected to be familiar with nomenclature used in the syllabus but otherwise the ASE (The ASE Companion to 16-19 Science) conventions will be used.

In particular, the names sulphite, nitrite, sulphur trioxide, sulphurous acid and nitrous acid will be used in question papers.

Grading Conditions

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

Disallowed Subject Combinations

Candidates may not simultaneously offer Chemistry at H1 and H2, or at different levels, e.g. A Level and O Level.

**H1
SUBJECT CONTENT**

PHYSICAL CHEMISTRY

1. ATOMS, MOLECULES AND STOICHIOMETRY

Content

- Relative masses of atoms and molecules
- The mole, the Avogadro constant
- The calculation of empirical and molecular formulae
- Reacting masses and volumes (of solutions and gases)

Learning Outcomes

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

Candidates should be able to:

- define the terms *relative atomic*, *isotopic*, *molecular* and *formula masses*, based on the ^{12}C scale;
- define the term *mole* in terms of the Avogadro constant;
- calculate the relative atomic mass of an element given the relative abundances of its isotopes;
- define the terms *empirical* and *molecular formulae*;
- calculate empirical and molecular formulae, using combustion data or composition by mass;
- write and/or construct balanced equations;
- perform calculations, including use of the mole concept, involving:
 - reacting masses (from formulae and equations);
 - volumes of gases (e.g. in the burning of hydrocarbons);
 - volumes and concentrations of solutions;
- deduce stoichiometric relationships from calculations such as those in (g).

2. REDOX REACTIONS

Content

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

Learning Outcomes

Candidates should be able to:

- (a) describe and explain redox processes in terms of electron transfer and/or of changes in oxidation number (oxidation state), as exemplified by $\text{Fe}^{3+}/\text{Fe}^{2+}$, $\text{MnO}_4^-/\text{Mn}^{2+}$ and $\text{Cr}_2\text{O}_7^{2-}/\text{Cr}^{3+}$;
- (b) construct redox equations using the relevant half-equations.

3. ATOMIC STRUCTURE**Content**

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

Learning Outcomes

Candidates should be able to:

- (a) identify and describe protons, neutrons and electrons in terms of their relative charges and relative masses;
- (b) deduce the behaviour of beams of protons, neutrons and electrons in both electric and magnetic fields;
- (c) describe the distribution of mass and charges within an atom;
- (d) deduce the numbers of protons, neutrons and electrons present in both atoms and ions given proton and nucleon numbers (and charge);
- (e)
 - (i) describe the contribution of protons and neutrons to atomic nuclei in terms of proton number and nucleon number;
 - (ii) distinguish between isotopes on the basis of different numbers of neutrons present;
- (f) describe the number and relative energies of the s, p and d orbitals for the principal quantum numbers 1, 2 and 3 and also the 4s and 4p orbitals;
- (g) describe the shapes of s and p orbitals;
- (h) state the electronic configuration of atoms and ions given the proton number (and charge);
- (i)
 - (i) explain the factors influencing the ionisation energies of elements (see the *Data Booklet*);
 - (ii) explain the trends in ionisation energies across a Period and down a Group of the Periodic Table (see also Section 8);
- (j) deduce the electronic configurations of elements from successive ionisation energy data;
- (k) interpret successive ionisation energy data of an element in terms of the position of that element within the Periodic Table.

4. CHEMICAL BONDING

Content

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

Learning Outcomes

Candidates should be able to:

- (a) describe ionic (electrovalent) bonding, as in sodium chloride and magnesium oxide, including the use of 'dot-and-cross' diagrams;
- (b) describe, including the use of 'dot-and-cross' diagrams:
 - (i) covalent bonding, as in hydrogen; oxygen; nitrogen; chlorine; hydrogen chloride; carbon dioxide; methane; ethane;
 - (ii) co-ordinate (dative covalent) bonding, as in the formation of the ammonium ion and in the Al_2Cl_6 molecule;
- (c) explain the shapes of, and bond angles in, molecules such as BF_3 (trigonal planar); CO_2 (linear); CH_4 (tetrahedral); NH_3 (trigonal pyramidal); H_2O (non-linear); SF_6 (octahedral) by using the Valence Shell Electron Pair Repulsion theory;
- (d) describe covalent bonding in terms of orbital overlap, giving σ and π bonds (see also Section 9.1);
- (e) predict the shapes of, and bond angles in, molecules analogous to those specified in (c);
- (f) describe hydrogen bonding, using ammonia and water as examples of molecules containing -NH and -OH groups;
- (g) explain the terms *bond energy*, *bond length* and *bond polarity* and use them to compare the reactivities of covalent bonds;
- (h) describe intermolecular forces (van der Waals' forces), based on permanent and induced dipoles, as in $CHCl_3(l)$; $Br_2(l)$ and the liquid noble gases;
- (i) describe metallic bonding in terms of a lattice of positive ions surrounded by mobile electrons;
- (j) describe, interpret and/or predict the effect of different types of bonding (ionic bonding; covalent bonding; hydrogen bonding; other intermolecular interactions; metallic bonding) on the physical properties of substances;
- (k) deduce the type of bonding present from given information;

- (l) show understanding of chemical reactions in terms of energy transfers associated with the breaking and making of chemical bonds;
- (m) describe, in simple terms, the lattice structure of a crystalline solid which is:
- (i) ionic, as in sodium chloride, magnesium oxide;
 - (ii) simple molecular, as in iodine;
 - (iii) giant molecular, as in graphite, diamond;
 - (iv) hydrogen-bonded, as in ice;
 - (v) metallic, as in copper;
- [the concept of the 'unit cell' is **not** required]
- (n) outline the importance of hydrogen bonding to the physical properties of substances, including ice and water;
- (o) suggest from quoted physical data the type of structure and bonding present in a substance;
- (p) recognise that materials are a finite resource and the importance of recycling processes.

5. CHEMICAL ENERGETICS

Content

- Enthalpy changes: ΔH of formation, combustion, and neutralisation; bond energy; lattice energy
- Hess' Law

Learning Outcomes

Candidates should be able to:

- (a) explain that some chemical reactions are accompanied by energy changes, principally in the form of heat energy; the energy changes can be exothermic (ΔH , negative) or endothermic (ΔH , positive);
- (b) explain and use the terms:
- (i) enthalpy change of reaction and standard conditions, with particular reference to: formation; combustion; neutralisation;
 - (ii) bond energy (ΔH positive, i.e. bond breaking);
 - (iii) lattice energy (ΔH negative, i.e. gaseous ions to solid lattice);
- (c) calculate enthalpy changes from appropriate experimental results, including the use of the relationship
- $$\text{enthalpy change} = mc\Delta T$$
- (d) explain, in qualitative terms, the effect of ionic charge and of ionic radius on the numerical magnitude of a lattice energy;

- (e) apply Hess' Law to carry out calculations involving given simple energy cycles and relevant energy terms (restricted to enthalpy changes of formation, combustion, and neutralization), with particular reference to:
- determining enthalpy changes that cannot be found by direct experiment, e.g. an enthalpy change of formation from enthalpy changes of combustion;
 - average bond energies;
- [construction of energy cycles is **not** required]
- (f) construct and interpret a reaction pathway diagram, in terms of the enthalpy change of the reaction and of the activation energy.

6. EQUILIBRIA

Content

- Chemical equilibria: reversible reactions; dynamic equilibrium
 - Factors affecting chemical equilibria
 - Equilibrium constants
 - The Haber process
- Ionic equilibria
 - Bronsted-Lowry theory of acids and bases
 - Acid dissociation constants, K_a
 - Base dissociation constants, K_b
 - The ionic product of water, K_w
 - pH: choice of indicators
 - Buffer solutions

Learning Outcomes

Candidates should be able to:

- explain, in terms of rates of the forward and reverse reactions, what is meant by a reversible reaction and dynamic equilibrium;
- state Le Chatelier's Principle and apply it to deduce qualitatively (from appropriate information) the effects of changes in concentration, pressure or temperature, on a system at equilibrium;
- deduce whether changes in concentration, pressure or temperature or the presence of a catalyst affect the value of the equilibrium constant for a reaction;
- deduce expressions for equilibrium constants in terms of concentrations, K_c , and calculate the value of K_c , given quantities of all the products and reactants present at equilibrium;
- describe and explain the conditions used in the Haber process, as an example of the importance of an understanding of chemical equilibrium in the chemical industry;

- (f) show understanding of, and apply the Bronsted-Lowry theory of acids and bases, including the concept of conjugate acids and bases;
- (g) explain qualitatively the differences in behaviour between strong and weak acids and bases in terms of the extent of dissociation;
- (h) explain the terms pH; K_a ; K_b ; K_w [The relationship $K_w = K_a K_b$ is not required];
- (i) calculate $[H^+(aq)]$ and pH values for strong acids, and strong bases;
- (j) explain the choice of suitable indicators for acid-base titrations, given appropriate data, in terms of the strengths of the acids and bases;
- (k) (i) explain how acidic buffer solutions control pH;
- (ii) describe and explain the uses of buffers, including the role of H_2CO_3/HCO_3^- in controlling pH in blood.

7. REACTION KINETICS

Content

- Simple rate equations; orders of reaction; rate constants
- Concept of activation energy
- Effect of concentration, temperature, and catalysts on reaction rate
- Enzymes as biological catalysts

Learning Outcomes

Candidates should be able to:

- (a) explain and use the terms: rate of reaction; rate equation; order of reaction; rate constant; half-life of a reaction; activation energy; catalysis;
- (b) construct and use rate equations of the form $rate = k[A]^m[B]^n$ (limited to simple cases of single step reactions, for which m and n are 0, 1 or 2), including:
- (i) deducing the order of a reaction by the initial rates method;
- (ii) justifying, for zero- and first-order reactions, the order of reaction from concentration-time graphs;
- (iii) calculating an initial rate using concentration data;
- [integrated forms of rate equations are **not** required]
- (c) recognise that the half-life of a first-order reaction is independent of concentration;
- (d) explain qualitatively, in terms of collisions, the effect of concentration changes on the rate of a reaction;
- (e) show understanding, including reference to the Boltzmann distribution, of what is meant by the term *activation energy*;
- (f) explain qualitatively, in terms both of the Boltzmann distribution and of collision frequency, the effect of temperature change on a rate constant (and, hence, on the rate) of a reaction;

- (g) (i) explain that, in the presence of a catalyst, a reaction follows a different pathway, i.e. one of lower activation energy, giving a larger rate constant;
- (ii) interpret this catalytic effect in terms of the Boltzmann distribution;
- (h) describe enzymes as biological catalysts which may have specific activity.

8. INORGANIC CHEMISTRY

Preamble

It is intended that the study should:

be based on a study of the patterns across the third Period of the Periodic Table

apply unifying themes to inorganic chemistry, such as redox (Section 2), atomic structure (Section 3), chemical bonding (Section 4), and the reactions of ions and acid-base behaviour, (Section 6) where appropriate;

include:

- the representation of reactions by means of balanced equations (molecular and/or ionic equations, together with state symbols);
- the interpretation of redox reactions in terms of changes in oxidation state of the species involved;
- the interpretation of chemical reactions in terms of ionic equilibria.

THE PERIODIC TABLE: CHEMICAL PERIODICITY

Content

- Periodicity of physical properties of the elements: variation with proton number across the third Period (sodium to argon) of:
 - (i) Atomic radius and ionic radius
 - (ii) Melting point
 - (iii) Electrical conductivity
 - (iv) Ionisation energy
- Periodicity of chemical properties of the elements in the third Period
 - (i) Reaction of the elements with oxygen and chlorine
 - (ii) Variation in oxidation number of the oxides (sodium to sulphur only) and of the chlorides (sodium to phosphorus only)
 - (iii) Reactions of these oxides and chlorides with water
 - (iv) Acid/base behaviour of these oxides and the corresponding hydroxides

Learning Outcomes

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

- (a) describe qualitatively (and indicate the periodicity in) the variations in atomic radius, ionic radius, melting point and electrical conductivity of the elements (see the *Data Booklet*);
- (b) explain qualitatively the variation in atomic radius and ionic radius;
- (c) interpret the variation in melting point and in electrical conductivity in terms of the presence of simple molecular, giant molecular or metallic bonding in the elements;
- (d) explain the variation in first ionisation energy;
- (e) describe the reactions, if any, of the elements with oxygen (to give Na_2O ; MgO ; Al_2O_3 ; P_4O_{10} ; SO_2 ; SO_3), and chlorine (to give NaCl ; MgCl_2 ; Al_2Cl_6 ; SiCl_4 ; PCl_5);
- (f) state and explain the variation in oxidation number of the oxides and chlorides;
- (g) describe the reactions of the oxides with water;
[treatment of peroxides and superoxides is **not** required]
- (h) describe and explain the acid/base behaviour of oxides and hydroxides, including, where relevant, amphoteric behaviour in reaction with sodium hydroxide (only) and acids;
- (i) describe and explain the reactions of the chlorides with water;
- (j) interpret the variations and trends in (f), (g), (h), and (i) in terms of bonding and electronegativity;
- (k) suggest the types of chemical bonding present in chlorides and oxides from observations of their chemical and physical properties;

In addition, candidates should be able to:

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

9. ORGANIC CHEMISTRY**Preamble**

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

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

9.1 INTRODUCTORY TOPICS

In each of the sections below, 9.1 to 9.6, candidates will be expected to be able to predict the reaction products of a given compound in reactions that are chemically similar to those specified.

Content

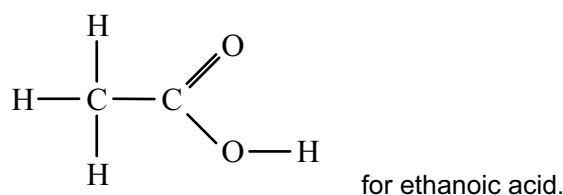
- Molecular, structural and empirical formulae
- Functional groups and the naming of organic compounds
- Characteristic organic reactions
- Shapes of organic molecules; σ and π bonds
- Isomerism: *structural*; *geometrical*


Structural formulae


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

Displayed formulae

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



The  convention for representing the aromatic ring is preferred.

The symbol  for cyclohexane is acceptable.

Learning Outcomes

Candidates should be able to:

- (a) interpret, and use the nomenclature, general formulae and displayed formulae of the following classes of compound:
- alkanes, alkenes and arenes;
 - halogenoalkanes;
 - alcohols (including primary, secondary and tertiary);
 - aldehydes and ketones;

- (v) carboxylic acids and esters;
 - (vi) amines (primary only), nitriles;
- (b) interpret and use the following terminology associated with organic reactions:
- (i) functional group;
 - (ii) addition, substitution, elimination, hydrolysis;
 - (iii) oxidation and reduction;
- [in equations for organic redox reactions, the symbols [O] and [H] are acceptable]
- (c) describe sp^3 hybridisation, as in the ethane molecule, sp^2 hybridisation, as in ethene and benzene molecules, and sp hybridisation, as in the ethyne molecule;
 - (d) explain the shapes of, and bond angles in, the ethane, ethene, benzene and ethyne molecules in relation to σ and π carbon-carbon bonds;
 - (e) predict the shapes of, and bond angles in, molecules analogous to those specified in (d);
 - (f) describe structural isomerism;
 - (g) describe geometrical isomerism in alkenes, and explain its origin in terms of restricted rotation due to the presence of π bonds;
- [use of E, Z nomenclature is **not** required]
- (h) deduce the possible structural and/or geometrical isomers for an organic molecule of known molecular formula;
 - (i) identify geometrical isomerism in a molecule of given structural formula.

9.2 HYDROCARBONS

Content

- Alkanes (exemplified by ethane)
 - (i) Combustion and substitution reactions
- Alkenes (exemplified by ethene)
 - (i) Addition and oxidation reactions
- Arenes (exemplified by benzene and methylbenzene)
 - (i) Influence of delocalised π electrons on structure and properties
 - (ii) Substitution reactions
 - (iii) Oxidation of side-chain
- Hydrocarbons as fuels

Learning Outcomes

Candidates should be able to:

- (a) recognise the general unreactivity of alkanes, including towards polar reagents;
- (b) describe the chemistry of alkanes as exemplified by the following reactions of ethane:
 - (i) combustion;
 - (ii) substitution by chlorine and by bromine;
- (c) describe the chemistry of alkenes as exemplified, where relevant, by the following reactions of ethene:
 - (i) addition of hydrogen, steam, hydrogen halides and halogens;
 - (ii) oxidation by cold, dilute manganate(VII) ions to form the diol;
 - (iii) oxidation by hot, concentrated manganate(VII) ions leading to the rupture of the carbon-to-carbon double bond in order to determine the position of alkene linkages in larger molecules;
- (d) describe the chemistry of arenes as exemplified by the following reactions of benzene and methylbenzene:
 - (i) substitution reactions with chlorine and with bromine;
 - (ii) oxidation of the side-chain to give a carboxylic acid;
- (e) explain why arenes undergo substitution reactions (but not addition reactions) based on the stability of the aromatic nucleus;
- (f) predict whether halogenation will occur in the side-chain or aromatic nucleus in arenes depending on reaction conditions;
- (g) recognise the environmental consequences of carbon monoxide, oxides of nitrogen and unburnt hydrocarbons arising from the internal combustion engine and of their catalytic removal.

9.3 HALOGEN DERIVATIVES**Content**

- Halogenoalkanes
 - (i) Substitution
 - (ii) Elimination
- Relative strength of the C-Hal bond

Learning Outcomes

Candidates should be able to:

- (a) recall the chemistry of halogenoalkanes as exemplified by:
 - (i) the following 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) interpret the different reactivities of halogenoalkanes with particular reference to hydrolysis and to the relative strengths of the C-Hal bonds;
- (c) explain the uses of fluoroalkanes and fluorohalogenoalkanes in terms of their relative chemical inertness;
- (d) recognise the concern about the effect of chlorofluoroalkanes (CFCs) on the ozone layer.
[the mechanistic details of how CFCs deplete the ozone layer are **not** required]

9.4 ALCOHOLS**Content**

- Alcohols (exemplified by ethanol)
 - (i) Formation of halogenoalkanes
 - (ii) Reaction with sodium; oxidation; dehydration
 - (iii) The tri-iodomethane test

Learning Outcomes

Candidates should be able to:

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

9.5 CARBONYL COMPOUNDS

Content

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

Learning Outcomes

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 addition reactions of hydrogen cyanide with aldehydes and ketones;
- (c) describe the use of 2,4-dinitrophenylhydrazine (2,4-DNPH) to detect the presence of carbonyl compounds;
- (d) deduce the nature (aldehyde or ketone) of an unknown carbonyl compound from the results of simple tests (i.e. Fehling's and Tollens' reagents; ease of oxidation);
- (e) describe the reaction of $\text{CH}_3\text{CO}-$ compounds with alkaline aqueous iodine to give tri-iodomethane.

9.6 CARBOXYLIC ACIDS AND DERIVATIVES

Content

- Carboxylic acids (exemplified by ethanoic acid)
 - (i) Formation from primary alcohols and nitriles
 - (ii) Salt and ester formation
- Esters (exemplified by ethyl ethanoate)
 - (i) Formation from carboxylic acids
 - (ii) Hydrolysis (under acidic and under basic conditions)

Learning Outcomes

Candidates should be able to:

- (a) describe the formation of carboxylic acids from alcohols, aldehydes and nitriles;
- (b) describe the reactions of carboxylic acids in the formation of:
 - (i) salts;
 - (ii) esters on reaction with alcohols, using ethyl ethanoate as an example;
- (c) explain the acidity of carboxylic acids in terms of their structures;
- (d) describe the acid and base hydrolysis of esters.

SUMMARY OF KEY QUANTITIES AND UNITS

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

Quantity	Usual symbols	SI unit
Base quantities		
mass	m	kg, g
length	l	m
time	t	s
electric current	I	A
thermodynamic temperature	T	K
amount of substance	n	mol
Other quantities		
temperature	θ, t	$^{\circ}\text{C}$
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 redox } potential	$(E^{\ominus}) E$	V
electromotive force	E	V
molar gas constant	R	$\text{J K}^{-1} \text{mol}^{-1}$
half-life	$T_{1/2}, t_{1/2}$	s
atomic mass	m_a	kg
relative { atomic isotopic } mass	A_r	-
molecular mass	m	kg
relative molecular mass	M_r	-
molar mass	M	kg mol^{-1}
nucleon number	A	-
proton number	Z	-
neutron number	N	-
number of molecules	N	-
number of molecules per unit volume	n	m^{-3}
Avogadro constant	L	mol^{-1}
Faraday constant	F	C mol^{-1}
enthalpy change of reaction	ΔH	J, kJ
standard enthalpy change of reaction	ΔH^{\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 dissociation constant	K_a	as appropriate
order of reaction	n, m	-
mole fraction	x	-

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concentration	c	mol dm^{-3}
partition coefficient	K	-
ionic product, solubility product	K, K_{sp}	as appropriate
ionic product of water	K_{w}	$\text{mol}^2 \text{dm}^{-6}$
pH	pH	-

MATHEMATICAL REQUIREMENTS

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

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

Calculators

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

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

GLOSSARY OF TERMS

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

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

In other contexts, describe and give an account of should be interpreted more generally, i.e. the candidate has greater discretion about the nature and the organisation of the material to be included in the answer. Describe and explain may be coupled in a similar way to state and explain.
7. *Discuss requires candidates to give a critical account of the points involved in the topic.*
8. *Outline implies brevity, i.e. restricting the answer to giving essentials.*
9. *Predict 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. *Deduce is used in a similar way as predict except that some supporting statement is required, e.g. reference to a law/principle, or the necessary reasoning is to be included in the answer.*
11. *Comment is intended as an open-ended instruction, inviting candidates to recall or infer points of interest relevant to the context of the question, taking account of the number of marks available.*
12. *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'.*
13. *Find is a general term that may variously be interpreted as calculate, measure, determine etc.*
14. *Calculate is used when a numerical answer is required. In general, working should be shown,*

especially where two or more steps are involved.

15. *Measure* implies that the quantity concerned can be directly obtained from a suitable measuring instrument, e.g. length, using a rule, or angle, using a protractor.
16. *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.
17. *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.
18. *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.
19. *Construct* is often used in relation to chemical equations where a candidate is expected to write a balanced equation, not by factual recall but by analogy or by using information in the question.
20. *Compare* requires candidates to provide both the similarities and differences between things or concepts.
21. *Classify* requires candidates to group things based on common characteristics.
22. *Recognise* is often used to identify facts, characteristics or concepts that are critical (relevant/appropriate) to the understanding of a situation, event, process or phenomenon.

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.

TEXTBOOKS

Teachers may find reference to the following books helpful:

Chemistry for Advanced Level by P. Cann & P. Hughes, published by John Murray

A-Level Chemistry (4th Edition) by E. N. Ramsden, published by Nelson Thornes

Understanding Chemistry for Advanced Level (3rd Edition), by T. Lister & J. Renshaw, published by Nelson Thornes

Chemistry in Action (2nd Edition) by Michael Freemantle, published by Macmillan Press

Advanced Chemistry through Diagrams by M. Lewis, published by Oxford University Press

Chemistry in Context (5th Edition) by Hill & Holman, published by Nelson Thornes

Chemistry in Context Laboratory Manual and Study Guide (5th Edition) by Hill & Holman, published by Nelson Thornes

Experiments and Exercises in Basic Chemistry (5th Edition) by S. Murov & B. Stedjee, published by John Wiley

Chemical Ideas (Salters Advanced Chemistry) by G. Burton, published by Heinemann

ILPAC Advanced Practical Chemistry (2nd edition) by A. Lainchbury, J. Stephens, A. Thompson, published by John Murray

These titles represent some of the texts available at the time of printing this booklet.

Teachers are encouraged to choose texts for class use which they feel will be of interest to their students and will support their own teaching style.

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

Data Booklet

for

Chemistry
(Advanced Level)

for use in all papers for the H1, H2, H3 Chemistry syllabuses, except practical examinations

TABLES OF CHEMICAL DATA

Important values, constants and standards

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

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

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

Bond energies**(a) Diatomic molecules**

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

(b) Polyatomic molecules

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

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

For ease of reference, two tabulations are given:

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

(a) E^\ominus in alphabetical order

Electrode reaction	E^\ominus/V
$\text{Ag}^+ + \text{e}^- \rightleftharpoons \text{Ag}$	+0.80
$\text{Al}^{3+} + 3\text{e}^- \rightleftharpoons \text{Al}$	-1.66
$\text{Ba}^{2+} + 2\text{e}^- \rightleftharpoons \text{Ba}$	-2.90
$\text{Br}_2 + 2\text{e}^- \rightleftharpoons 2\text{Br}^-$	+1.07
$\text{Ca}^{2+} + 2\text{e}^- \rightleftharpoons \text{Ca}$	-2.87
$\text{Cl}_2 + 2\text{e}^- \rightleftharpoons 2\text{Cl}^-$	+1.36
$2\text{HOCl} + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{Cl}_2 + 2\text{H}_2\text{O}$	+1.64
$\text{Co}^{2+} + 2\text{e}^- \rightleftharpoons \text{Co}$	-0.28
$\text{Co}^{3+} + \text{e}^- \rightleftharpoons \text{Co}^{2+}$	+1.82
$[\text{Co}(\text{NH}_3)_6]^{2+} + 2\text{e}^- \rightleftharpoons \text{Co} + 6\text{NH}_3$	-0.43
$\text{Cr}^{2+} + 2\text{e}^- \rightleftharpoons \text{Cr}$	-0.91
$\text{Cr}^{3+} + 3\text{e}^- \rightleftharpoons \text{Cr}$	-0.74
$\text{Cr}^{3+} + \text{e}^- \rightleftharpoons \text{Cr}^{2+}$	-0.41
$\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6\text{e}^- \rightleftharpoons 2\text{Cr}^{3+} + 7\text{H}_2\text{O}$	+1.33
$\text{Cu}^+ + \text{e}^- \rightleftharpoons \text{Cu}$	+0.52
$\text{Cu}^{2+} + 2\text{e}^- \rightleftharpoons \text{Cu}$	+0.34
$\text{Cu}^{2+} + \text{e}^- \rightleftharpoons \text{Cu}^+$	+0.15
$[\text{Cu}(\text{NH}_3)_4]^{2+} + 2\text{e}^- \rightleftharpoons \text{Cu} + 4\text{NH}_3$	-0.05
$\text{F}_2 + 2\text{e}^- \rightleftharpoons 2\text{F}^-$	+2.87
$\text{Fe}^{2+} + 2\text{e}^- \rightleftharpoons \text{Fe}$	-0.44
$\text{Fe}^{3+} + 3\text{e}^- \rightleftharpoons \text{Fe}$	-0.04
$\text{Fe}^{3+} + \text{e}^- \rightleftharpoons \text{Fe}^{2+}$	+0.77
$[\text{Fe}(\text{CN})_6]^{3-} + \text{e}^- \rightleftharpoons [\text{Fe}(\text{CN})_6]^{4-}$	+0.36
$\text{Fe}(\text{OH})_3 + \text{e}^- \rightleftharpoons \text{Fe}(\text{OH})_2 + \text{OH}^-$	-0.56
$2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{H}_2$	0.00
$\text{I}_2 + 2\text{e}^- \rightleftharpoons 2\text{I}^-$	+0.54
$\text{K}^+ + \text{e}^- \rightleftharpoons \text{K}$	-2.92
$\text{Li}^+ + \text{e}^- \rightleftharpoons \text{Li}$	-3.04
$\text{Mg}^{2+} + 2\text{e}^- \rightleftharpoons \text{Mg}$	-2.38
$\text{Mn}^{2+} + 2\text{e}^- \rightleftharpoons \text{Mn}$	-1.18
$\text{Mn}^{3+} + \text{e}^- \rightleftharpoons \text{Mn}^{2+}$	+1.49
$\text{MnO}_2 + 4\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{Mn}^{2+} + 2\text{H}_2\text{O}$	+1.23
$\text{MnO}_4^- + \text{e}^- \rightleftharpoons \text{MnO}_4^{2-}$	+0.56
$\text{MnO}_4^- + 4\text{H}^+ + 3\text{e}^- \rightleftharpoons \text{MnO}_2 + 2\text{H}_2\text{O}$	+1.67
$\text{MnO}_4^- + 8\text{H}^+ + 5\text{e}^- \rightleftharpoons \text{Mn}^{2+} + 4\text{H}_2\text{O}$	+1.52
$\text{NO}_3^- + 2\text{H}^+ + \text{e}^- \rightleftharpoons \text{NO}_2 + \text{H}_2\text{O}$	+0.81
$\text{NO}_3^- + 3\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{HNO}_2 + \text{H}_2\text{O}$	+0.94
$\text{NO}_3^- + 10\text{H}^+ + 8\text{e}^- \rightleftharpoons \text{NH}_4^+ + 3\text{H}_2\text{O}$	+0.87
$\text{Na}^+ + \text{e}^- \rightleftharpoons \text{Na}$	-2.71
$\text{Ni}^{2+} + 2\text{e}^- \rightleftharpoons \text{Ni}$	-0.25

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$[\text{Ni}(\text{NH}_3)_6]^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Ni} + 6\text{NH}_3$	-0.51
$\text{H}_2\text{O}_2 + 2\text{H}^+ + 2\text{e}^-$	\rightleftharpoons	$2\text{H}_2\text{O}$	+1.77
$\text{O}_2 + 4\text{H}^+ + 4\text{e}^-$	\rightleftharpoons	$2\text{H}_2\text{O}$	+1.23
$\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^-$	\rightleftharpoons	4OH^-	+0.40
$\text{O}_2 + 2\text{H}^+ + 2\text{e}^-$	\rightleftharpoons	H_2O_2	+0.68
$2\text{H}_2\text{O} + 2\text{e}^-$	\rightleftharpoons	$\text{H}_2 + 2\text{OH}^-$	-0.83
$\text{Pb}^{2+} + 2\text{e}^-$	\rightleftharpoons	Pb	-0.13
$\text{Pb}^{4+} + 2\text{e}^-$	\rightleftharpoons	Pb^{2+}	+1.69
$\text{PbO}_2 + 4\text{H}^+ + 2\text{e}^-$	\rightleftharpoons	$\text{Pb}^{2+} + 2\text{H}_2\text{O}$	+1.47
$\text{SO}_4^{2-} + 4\text{H}^+ + 2\text{e}^-$	\rightleftharpoons	$\text{SO}_2 + 2\text{H}_2\text{O}$	+0.17
$\text{S}_2\text{O}_8^{2-} + 2\text{e}^-$	\rightleftharpoons	2SO_4^{2-}	+2.01

(a) continued...

Electrode reaction		E^{\ominus}/V
$S_4O_6^{2-} + 2e^-$	$\rightleftharpoons 2S_2O_3^{2-}$	+0.09
$Sn^{2+} + 2e^-$	$\rightleftharpoons Sn$	-0.14
$Sn^{4+} + 2e^-$	$\rightleftharpoons Sn^{2+}$	+0.15
$V^{2+} + 2e^-$	$\rightleftharpoons V$	-1.20
$V^{3+} + e^-$	$\rightleftharpoons V^{2+}$	-0.26
$VO^{2+} + 2H^+ + e^-$	$\rightleftharpoons V^{3+} + H_2O$	+0.34
$VO_2^+ + 2H^+ + e^-$	$\rightleftharpoons VO^{2+} + H_2O$	+1.00
$VO_3^- + 4H^+ + e^-$	$\rightleftharpoons VO^{2+} + 2H_2O$	+1.00
$Zn^{2+} + 2e^-$	$\rightleftharpoons Zn$	-0.76

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

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

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

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

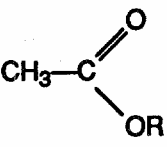
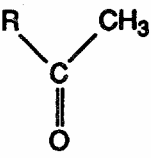
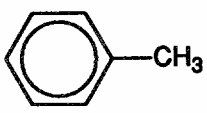
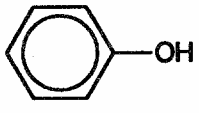
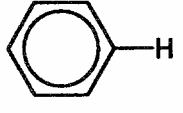
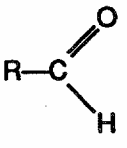
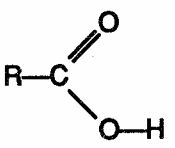
Atomic and ionic radii

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

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

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

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

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

*Sensitive to solvent, substituents, concentration

The Periodic Table of the Elements

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

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

